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Agroecological Footprints Management for Sustainable Food System

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Preface

Agroecology is a major component of the food system on the earth and has interaction between the living components in many directions. It provides various ecosystem services like combating climate change, carbon sequestration, soil conservation, and maintaining productivity and yield to fulfil the demand of the ever-increasing human population. With the rising food demand, the sustainability and management of the agroecosystems are under threat of degradation. The ecological footprints are gradually rising day by day with increased resources use by the adoption of advanced technologies. The food production system is also suffering from the issues of food crisis, security, and overproduction beyond the biocapacity of the ecosystem. Therefore, there is an urgent need for proper management of the agroecosystem and food production system.

This book addresses the critical issue of various forms of footprints associated with the agroecosystem and its subsequent management. Agriculture is the backbone for all developing countries across the globe and therefore, its proper management is the need of the hour. The book covers a comprehensive approach towards effective management of ecological footprints in the agroecosystem. It covers an introduction revealing the basic concepts of various forms of footprints associated with the agroecosystem. Further, the book analyses the critical aspects of energy, carbon, nitrogen, climate, water, land, mangrove and river ecosystems, corporate sector, and livestock footprints through methodological and scientific approach leading to their effective management. The present book has also addressed specific strategies, planning, and policy formulation towards mitigating the various forms of ecological footprint based on research and developmental activities within the agroecosystem. The book can also be a future directive for the international scientific community regarding the sustainable use of resources aiming towards low footprint economy and growth.

For today's world, integration of diverse disciplines such as agriculture, ecology, forestry, and the environment is the need of the hour. Different textbooks and separate edited volumes are not available to address the specific issues on "Agro-ecological Footprints Management for Sustainable Food System". Further, recent updates are much important concerning agroecosystem, environment, and ecological footprints. Therefore, the book has attempted to address this diverse issue along with its recent developments and holistically bring them under a single umbrella which would give diverse academic benefits to its readers. The objectives of this book are: (1) address the issue of agroecosystem, environment, and ecological footprints, (2) to generate awareness and concept about the issues, and (3) to know about the current development and trends in the respective disciplines to plan future research and developmental strategies.

It will be helpful for teachers, researchers, climate change scientists, capacity builders and policymakers, undergraduate and graduate students of agriculture, forestry, ecology, soil science, and environmental science. Highly professional and internationally renowned researchers have contributed, authoritative, and cutting-edge scientific information on a broad range of topics covering on agroecosystem, environment, and ecological footprints and sustainability. All the chapters are well-illustrated with appropriately placed data, tables, figures, and photographs and supported with extensive and most recent references. Therefore, this book will support the government planners, policymakers, researchers, academicians, and students to develop a vision for sustainable food, environmental, and an economic system to fulfil the "Sustainable Development Goals".

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Varanasi, India — Ram Swaroop Meena
Ambikapur, India — Manoj Kumar Jhariya
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About the Editors

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Manoj Kumar Jhariya is Assistant Professor at the Department of Farm Forestry, Sant Gahira Guru Vishwavidyalaya (formerly Sarguja University), Ambikapur (Chhattisgarh), India, and author or co-author of more than 68 scientific papers, 8 books, 33 book chapters, and several extension articles. He acquired B.Sc. (agriculture) and M.Sc. and Ph.D. (both in forestry) degrees from Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. He was awarded a UGC-RGNF Fellowship, New Delhi, India, and received a Chhattisgarh Young Scientist Award from Chhattisgarh Council of Science and Technology in 2013. He is an editorial board member for several journals and a life member of numerous societies.

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Ecological Footprints in Agroecosystem: An Overview

1

Arnab Banerjee, Manoj Kumar Jhariya, Ram Swaroop Meena, and Dhiraj Kumar Yadav

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Abstract

Agroecology has many pyramids on the earth, and has interaction between the living components. It encompasses the key issues such as food system on the planet and ecological concepts for greener future. Ecological footprint is a holistic approach which assesses the issue of sustainability both at macro-scale and micro-scale. In the present era, it has been observed that reduction in agricultural inputs helps to reduce the ecological footprints and support to the sustainable food system. However, this is absent due to intensive agricultural practices and huge use of agrochemical to feed the booming population of human being. The values of ecological footprints vary site wise. According to global footprint network food production contributes ~30% of the ecological footprint of the human civilization. On the basis of hectares per individual the value is 3 ha per individual globally for the food system. It is very interesting to note that the value of the developed nation stands to be higher in comparison to the poor economy or developing economy based on the status of countries. For example, the ecological footprints value of North America, Oceania and Europe ranges between 5 and 7 global hectares per individual and, on the other hand, the value of Africa, Asia, Latin American countries ranges between 0 and 3 global hectares per individual. In the Indian context, it is again much lesser of about 0.77 ha on individual basis. It has been observed that with intensive agriculture practices for more production agroecosystem stability reduces. Technological intervention is required for greener production, move towards low carbon economy, improving the biocapacity of the land which would help to reduce ecological footprint of the ecosystem. Hence, proper accounting of the natural resource is required for overall sustainability of the agroecosystem. Therefore, this book will support the government planners, policymakers, researchers, academicians and students to develop a vision to sustainable food, environmental and an economic system to fulfil the "Sustainable Development Goals".

Keywords

Agroecosystem · Biocapacity · Ecological footprint · Sustainability

Abbreviations

BC	Biocapacity
BD	Biocapacity deficit
BR	Biocapacity remainder
CF	Carbon footprint
CO_2	Carbon dioxide
CO_2e	Equivalent of carbon dioxide
C-stocks	Carbon stocks
EF	Ecological footprint
EFA	Ecological footprint analysis

FAO	Food and Agriculture Organization
GDP	Gross domestic product
Gha	Global hectare
GHG	Greenhouse gas
SRI	System of rice intensification
WF	Water footprint
WWF	World Wildlife Fund

1.1 Introduction

Agroecological system is a combination of biotic and abiotic systems with a nexus of natural resources under the anthropogenic control. Main aims of agroecological sustainability are to provide healthy food and generate social value for all human being, living and biological organisms. In the previous time agroecosystem was considered to be an anthropogenic interference in the form of forest fire, cutting trees for expansion of agricultural areas, *Jhum cultivation* and pasturing for maintaining livestock population. In the crunch of more production, people has overexploited the natural resource in an unprecedented way leading to long-term ecological impacts such as pest infestation, soil loss and nutrient depletion of soil (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b).

Agroecosystem aims towards acting as a production unit considering the environmental counterpart along with developing social equity across the globe for betterment of human civilization (Meena et al. 2020). Therefore, agroecosystem has a multidimensional approach towards maintaining resource stock, reduce allochthonous inputs to the system, regulation of pest and disease mechanism and attaining ecological homeostasis. The concept of sustainable agriculture may be integrated with agroecosystems through some effective policies such as utilization of renewable resources, opt for fixing nitrogen biologically, emphasize more use of naturally occurring substances and proper nutrient recycling (Meena and Lal 2018). It also aims to reduce the use of toxic hazardous substances which poses significant threat to man as well preventing occurrence of eutrophication to take place. It also strives for sustainable use of water resources in the form of micro-irrigation, sprinkler irrigation, etc. Agroecosystem also helps to maintain the quality and fertility of soil system. In the present context of bursting human population, it is very much necessary to maintain the agro-diversity at the genetic level across the world. Then only we would be able to cope up with the challenges of food security and crisis in the time to come. Such approaches would promote a better healthy agroecosystem which would uplift the rural livelihood and boost up the economy of agroecosystem through sustainable practices. It is estimated that in 2014, the total output of agroecosystems is up to 3.0 trillion per annum sharing more than 3% global [gross domestic product (GDP)] (Roy 2015).

Globally agroecosystem tends to produce food up to $1.3 trillion annually. This food contributes 94 and 99% protein and energy in terms of calories to the humans. Agroecosystems provide food and it is valued at around $1.3 trillion per year. Such production system directly engages up to 1.3 billion people (WRI-EarthTrends 2000).

Agroecosystem plays significant role towards climate change. The prevailing monoculture system in the agriculture practice tends to make the arable land more vulnerable in front of the changing climate (Meena et al. 2020a). This issue could be addressed through agroecological principles in the agroecosystem which would promote climate resilient agriculture practices. Further agro-biodiversity also promotes efficient use of energy and therefore reduces the energy and climate footprint of the agroecosystem. Multi-cropping system is an integrated approach which helps in weed control, disease outbreak and improvement of soil quality. Agroecosystems provide potential benefits in terms of increase in the productivity along with soil fertility enhancement. It also reflects higher carbon sequestering potential; promotes soil and water conservation as well as increases biodiversity value of the entire ecosystem (Raj et al. 2018). Assessment of footprint among the various components of agroecosystem would help to manage this precious ecosystem in a sustainable way for betterment of human civilization. Agroecosystem crop diversification leads to development of resiliency of crop ecosystem followed by low input agriculture practice along with sustainable yield. For example, estimation of carbon footprint (CF) and water footprint (WF) would help to reduce carbon emission and promote water conservation (Platis et al. 2019; Meena et al. 2020b).

In agroecosystem CF refers to the greenhouse gas emission from a product under cradle to grave situation. The concept of WF in agroecosystem may be divided into three forms: (1) The amount of water used by the crops stored in the form of moisture in the soil from precipitation known as green footprint (2) amount of underground water utilized for agro production known as blue footprint and (3) amount of water that becomes contaminated or polluted by the different agro-pollutants during the agricultural activity referred to as grey footprint (Hoekstra 2017). It was reported that proper evaluation of CF and WF helps to regulate the inputs in agroecosystem which reduces the pollution and makes it a more sustainable approach. Proper way of cultivation often leads to reduction of CF and WF (Platis et al. 2019).

Ecological footprint measurement is an important issue from global agroecosystem perspective. At micro level it addresses the energy use pattern, level of GHG emission, energy inputs and outputs through agroecosystem. It also considers the nutrient budget within the agroecosystem. At macro-scale it reflects the biocapacity of the food production system for a country. It also provides an insight on the consumption pattern of a particular country that is putting pressure on the food production system to reflect unsustainable mode of operation. It also has a severe importance in relation to the human development index. This also necessitates the changes in the consumption pattern with an eco-friendly lifestyle. Ecological footprint has also wide scale importance at the individual level which can reflect the individual footprint value depending upon the lifestyle of the concerned individual. Further at the broad scale it reflects the ecological impact of the human beings on nature. It also has a significant role in awareness generation in the farming community for lesser inputs in the agroecosystem through low input agriculture practices, reducing the footprints at the corporate institutions as a part of corporate social responsibility.

Human beings are the major cause of environmental degradation over earth. They cumulatively have given rise of mega events such as climate change, global warming, ozone depletion and mostly pollution (Meena and Lal 2018). The reports of United Nation also emphasized the problem of resource depletion as well as various other associated social issues. As a consequence of that human civilization would be under the grave of extinction (Holden 2004). At present moment consumptive life style of humankind has aggravated the problems and issues of resource depletion, environmental degradation, loss of biodiversity and over all environmental pollution. This indicates that we are far away from the concept of sustainable development and sustainability (Wackernagel et al. 1997). Therefore, human's need to change their attitude towards nature by compromising with the supportive capacity of nature so that the problem of ecological overshoot does not arise (Wackernagel and Rees 1996). Hence the concept of ecological footprint (EF) came into existence to achieve sustainability. Sustainability is such an issue which focuses on optimum use of resource and takes care about the carrying capacity of the habitat. One should know about the ecological limits of the nature and to know about such aspects one needs to go for proper monitoring and trend analysis of human use of nature.

Food system is an important component to maintain the sustainability of human civilization. It is also necessary to feed the growing population. Therefore, production process should be maintained without causing environmental consequences. According to global footprint network food production contributes 26% of the EF of the human civilization. Globally, the value of EF is 3 ha per individual for the food system. It is very interesting to note that the value of the developed nation stands to be higher in comparison to the poor economy or developing economy based countries. For example, the value of North America, Oceania and Europe ranges between 5 and 7 global hectares per individual and, on the other hand, the value of Africa, Asia, Latin American countries ranges between 0 and 3 global hectares per individual (NFA 2018).

Equilibrium in ecosystem depends upon the absorptive capacity of the ecosystem which can be regarded as the assimilative capacity of the ecosystem. The major task in this aspect is to understand the interaction of man and nature (Silva et al. 2013). As a consequence of that in early ninety's the concept of EF came into existence as a measure of human actions over nature (Wackernagel and Rees 1996). With gradual progress and development of EF concept it was studied in different form such as CF, WF by various workers. Overall the various forms of footprint address the problem of resource use by mankind (Hoekstra 2017). Later on works of Galli (2015) reflected different forms of footprint acting as an indicator for sustainable development. Table 1.1 represents the values of EF of different countries across the globe. The values clearly reflect that there is significant level of variation in the EF values depending upon the human consumption pattern, lifestyle, livelihood maintenance and resource dependency.

The concept of EF can be observed and visualized in various stages or components. First step includes identification and inventorization of footprints,

Table 1.1 Ecological footprint of different countries (data source: Living planet Report 2004)

Name of countries	Ecological footprint (ha per capita)
United Arab Emirates	10
United States	10
Kuwait	10
Haiti	<1
Somalia	<1
Afghanistan	<1
Canada	8.8
Costa Rica	1.95
India	0.77

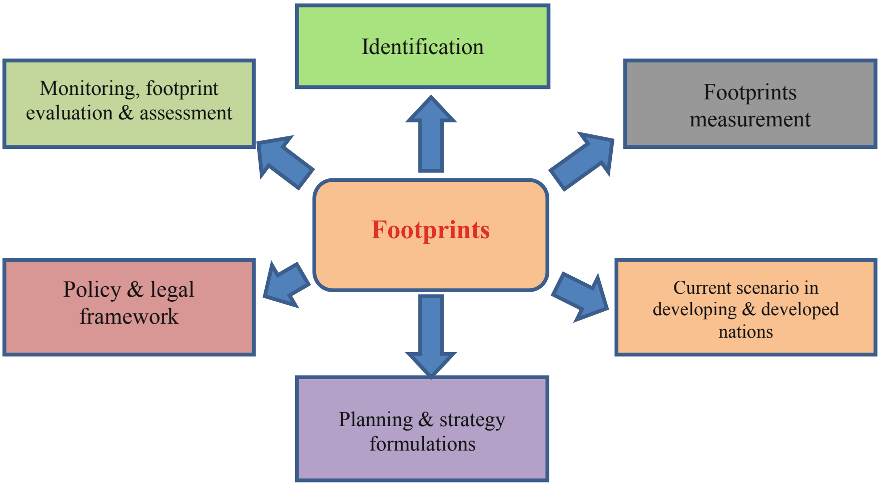

Fig. 1.1 Ecological footprint: an introductory framework

followed by measurement in developed and developing countries. Depending upon the outcome of measurements, planning and strategy formulation is done to reduce the footprints. Legal framework executes the enactment of footprint reducing policies. Further, monitoring and assessment is done regarding effectiveness of the footprint reducing policies (Fig. 1.1).

1.2 Concept of Ecological Footprint

Human beings are very much dependent upon nature to derive their basic human needs. They depend on nature for food, for water, for air and habitat. In this way they tend to consume various ecosystem services which need to be evaluated properly in order to assess their future existence. The carrying capacity of nature can be divided into assimilative and supportive capacity. Therefore, proper balance needs to be maintained between these two capacities to overcome the problem of ecological

Table 1.2 Trend of world population and total ecological footprint

World population (in billions)	Total ecological footprint (billion global hectare)
3	Up to 8
4	10
5	12
6	>14
7	>16

overshoot. How much a man consumes would reflect in the form of ecological impact as a whole (Wackernagel et al. 1997). The major principle of EF lies on accounting of human use of resources followed by waste conversion to bio productive areas (Holden 2004). Thus, EF indicates the human use of nature. Table 1.2 represents the population growth along with increasing level of EF values. An increase in human population up to 4 billion doubles the total EF value across the world.

The entire calculation of EF is based upon some basic assumptions. This includes quantification and measurement of the amount of resources consumed by human beings followed by waste generation by humankind. Secondly, scaling of biologically productive area and its representation as global hectares of land need to be done. Thirdly, measurement of the flow of inputs and outputs from agroecosystem in terms of resource and waste is to be done. Fourthly, finding out the overall demand of human civilization and representation of the ecological services in the form of global hectare for calculation of ecological overshoot condition is required (Oloruntegbe et al. 2013). Accounting of footprint focuses on six different components of agroecosystem. It includes measurement of cultivable land area, area of forest land required for sequestering carbon emission from humankind, area for grazing activity to produce animal commodity, area of sea for fishery production, area of land use for different human activities (Goldfinger et al. 2014). Human consumption is a major issue that determines the fate of EF over a particular area for a particular time. The consumption type includes food material, nature of shelter and transportation along with economic commodity (Oloruntegbe et al. 2013).

The different footprints are dependent upon the consumption pattern of human beings. In order to reduce EF one should go for organic farming practices. Significant level of awareness in relation to footprint should be gathered. The impact of EF in human health needs to be explored properly. New eco-friendly technologies involving lab to land programme should be designed in order to maintain ecosystem homeostasis. The overall assessment of footprint value would improve the societal environment of human beings.

As per scientific report the EF of the globe stands to approximately 18 billion global hectares with global biocapacity (BC) value is more than 10 billion global hectares as up to 2010. However, 3% decline in EF value was recorded within a year (2008–2009) due to reduction of demand function of coal oil and natural gas along

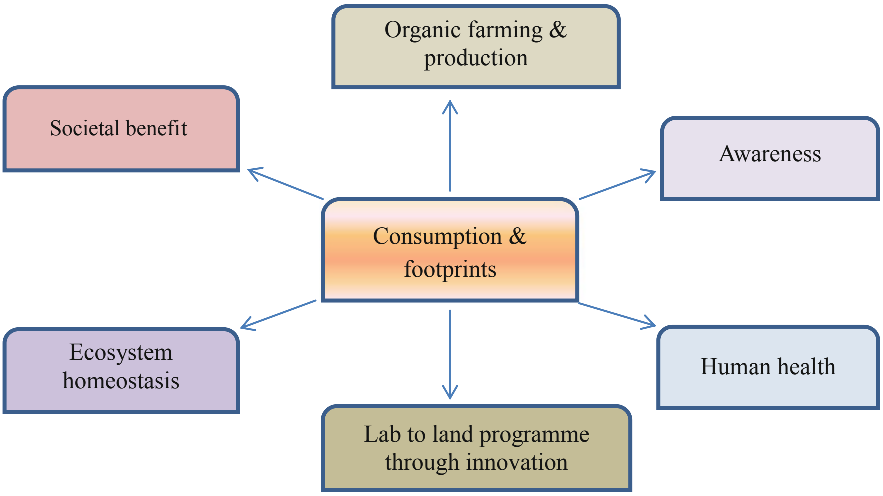

Fig. 1.2 Interaction of ecological footprint

with products of forest. However, the ecological overshoot condition has already taken place across the globe.

The concept of ecosystem footprint in agroecosystem is a holistic approach that considers all segments in the agroecosystem. The consumption pattern determines the fate of ecological footprint within the agroecosystem. Increasing footprint leads to adversely affect the human health and disrupts the ecosystem homeostasis. Innovative approaches in the agriculture sector in the form of organic farming through lab to land approach may reduce the footprint of the agroecosystem. Further it would lead to societal benefit (Fig. 1.2).

Managing EF of the agroecosystem and the food system is the need of the hour as more the footprint is increasing more there would be degradation of the soil quality, unsustainable mode of production leading to depletion of natural resource. Reducing and proper management of footprints requires traditional nature based farming practices, changes in the human consumption pattern, integrated system of sustainable agriculture along with development and implementation of eco-friendly agrotechnology. Such strategies would work in an integrated manner to reduce the footprints of the agroecosystem followed by addressing the issue of sustainability.

1.3 Ecological Footprint and Sustainability

The key to sustainability and sustainable development is the appropriate use of resources. In order to check the resource depletion worldwide conservation is the main tool to deal with. Various sustainability indicators have been determined across the globe in order to assess the current trends of sustainability. In this, resource accounting is a major task which addresses the issue of EF (Van den Bergh and

Table 1.3 Ecological footprint studies across the globe

Ecological footprint studies	References
National and global footprint calculation	Wackernagel et al. (2004)
Utilization of EF calculation for assessment of sustainability of food systems	Van der Werf et al. (2007)
Ecological carrying capacity assessment for six crop systems	
Comparative studies on assessing environmental impacts for different farming practices	Mózner et al. (2012)
Role of farming technique in crop land and its impact on EF	Passeri et al. (2013)
EF analysis of agro-products	Shuyan et al. (2014)
EF accounting and their rationale	Galli (2015)
EF based assessment of environmental impact on crop system	Blasi et al. (2016)
Environment economic valuation of farm through EF	Blasi et al. (2016)

Verbruggen 1999). Table 1.3 represents various EF studies based on agroecosystem across the globe.

Often considered a primary focus of sustainable development, is the reduction in resource use. EF is a simple comparison between various modes of resource use and evaluation of the balance between resource consumption and waste accumulation by the humanity in terms of productive land. According to a report of World Wildlife Fund (WWF) (2002) the global footprint was calculated to be 2.3 global hectares on individual basis which reflects that such amount of area is required to support each individual of human beings on this earth surface. Similarly the BC value of earth stands to be 1.9 on individual basis. Comparison between the two values reflects the condition of unsustainable pattern of human consumption lifestyle and ecological overshoot. Hence, the residence time of resources is getting reduced. Therefore, optimum and equitable distribution of the resource is the need of the hour as well as sustainable development (Wackernagel and Rees 1996). EF highlights the sustainability issue of the current situation and explains us what to do or what not to do (Fig. 1.3).

1.4 Ecological Footprint Analysis

EFA (Ecological footprint analysis) is an indicator which is based upon the area as well the number of individuals in that area at a particular time and their probability of resource use and discharge of waste in relation to the capacity of the area to provide the services (Wackernagel and Rees 1996). Different level of productivity exists among different ecosystems. Per hectare area of different biological productivity gets converted into global productivity through their relative weightage of their productivity in comparison to productivity at global level. Using this conversion we calculate productivity of some importance factor under different land use category and global average productivity, etc., as well as we capture the yield factors and

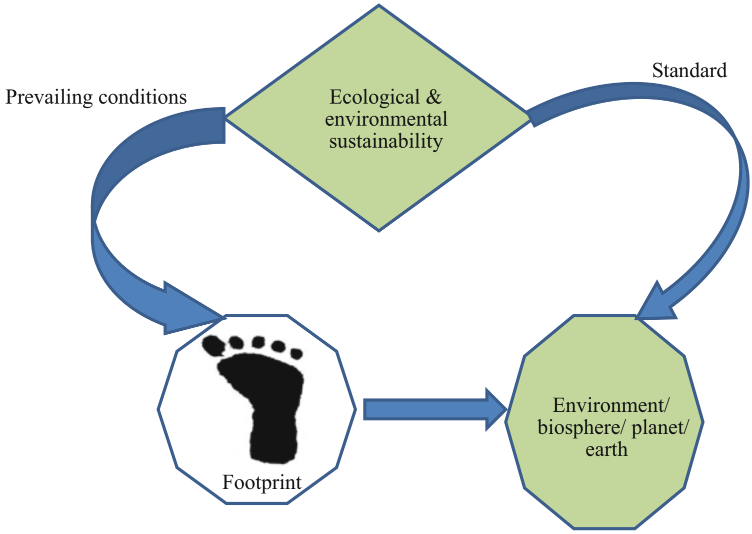

Fig. 1.3 Ecological footprint and sustainability

find out the difference between the local and global average productivity. Equivalence factor is the ratio between average and average productivity. The term average refers to the land type of world and average productivity refers to the average productivity of any land type at global level which is converted to the global ha productivity (Norse and Xiaotang 2015). The formula for calculating the equivalence factor includes the following:

$$\mathrm{EQ} = P/T_{\mathrm{p}} \tag{1.1}$$

where P is the individual productivity of a land type and T_{p} refers to the total productivity of all the different land types.

BC is an integrated term which includes both water and land which is biologically productive at a certain time interval and area within the geographical boundary of a country. BC is usually calculated for different land use types in the form of per capita gha. The values of BC varied on the time frame due to climatic perturbations, conditions prevailing in ecosystems and soil habitat as well as pattern of farming system involved. The formula used for calculating the BC includes the following:

$$\text{Biocapacity} = \sum(\text{area} \times \text{equivalence factors} \times \text{yield factor}) \tag{1.2}$$

$\mathrm{BC} = \sum (A \times \mathrm{EQ} \times \mathrm{YF})$ (where value of A is the BC of a particular land type, EQ refers to the equivalence factor for a land type and YF refers to the yield factors).

The difference value between ecological footprint and BC refers to as BR or BD (Biocapacity Remainder or Biocapacity Deficit). It can be calculated for an

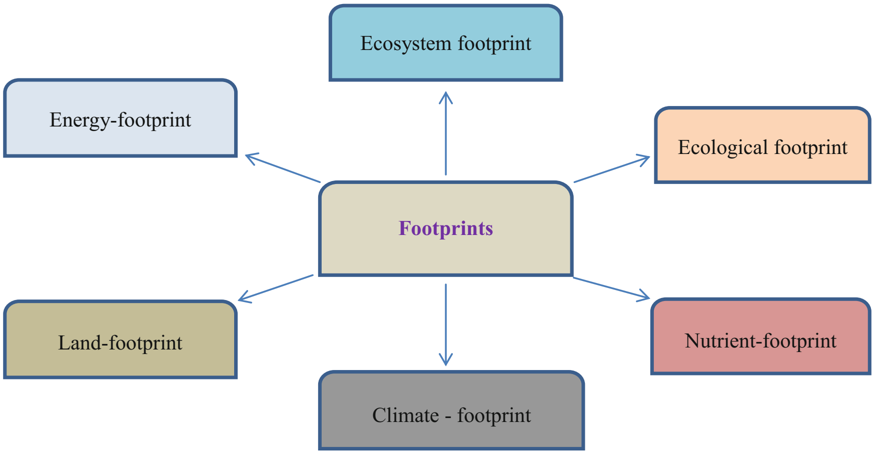

Fig. 1.4 Various forms of footprints

individual person, a particular region or for a particular country. The formula for calculating BR or BD is the following (Li et al. 2016):

$$\text{BD or BR} = \text{BC} - \text{EF} \tag{1.3}$$

There are two most important aspects of BC which helps to maintain the balance of agroecosystems and different land uses of the world. One is BD which occurs due to overshoot of EF over BC of a particular area available for human population. The other is BR which is just the reverse condition of BD. If BC takes place at regional or national level, it reveals the import of BC through business activities as well loss of the assets of the ecosystem. For example, in case of Beijing City of Peoples Republic of China the BD value appears to be 0.8894 gha (global hectare) on individual basis. City needs to improve its business activity to meet up the BD of per capita food consumption. However, BC at global level cannot be adjusted through business activity resulting into overshoot conditions. Figure 1.4 represents various forms of footprints that exist in our environment.

1.5 Forms of Footprints

Climate change is a very serious problem and challenging task of the twenty-first century and most of all developing countries are affected due to this serious problem. Climate change is mainly caused by anthropogenic perturbations on the global carbon cycle while it is the developing countries that are suffering most from its effects. Therefore, both, identifying and maintaining viable sinks for atmospheric CO_2 (carbon dioxide) must gain high priority on the political agenda. Carbon trading is one of the possible instruments in order to decrease GHG (greenhouse gas) emissions. Another market-based option is the product communication through CF

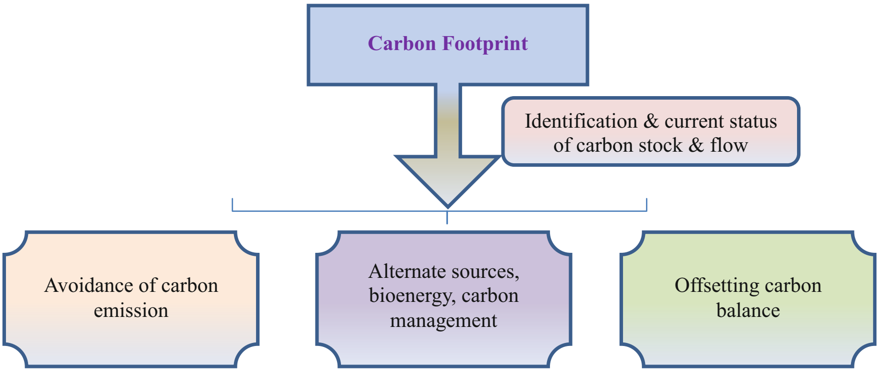

Fig. 1.5 Carbon footprint

as a value-added service of the supply chain. Policies such as use of alternate fuel sources, avoidance of carbon emission through advance technologies offsetting carbon balance may tend to reduce the CF of human society (Fig. 1.5). So far, C credit benefits with regard to land use have not much exceeded the considerations of (forest) biomass, but agricultural soils can also have a considerable potential in terms of their C-stocks (carbon stocks). According to the Food and Agriculture Organization (FAO), nearly 90% of the climate change mitigation potential of agriculture could be realized through soil carbon sequestration (Mavrakis 2011).

CF is the most important parameter to measure at the present context of climate change. It considers the amount of direct or indirect emission of greenhouse gases due to anthropogenic activity or amount calculated for life cycle of a product. The calculation of CF is done through the following formula (Li et al. 2016):

$$\mathrm{CF} = \sum (I \times \mathrm{EF}) \tag{1.4}$$

Here I = amount of input of resources; EF = emission factor for a particular resource

1.5.1 Water Footprint

Water is the life of planet earth and a major component of agroecosystem interlinked with the issues of food security and crisis. It influences the overall productivity of the globe ecosystem. Water in nature is regulated through the global water cycle.

Agroecosystem is a complex unit serving the purpose of production for mankind. The two-third portion (>75%) nature of productivity comes from the plant sources and other portion comes from animal sources. According to an estimate it is the worldwide leader in production through consumption of more than 6 trillion m^3 of water through irrigation or through precipitation. Gradual growth of human population has promoted human beings to go for more food production. As a result, unsustainable ways of using water resource is depleting this precious resource of nature at an unprecedented rate. Such events have given rise to major events of irregularities in rainfall, change in rainfall pattern and acute water shortage condition. Under such circumstances accounting of water resource is the need of the hour so that we can be aware about the availability of water and act accordingly. Thus, the concept of WF is very much relevant in this context (Ondrasek 2018).

WF is the amount of water resource usage by an individual person, any community and business/industries per day/per year. It can also be defined as the total volume of water consumption by the local people/individual use, any community and industry use of water for different purposes for a particular time and place. It can be quantified as:

$$\mathrm{WF} = \mathrm{WC}/Y \tag{1.5}$$

Here WC = amount of consumption; Y = quantity of i^{th} resource.

1.5.2 Energy Footprint

The basic definition of energy is the capacity to do a work. From ecological standpoint Odum defined energy as the amount of work done/amount of available energy in the production of a good or services.

From footprint perspective the amount of land area required to absorb CO_2 emissions is considered as energy footprint. By this approach one may reduce their emissions in order to reduce the land requirement as corrective measures. As per the reports of Living Planet the EF was more than 6 billion hectares up to 1999. The total global EF appeared to be 13.65 billion hectares up to 1999. Therefore, the EF stands for more than 50% of the EF of the earth. A 4.2 billion hectares increased of EF were observed within a span of 38 years (1961–1999). The major aspect to reduce EF lies on various afforestation and reforestation activities through which EF reduction can be achieved. After that switching over to renewable energy sources such as wind, hydro and solar energy could be a second option for reducing EF.

1.5.3 Climate Footprint

Climate footprint is a holistic approach that encompasses all the greenhouse gases under the purview of Kyoto Protocol. It reflects the human impact or activities on the climate. It is usually calculated as equivalent of CO_2 through application of global warming potential values of GHGs for 100 years (Wright et al. 2011). The climate footprint is intricately related with the CF of the earth surface. In order to reduce the climate footprint and address sustainability one needs to move forward towards carbon trading and low carbon economy (Fig. 1.6).

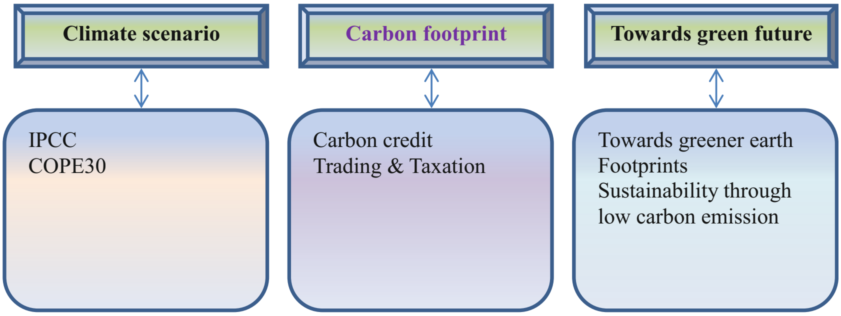

Fig. 1.6 Climate footprint

1.5.4 Land Footprint

The term land footprint is usually referred to as the usable form of land area for production purpose (Giljum et al. 2013). It acts as an indicator reflecting the environmental quality based upon the consumption pattern of the humanity.

1.5.5 Nutrient Footprint

Biogeochemical cycling of the nutrients in agroecosystem is an important aspect in order to maintain the agricultural productivity. Under the process there is frequent exchange of carbon, nitrogen and phosphorous between crop and soil ecosystem. It has been observed that non-judicious use of chemical fertilizer has increased the concentration of carbon, nitrogen and phosphorous in the soil altering the nature of the soil. On the other hand, agricultural pollution is leading to major problems such as GHG emission, conversion of productive land into non-productive one. Thus to maintain the sustainability in the agroecosystem is the biggest challenge for the upcoming century. In this context, proper nutrient budgeting is the key for attaining sustainability. Accounting of the nutrient and its various sources in agroecosystem demands the calculation of nutrient footprint estimation of agroecosystem. In the process of nutrient footprinting one needs to understand the mechanism of biomass synthesis and its subsequent decomposition by microbe community to release the nutrients. In modern system of agriculture plant breeding maximizes yield with lesser carbon input to the plant body which may reduce the soil carbon pool (Kell 2011). This may lead to lesser biomass accumulation which in turn would release lesser nutrients in the soil. However, the entire process would be governed by soil microbial activity who would govern the processes such as mineralization, decomposition, nutrient mobilization between crop and soil in agroecosystem (Cotrufo et al. 2013; Mooshammer et al. 2014). It was observed that soil organic matter is an important component of soil which helps it to adsorb higher amount of nitrogen (Kleber et al. 2015). Therefore, amount of soil organic matter governs the fate of soil nutrient (Richardson et al. 2014). Thus in agroecosystem soil organic matter (SOM) development along with stoichiometric dynamics of nutrient coupling-decoupling mechanism is very much important for soil carbon sequestration and build up of soil nutrient pool (Kallenbach and Grandy 2011).

1.6 Carbon and Water Footprint in Agroecosystems

Research report reveal that agroecosystem sequesters carbon and thus reduces the anthropogenic emissions (Lal 2010a) which helps to combat the issue of climate change. Elevated temperature alters the rate and dynamics of C sequestration both in soil environment and in biomass. A positive correlation exists between elevated temperature and carbon emission due to plant physiological processes in agroecosystem (Arnone III et al. 2008). As soil carbon pool is reduced it hampers the quality of soil in agroecosystem (Lal 2010b). Therefore the concept of CF and WF is very much important for sustainability of agroecosystem. Accounting of the carbon in terms of CF would help to reduce the overall emission of GHGs which would reduce the global warming leading to lesser requirement of water for crop cultivation. CF calculation considers the total GHG emission during the entire lifecycle of a product. On the other hand, WF in agroecosystem accounts for amount of water consumption during agricultural productivity. The concept of WF has been subdivided into various categories such as green, blue and grey footprints. Green refers to the amount of water consumption in the form of soil moisture due to atmospheric deposition during crop production. Blue colour expressed to the use of surface and underground as well as production time and grey colour denotes the total amount of water pollution during the farming production and practices (Hoekstra 2017).

The calculation of CF and WF for agricultural system is very much important as with gradual reduction in the values reduces the GHG emissions as well as promotes sustainable utilization of water resources in the agricultural sector (Michos et al. 2017; Taxidis et al. 2015). The advantages of such measurements for consumer of agro-products lie with proper selection of eco-friendly products that would help in combatting climate change, evaluate the quality of the product in comparison to other products of the market as well as environmental well-being. Therefore, purchasing agro-products with low carbon and WF values could be an effective strategy to attain sustainability in agroecosystem (Escribano et al. 2018).

If we compare the CF and WF values in different agroecosystems, we may obtain different results. Agroforestry system concentration on livestock production represents higher CF. The tree component of the agroforestry system elevates more carbon sequestration in comparison to grassland ecosystem. This results into net increase in the CF value (Eldesouky et al. 2018). It has also been reported that different livestock production system performs differently depending upon the WF value. For example, agro-pastoral system reflects higher WF value followed by agro-silvopastoral system (Eldesouky et al. 2018). Factors such as the climate, local hydrology should also be incorporated in the measurements of WF studies

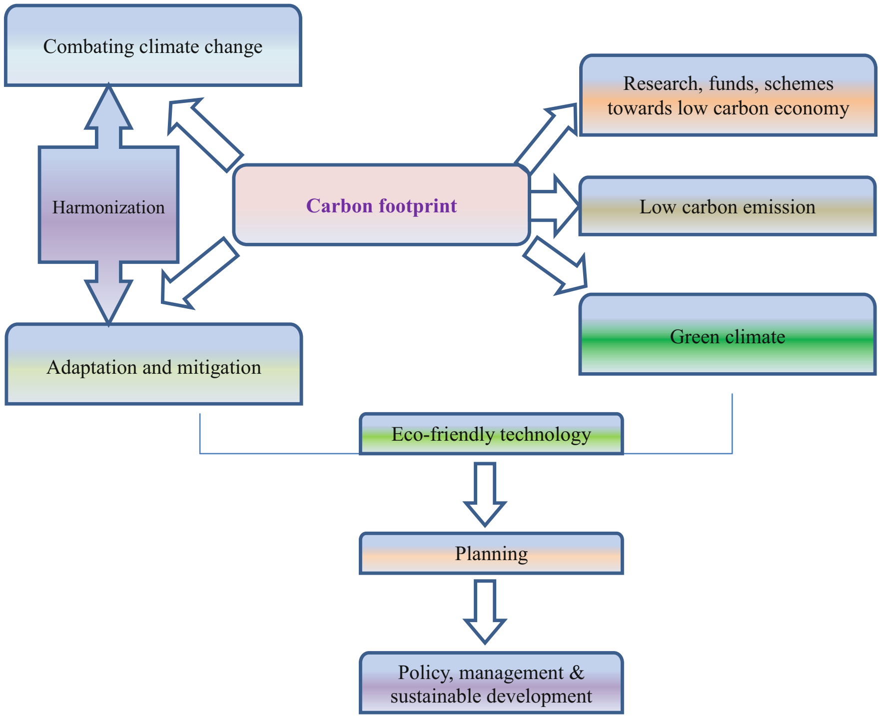

Fig. 1.7 Policy for regulating carbon footprint

(Naranjo-Merino et al. 2018). Figure 1.7 represents policies regarding combating climate change as well as reduction of CF.

1.7 Research and Development in Ecological Footprint

The mega events such as the global warming, global climate change are a severe threat for both mankind and agroecosystem. Modern agriculture has now become too much expensive, technology oriented, energy intensive and unsustainable form of application causing all round pollution of the environment. Considering the inputs in the agriculture sector is creating major problems in terms of GHG emissions (Khan et al. 2020a, b). The major problem is that we cannot reduce the emissions as they are the integral part of agricultural activity. The major aim of research in this sector is to move forward towards zero emissions by 2050. Newer techniques and technologies are being designed across the globe to develop eco-friendly practices to reduce these emissions.

In this context restoration, bio-energy is some of the notable examples (Banerjee et al. 2018; Jhariya et al. 2018a). Therefore, one should go for energy saving farming practices and tackle the various autochthonous and allochthonous inputs of

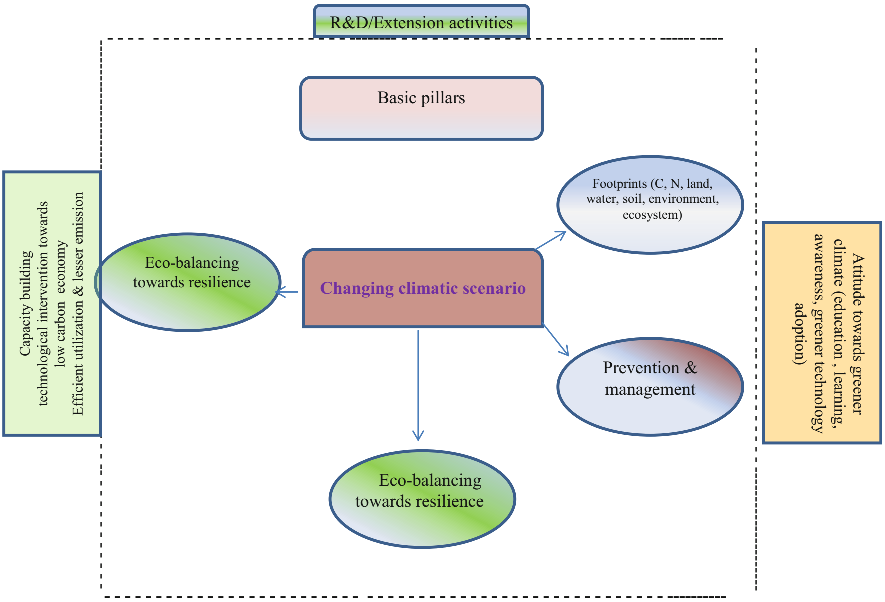

Fig. 1.8 Research and extension activities for ecological footprint

agroecosystem. From agroecosystem perspective carbon sequestration in crop and soil should be given major emphasis. In doing so, proper accounting of the carbon from various components of agroecosystem needs to be done properly. Screening of agro-technologies and agro-products with lesser CF and WF should be done with immediate effect in order to achieve the zero emission targets till 2050. Therefore, research and development in the field of footprint should focus on optimizing carbon sequestration in crop and soil, strategy formulation for proper habitat restoration and reforestation, developing suitable alternate land use systems, consumption of eco-friendly material in infrastructure development and development of eco-friendly agro-technologies such as biofuel, bio-pesticide, biofertilizer, etc. Key research areas should focus on capacity building along with technological innovation towards low carbon economy, reducing various forms of footprints with sustainable approaches (Fig. 1.8).

1.8 Future Roadmap of Ecological Footprint in Agroecosystems

Agroecosystems are the crucial component for survivability of human beings on earth surface in the upcoming future. Researches across the globe have revealed that agroecosystem at present is under the severe stress of water scarcity from its various sources. It is, therefore, the biggest challenge for the future mankind to combat the problem of water scarcity followed by negative ecological consequences in terms of reduction in yield and productivity. From future perspective, long-term policies need to be formulated for water conservation, sustainable water use and water intensive farming. For example, the problem of water logging is further aggravated by global warming, changing climatic condition, increasing demand due to human population growth, etc. Therefore future research should focus on upgradation of the existing technologies such as system of rice intensification (SRI), development of micro-irrigation or sprinkler irrigation for water conservation, use of precision farming techniques for optimum application of chemical fertilizer by application of remote sensing and geographical information systems. The main motto behind such approaches would be to reduce the CF and WF of an agroecosystem and efficient use of agroecosystem (Hodgson 2012).

Achieving sustainability in agroecosystem is very much in its initial phase. It requires a holistic approach such as agro ecology to move towards sustainable agricultural practices. Another bigger problem that lies with the concept of agriculture is viewed from economic perspective. Awareness regarding ecological perspective of agroecosystem and utility of various forms of footprint needs to have wide circulation across the world. People should realize the necessity of these aspects for upcoming time period. We need to go for an inter-disciplinary approach by assessing the environmental scenario of agroecosystem followed by various agroecological interactions in order to maintain the long-term productivity of the ecosystem. After understanding the ecological perspective of agroecosystem one should add the socio-economic and political dimensions to it to reveal the complex nature (Gliessman 2004).

Another bigger issue in calculating EF is diverse in different countries. The difference is more prominent between the developed and developing countries. For example, footprint of Canada appears to be 8.8 ha on individual basis, the value of the same thing is 1.95 ha on individual basis in Costa Rica. In Indian context, it is again much lesser of about 0.77 ha on individual basis (World Wildlife Fund 2002). This reflects a diverse lifestyle, human consumption pattern and demand for resources leading to a condition of ecological overshoot as a whole. Policies, future research and development need to be addressed on these aspects so that the value of footprint of the humanity decreases to achieve sustainability (Wackernagel and Rees 1996). As EF acts as a decision-making tool cost benefit analysis of the decision along with identification of key factors to achieve sustainability needs to be done properly. From future perspective EF accounting should be precisely done through technological modifications, alteration in the trade policies followed by ecological subsidies for net loss of the capital.

1.9 Policy and Legal Framework for Managing Footprint in Agroecosystem

Agroecosystem is an integrated component harbouring diverse footprints in terms of carbon, nitrogen, energy, land and water which is very much important for maintaining sustainability in agroecosystem. Therefore, reducing footprints and managing ecosystem is one of the major tasks ahead in the upcoming century to move towards sustainable development. In this context, one needs to establish the intricate relationship between cultivation approaches and the ecosystem services. The major policy behind this should be farmer friendly so that adoption of suitable farming techniques can be made possible by the farming community across the globe (Wunder 2005). Screening of suitable techniques, processes is very important in order to reduce various forms of footprints present in the agroecosystem. For conserving biodiversity one may go for bio-pesticide application, maintain proper crop rotation, diversify agriculture practices, optimum rate of stocking for production, promote agroecological principles which could be fruitful. Proper management of agroecosystem requires comprehensive assessment of agroecosystem health. Assessing agroecosystem health should be key policy issues for proper management of agroecosystem.

Government has to play a key role in order to frame scientific ecological principles for sustainable management of agroecosystem. Government should act as a key factor for regulating the production process in a sustainable way and promote conservative approach among the society for better management. From legal perspective government should frame proper law, acts that promote and maintain the overall health of agroecosystem. Participatory management is another bigger aspect as it includes community awareness regarding sustainable agroecosystem. It also emphasizes the active supervision of the public for effective implementation of agroecosystem.

From footprint perspective reducing CF, energy footprint, nutrient footprint is the biggest challenge in order to achieve sustainability in agroecosystem. Specific farming practices such as cultivation of grain crops, no till cropping, effective management of the crop residue may tend to reduce the carbon footprint. The issue of nutrient footprint in terms of nitrogen and phosphorous footprint can be reduced in terms of application of biofertilizer, compost, green manuring and leguminous–non-leguminous crop rotation practices (Liu et al. 2016; Jhariya et al. 2018b).

For reducing water footprint optimum use of water, water conservation practices such as sprinkler irrigation, drip irrigation as well as water intensive farming are the suitable techniques that can be adopted across the globe.

1.10 Conclusion

EF is a major issue on the present context as it has got a holistic approach for natural resource accounting. Agroecosystem is becoming critical day by day due to modernized agricultural practices as well as ever increasing demand of food by the human beings. Therefore, the gap between resource demand and renewability of resources is increasing day by day. Unsustainable form of cultivation practices has increased the ecological footprint of the agroecosystem. It is reflecting its impact in the form of GHG emission, pollution, depletion of soil quality, decline in the crop productivity and alteration in the consumption pattern. At a time EF takes into account of human consumption pattern of natural resources, demand for land and water for food production followed by amount of waste that can be assimilated to keep a balance between assimilative and productive capacity of agroecosystem. As EF is a holistic approach it addresses the footprint in agroecosystem in different dimensions. Major aspects include water, soil, land, nutrient, energy footprints. Addressing these various footprints would bring societal upliftment for the human civilization in terms of lesser degradation of resources, lesser pollution, sustainable yield and production. Innovative technologies such as organic farming, green manuring, low input agriculture practice, lesser mechanized activities should be implemented at the base level in order to reduce the various forms of footprints in agroecosystem and move towards greener future.

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Natural Resources Intensification and Footprints Management for Sustainable Food System

2

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Abstract

The global population are approaching to 10 billion by the year 2050, therefore to encounter the food security of the increasing population it has been anticipated that production of food must be improved by 70%. Despite more food production and increasing the poverty level are the foremost difficulties to fulfil the nutrition and food demand for the emerging world. At the same time, climate change creates a great barrier to improve agricultural productivity. It has been recognized and proved that traditional agricultural practices do not reduce the rural poverty and degradation of the ecosystem. Food production systems are not always environmentally friendly and cost-benefit depends on imbalanced use synthetic fertilizers and pesticides. Therefore, it is indispensable to expand environmentally friendly technologies for sustaining crop yield. Earlier evidence proved that under the future changing climate, the food demand for the growing people across the globe can be only attained through the management of agroecology; since it emphasizes on resource conservation farming practices, reworking small farm enterprises, the participation of more farmers, traditional knowledge of the farming community, improved plant genetic multiplicity, and avoid to use of imbalanced synthetic pesticides and manures. The chapter focuses on the sustainable agroecological based crop production systems without hindering the agroecological environment for the nourishment of the growing population particularly in emerging nations of South Asia under changing climate.

Keywords

Agriculture · Agroecology · Climate change · Food security · Sustainability

Abbreviations

ALF	Agricultural Land Footprint
AWD	Alternate Wetting and Drying
BF	Biodiversity footprint
BLF	Built-up Land Footprint
BWF	Blue Water Footprint
CA	Conservation Agriculture
CF	Carbon Footprint
CH_4	Methane
CLF	Crop Land Footprint
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CT	Conventional Tillage
DSR	Direct Seeded Rice
ECF	Economic Footprints
EF	Ecological Footprint
EMF	Emission Footprint
ENF	Energy Footprint
FF	Financial Footprint
FGF	Fishing Grounds Footprint
FLF	Forest Land Footprint
GDP	Gross Domestic Product
GHGs	Green House Gases Emission
GLF	Grazing Land Footprint
GWP	Global Warming Potential

HF	Human Footprint
HYV	High Yielding Crop Variety
IGPs	Indo-Gangetic Plains
INM	Integrated Nutrient Management
LCA	Life Cycle Assessment
LCC	Leaf colour chart
LF	Land Footprint
MI	Maintainable Improvement
N_2O	Nitrous oxide
NF	Nitrogen Footprint
NH_3	Ammonia
PF	Phosphorus Footprint
RCTs	Resource Conservation Technologies
RW	Rice–Wheat systems
RWRs	Renewable Water Resources
SA	South Asia
SD	Sustainable Development
SO_2	Sulphur Dioxide
SOC	Soil Organic Matter
SOM	Soil Organic Matter
SPI	Sustainable Process Index
SRI	System of Rice Intensification
SSNM	Site-Specific Nutrients Management
WF	Water Footprint
WPF	Water Pollution Footprint
WSF	Waste Footprint
ZT	Zero-Tillage

2.1 Introduction

The population across the globe are approaching to 10 billion by the year 2050, therefore to encounter the food security of the increasing population it has been anticipated that production of food must be improved by 70% (de Schutter 2010; European Commission 2011; Ojha et al. 2014). Therefore, to satisfy the food and nutrition in the emerging world, there is an urgent to improve food production. At the same time, agricultural productivity is going to face the extreme event of the changing climate (IPCC 2007). Anxieties are increasing for adaptation of agriculture to the changing climate (Vermeulen et al. 2012), it is due to not only the threat of climate change to agriculture (Aggarwal 2008) but also link to the livelihoods of rural poor across the globe (Mew et al. 2003; Rosegrant and Cline 2003; Parry et al. 2004; Mall et al. 2006).

Several studies already evidenced that changing climate already hits South Asia. (Nelson 2009). For example, Kumar and Parikh (2001) anticipated the damage of about 8.4% of the overall net-returns of farmers in India as a result of the hostile consequences of environment. The people in the region are experiencing the climate change crisis also reported by Ojha et al. (2014), who conducted a study with 303 farm households across three countries of South Asia (SA) (India, Bangladesh, and Nepal) and revealed that 78% farmers are approved that summer day are getting hotter; 66% are approved that winter-time is getting colder and 44% are approved that precipitation during the rainy season is scared as compared to earlier. The agroecological condition of South Asian countries is deteriorating day by day due to traditional agricultural practices. It has been recognized and proved that traditional agricultural practices could not reduce the rural poverty and degradation of the ecosystem. The food production systems are not always environmentally friendly and cost-benefit and depend on imbalanced use synthetic fertilizers and pesticides (de Schutter 2010; European Commission 2011; Ojha et al. 2014; Meena et al. 2020a). Therefore, without considering agroecology, it is impossible to encounter the nutrition safety of the growing people.

Agroecology is the initial frame in the house of worship of the 'Green Revolution', expressed by Dr. José Graziano da Silva, head of the FAO in the closing ceremony of a two days convention, entitled 'Agroecology for Food and Nutrition Security', which was held on 18–19 September 2014 at FAO's headquarters in Rome, Italy. In his new version, Dr. Silva mentioned that agroecology must be well-thought-out as key attention for the rising global substitutions for resolving food safety of the increasing population in the modern era of the changing climate (Gliessman and Tittonell 2015). The benefits of the agroecological farming also urged by organizations (i.e., the FAO, UNEP, and Biodiversity International) included in World Food Security-1 in the year 2012 (de Schutter 2010; European Commission 2011).

Therefore, it is crucial to improve resource conservation, cost-effective, and environmentally friendly technologies for conserving agricultural outputs. The sustainable nourishment for the growing inhabitants can only be attained through the management of agroecology; since it emphasizes on resource conservation farming practices, reworking small farm enterprises, the participation of more farmers', traditional knowledge of the farming community, improved plant genetic multiplicity, and escape to over-use of excessive synthetic pesticides and fertilizers.

The chapter focuses on the sustainable agroecological based crop production systems without hindering the agroecological environment for the nourishment of the growing population particularly in emerging nations of South Asia under changing climate.

2.2 Major Components of Agroecology in South Asia

The term agroecology refers to an integrated approach of ecological and social principles, and their application to design agriculture and allied systems in sustainable manners. It aims to optimum use of natural resources and their interaction with each other to build up a fair and sound farming system. The different components of

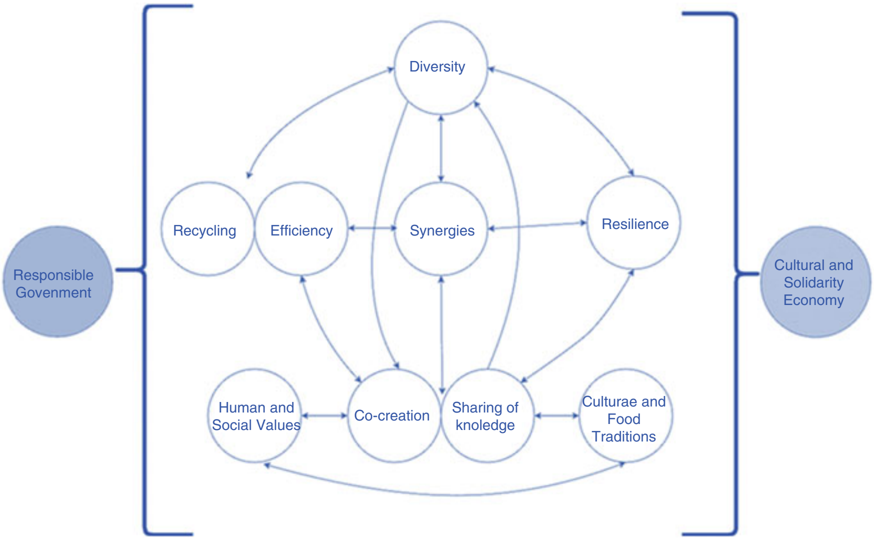

Fig. 2.1 Intra-relationship between the major components of agroecology

the agroecology are intra-related to each other (Fig. 2.1). In this section, we have discussed the major components and their present status in the South Asian region.

2.2.1 Diversity

Diversity is the key component to agroecology that strengthens ecological and socio-economic resilience by understanding the way of conserving and increasing the resource use efficiency. SA comprises of 8 countries and 5 time zones. Hence, a wide range of agro-climatic diversities, cultures, traditions, food habits, and economics exist in this region as follows:

2.2.1.1 Diversity in Land Resources

Huge population pressure and no scope for horizontal augmentation of arable land make it the most crucial resource in SA. Bangladesh uses the maximum land (70%) under cultivation over the total land area, closely followed by India (60%). However, Pakistan, Sri Lanka, and Nepal have utilized 30% of their land only for cultivation purposes (FAOSTAT 2004). Additionally, Bangladesh accounted for the maximum value in irrigation intensiveness (165%), whereas it was 110% for Pakistan (Weligamage et al. 2002).

2.2.1.2 Diversity in Water Resources

In SA countries the maximum rainfall happens through S-W monsoon and winter faces a huge water crisis. Almost 4000 mm precipitation occurs in Bhutan and just 1083 mm is received by India. Pakistan has received only 80 mm of rainfall (Ali et al. 2012). In case of renewable water resources (RWRs), India has the highest RWRs (1911 km^3) next to Bangladesh (1200 km^3), Pakistan (223 km^3), Bhutan (78.0 km^3), and Sri Lanka (52.8 km^3) (FAO 2011). Bhutan is known as the water surplus country, while Pakistan runs in negative in the context of available water resources.

2.2.1.3 Diversity in Climate Change

It has been projected that in SA region 0.5–1.2 °C temperature will rise at the end of this century and 0.88–3.16 °C by the year 2050, and 1.56–5.44 °C by 2080 (reported by IPCC 2007). The effect of global warming would be more in low altitude and dry season in developing countries. Some parts of India such as the west coast, a part of Gujarat and Kerala would be received 6–8% more rainfall than normal in recent future (FCCC 2012). The spatial distribution of temperature change indicates that the central, peninsular, north-east, and west coast India will face the challenge of higher temperate, while north-west and southern India will observe the cooling trend (Kavikumar 2010).

2.2.1.4 Crops Diversification

The diversification of crops refers to the accumulation of different types of crops or systems of cropping into a farming system for getting a higher return. The mono-cropping system has been gradually diversified by the high-value field crops, fruits, and vegetables in SA. Introduction of the dwarfing gene in the agricultural system is a key point for the advancement of diversification in this region. Though the rice–wheat system is the main cropping system for livelihood support in IGPs of SA, but recently rice-maize, cotton-wheat, rice-pulses are being popularized. Among the SA countries, Bangladesh, India, Nepal, and Sri Lanka are most rice intensive countries. Besides the crop diversification, integrated farming, rice cum fish, livestock rearing is gaining attention among the farming communities.

2.2.1.5 Land Diversification

Land diversification refers to the modification of crop establishment techniques, alternate land-use, tillage system, and land management to increase the soil health as well as productive capacity per unit area. Conservation agriculture (CA) is the most promising cost-effective and environmentally friendly technique that includes the least soil-disturbance, soil-cover, and crop diversification. Currently, in SA covers 5 Mha land under conservation agriculture (Friedrich et al. 2012). In India, zero-till wheat cultivation after harvesting of *Kharif* (rainy) rice under the presence of crop residue is most popular conservation agriculture practice in the north-western states. Another approach of alternate land-use system is agroforestry. The most popular agroforestry systems in SA are agri-silviculture and agripastoral system. Poplar and Eucalyptus are major tree species and tea, coffee, black pepper, and cardamoms are also cultivated with perennials trees. The agroforestry not only properly utilizes the spatial and temporal resources but also it is considered as a great source (Jhariya et al. 2015; Singh and Jhariya 2016).

2.2.2 Establishment and Disseminate of Experiences

The effectiveness of farming innovations realizes better when farmers sharing their experiences through a common participatory programme. The co-creation of traditional or indigenous knowledge, practical knowledge blends with scientific knowledge may be very effective to bring the innovation to address the common challenges in agriculture. In SA, farmers' participatory programme, front line demonstration, method demonstration, lab to the land programmes are operated for this aspect (Glendenning et al. 2010).

2.2.3 Government Policies, Institutions, and Public Goods

The effect of Green Revolution in India was realized in 10% of the area with adequate facilities like irrigation system, availability of HYVs, electricity, and nutrient management but most of the area in SA, agriculture systems have been inhibited by the absence of structure. Most of the govt. policies favour urban areas and manufacturing sectors rather than agriculture. Decentralization of government policies and indigenous institutional presentation will be the significant concerns in the progress of maximum agricultural systems. The increase in participation of women in agriculture is another advantage of decentralization.

2.2.4 Synergies

Construction of collaborations in food systems delivers numerous welfares. By improving natural collaborations, agroecological performance boosts the ecological utilities, leading to better reserve use effectiveness and flexibility. As a piece of evidence, incorporation of pulses in the cropping system saves 10 million US $nitrogenous fertilizer in every year (FAO 2016). Crop–livestock interaction provides 15% of nitrogen out of total applied N to crops (FAO 2017). In SA, integrated rice systems in combination with other foodstuffs such as fisheries, duck raring, and trees plantation maximize the synergies in respect to dietary multiplicity, produce, control of the weed, soil properties, and productiveness, as well as providing biodiversity habitation and nuisance control (FAO 2016).

2.2.5 Resource Use Efficiency

Improved reserve usage efficacy is embryonic stuff of agroecological systems that judiciously design and accomplish the assortment to create collaborations between components of diverse systems. As a proof, zero-tillage (ZT) has the potential to save 75% of fossil fuel consumption, and 40–50 US$ over conventional tillage (CT) (Malik et al. 2002; Meena et al. 2020a). Furthermore, zero-tillage (ZT) increases soil C sequestration and converting CO_2 into O_2 as well as enriches

SOC. Bed planting in the rice–wheat system at IGPs saves 18–50% of irrigated groundwater (Jat et al. 2005). Implementation of SSNM technique improves the crop yield by 58% and 42% in the rice–wheat system and accounted for 48% more yield in rainy season rice and 52% in winter rice (PDFSR 2011). Leaf colour chart (LCC) based N application has curtailed 50% of nitrogenous fertilizer ha^{-1} without altering the rice productivity as compared to growers' practice and improved the N usage effectiveness by 20–35% in both maize and rice (Ramesh et al. 2016). The implementation of resource conservation yielded 0.5 MT more wheat and hold back 80 million US$ by lowering fuel consumption, tillage practices, and input use.

2.2.6 Recycling

'Waste' is an anthropological perception—it does not be present in natural environments. By emulating natural ecology, agroecological accomplishes and biological procedures that initiate the recycling/reusing of nutrients, biomass and water within production systems, the natural reserves utilization ability can be assessed. For example, deep-rooted crops in agroforestry system hold the nutrient leaching beyond the root zone that enhances the soil available nutrients (Buresh et al. 2004). In SA, recycling of 668 t rice residues has the potential to generate 708.70 lit of bio-ethanol (Kim and Dale 2004).

2.2.7 Resilience Building

Resilient building in agriculture and ecosystem is the key component for sustainability. In recent years, climate-resilient is the major focus in all over the world. SA countries are situated in the diverse agro-climatic region. Hence, location-specific and cost-effective adaptation and mitigation strategies are essential. Aerobic rice cultivation and livestock management can help to reduce 9% of total anthropogenic CH_4 emission (Smith et al. 2007; Meena et al. 2018). Location-specific conservation agriculture enhances C sequestration up to 1.0 t ha^{-1} (Corsi et al. 2012). However, the lower adaptation of CA (4.72 Mha) and awareness are the major constrain in SA (Friedrich et al. 2012). Furthermore, micro-irrigation such as sprinkler does not release any CH_4 (Pathak et al. 2011). They also observed that if the flooded rice field can be adjusted to mid-season drainage the global warming potential (GWP) will be reduced to 5.6 MT CO_2 eq. and would mitigate GWP by 16.7%. LCC based N application has reduced the N_2O emission by 16% and CH_4 by 11% in rice (Bhatia et al. 2012) in SA. For small holding farmers, adoption of agroforestry can sequestrate 1.5–3.5 t C/ha per year (Montagnini and Nair 2004). Other land management practices like contour farming in a hilly area cover cropping reserved 20–40% more top-soil, agonized fewer destruction, and skilled inferior monetary losses than conventional farming practices (Holt-Giménez 2002).

2.2.8 Social and Human Values

Agroecology poses robust importance on human such as self-respect, fairness, addition, and impartiality to entirely the level of society engaged in the farming activity for improving livelihood dimension. Agroecology encourages gender equality to create opportunities for women as they contribute almost half of the agricultural workforce. Agroecology also provides promising sources of income generation in various ways that are knowledge-intensive, eco-friendly, socially acceptable, innovative, and economically viable.

2.2.9 Tradition of Culture and Food

Human heritage, culture, and food habits are the considerable component of location-specific agricultural planning, as the demand for the foods in the market depends on those aforesaid components. When scientific management practices are merged with indigenous knowledge and culture, wealth agroecological solutions become visible. As an example, India is the origin of more than 50,000 indigenous rice varieties (NBPGR 2013), famous for their taste, nutrient content, disease and pest-fighting ability, and their adaptableness to a wide assortment of situation. Cooking strategies and food habits build up based on those properties of indigenous cultivars. Taking this accrued body of outdated experiences as a controller, agroecology can help to realize the prospective of regions to sustain their peoples.

2.3 Impacts of Intensive Agriculture and Climate Change on Agroecology

Agroecology is the foundation of sustainable agriculture. It provides a robust set of solutions to environmental and economic pressures. Intensive agriculture refers to involvement of heavy tillage, lots of labour and capital, injudicious application of water and fertilizer, crop residue, and fossil fuel burning to obtain higher productivity and profitability without concerning ecological sustainability that degrades natural agroecological system (Poppy et al. 2014). Thus, resource-rich agriculture has been shifted towards resource-poor agriculture day by day. Additionally, climate change poses a predominant threat to humankind. Altering rainfall pattern and temperature fluctuation changes the activities of agricultural landscapes in overwhelming and often destructive ways (Rani and Maragatham 2013). The agriculture sector has been contributed 24% of the total anthropogenic emission (IPCC 2007) which is consisted of CO_2, N_2O, and CH_4, the three major greenhouse gases. Rigorous energy uses in farming activity and land management are the broad anthropogenic sources of GHGs emission. From the aforesaid, it has accredited that intensive farming activities to meet the food demand and climatic variability during the twenty-first century have been affected by the existing agroecology in several avenues.

2.3.1 Global Warming and Weather Migration

Climate change, a consequence of the rising GHGs emission, particularly upper level of CO_2 emissions will lead to increase the global average temperature by 2–6 °C within the year 2100, which is almost more than doubled as compared with the existing temperature, predicted by IPCC (Calzadilla et al. 2013; IPCC 2020). The average global temperature rising will lead to the shifting of weather patterns 300–500 km away from the equator and towards the poles, thus changes the existing agroecology, cropping pattern, pest infestation, etc. Higher CO_2 concentration and soil temperature lead to a higher C:N ratio, which may reduce the decomposition rate, and thereby lowers the nutrient mobilization.

2.3.2 Land Value Degradation

Rising ocean temperature, glaciers, and ice sheets melting are attributed as major reasons for the contemporary sea-level change. It was estimated that at the finishing of the era, the average sea level would be raised by more 1 m and consequently the frequency of the cyclonic events and storm surges would likely to be increased (IPCC 2007). It was evidenced that rice yield has declined by 1.6–2.7%, accounted for US$ 10.6 billion financial losses from last 45 years (Chen et al. 2012) only due to the land value degradation.

Major rice exporting countries like Myanmar, Vietnam, and Egypt are expected to shift as importer countries. Intensive agriculture such as heavy traffic movements in the crop field, bare soil, and frequent tillage operations makes soil vulnerable to erosion. In India, an area of 174.2 m ha is hypothetically unprotected to several degradations such as water (153.2 m ha) and wind (15 m ha) erosion and as a consequence, the per capita land availability has been declined from 0.32 ha to 0.19 ha from 2001 to 2050 (Table 2.1). Furthermore, soil acidity and alkalinity cause 25 m ha and 3.6 m ha of land degradation in India, respectively. It is estimated that only 141 m ha land is available for agricultural practices and a very little scope exists

Table 2.1 Available resources and projected resources in future

Land resource	Total area (Mha)	Per capita availability (ha)		
		2001	2025	2050
Total land area	328	0.32	0.23	0.19
Net sown area	150	–	0.11	0.09
Gross cropped area	250	0.19	0.18	0.14
Net irrigated area	87	0.06	0.06	0.05
Gross irrigated area	100	0.08	0.07	0.06
Area under forest	75.5	0.07	0.05	0.04
Total area covering greenness	120	0.12	0.08	0.07
Total area that can produce biomass	270	0.26	0.19	0.15

Data source: State of Indian Agriculture (2009) for further increase in agricultural land (Manivannan et al. 2017; Meena and Lal 2018).

2.3.3 Deterioration of Soil Quality

Both intensive farming and climate change affect the soil physical, chemical, and biological properties. Rapid tillage accelerates soil erosion and hardpan formation. It was reported that intensive practices lower the soil organic matter (SOM) by 61.7%, devastation of soil construction 27.0%, and cause soil destruction 4.3% (Kughur and Audu 2015; Meena et al. 2020b). The most significant impact of climatic variability is the changes in CO_2 concentration in the atmosphere and this gaseous component has acknowledged as the key element of plant photosynthesis. However, the excessive level of CO_2 concentration supplemented with other climatic anomalies may deprive the production ecology below the existing level (Khan et al. 2020a, b). Root surface area is mostly affected by belowground climate change than other factors. Additionally, studies regarding the influence of soil biological environment due to climate change have strongly associated with the changing the soil temperature and CO_2 concentration. This situation significantly influenced the N mineralization process and increased the concentration of solution-phase N (Pendall et al. 2004; Meena et al. 2020c). Nevertheless, it is very problematic to forecast the behaviour of other macronutrients like K in soil solution as its availability does not considerably regulate by soil biological environment. The SOM has a vigorous function for sustaining the fertility of the soil by holding the macro and micronutrients for plant growth. The SOM also plays a significant role for holding the soil particles together as stable aggregates, improvement of soil physical possess ions including water-holding capability, and delivers gaseous interchange and growth of plants root (Lal 2004; Jat et al. 2018). It is also the food source for soil microorganism and acts as a balancing agent for toxic materials by sorption of this heavy metal. Currently, human-made forest firings for horizontal land intensification, clean cultivation, and continuous mono-cropping and fallow land mainly in the dry season are lowering C sequestration for the prospect of farmland. When the presence of this organic carbon in soil increases, the chances of storing to the atmosphere will reduce; as a result, the potentiality of global warming will be alleviated. It was estimated that for Indian soil the optimum soil organic carbon (SOC) should be in between 1 and 1.5%, while its value has come down to 0.3–0.4% (Singh et al. 2014). It was reported that almost 46% of the soil of India has a deficiency of nutrient because of the poor inherent fertility of soil aggravated by the imbalance fertilizer dose. The tendency of marginal farmers of SA to use higher amount N in comparison to P, K, and other secondary and micronutrients creates a nutrient imbalance and widening N:P:K ratio (White et al. 2012; Shew et al. 2019). Nutrient imbalances, immense deforestation, lower SOC, least cultivation of soil restorative crops are measured as the chief causes for the destruction of soil biodiversity.

2.3.4 Worldwide Water Scarcity

Recent reports regarding the climate change revealed that the weather uncertainty has mostly affected on global hydrological system. Arnell (2004) reported that more than 900 million people would be experienced with the severe water shortage in the 2050s. In future, the doubling in CO_2 concentration may not be a cause for a key alteration in precipitation patterns but may result in a huge growth in evaporation and a reduction in water restoration. In India, the intensive farming practices lead to over-extraction of groundwater resources mainly in the agriculturally developed zone, such as northern and eastern India appeared as major hotspots of groundwater depletion as more intensive cultivation of wheat and rice, respectively, demarcated as 'dark zone'. Climate change in terms of maximization of temperature can affect the water quality in various ways such as lowering the dissolved oxygen levels, increasing algal blooming, and most importantly saltwater illustration in the coastal ecosystem. Pollutants transport through the river also likely to be increased as a result of higher rainfall intensity. It is projected that global net irrigation requirements would increase by 3.5–5% by 2025, and 6–8% by 2075 irrespective of climate change (Döll and Siebert 2001; Fischer et al. 2001). Not only water scarcity, but water quality has also been affected for injudicious application of pesticide, fertilizer, and other chemicals to fulfil the aim of intensive agriculture.

2.3.5 Impact on Crop Production and Associative Environment

Crop productivity in agriculture is influenced by climate change either directly, by affecting the factors such as precipitation, temperature, or CO_2 level that directly related with plant growth and development mechanisms or indirectly influenced on associative factors. In general, increasing CO_2 concentration may positively be influenced by photosynthesis rate in C_3, while C_4 type plants show neutral response in a higher concentration of CO_2 as they have a higher affinity on CO_2 (Pep-carboxylase). At a higher level of CO_2 concentration, C_4 plants survive easily in less water than C_3 because of the higher rate of CO_2 uptake and greater stomatal resistance to water loss (Sarkar et al. 2016; Brahmachari et al. 2019). Therefore, the consequence of global warming may not always negatively influence the overall. Apart from CO_2, crop phenology is expressively exaggerated by fluctuations in high temperature. A 1 °C rise in mean temperature shrinkages the grain yield of C_3 plants like rice by 6% and 3–7% in wheat, soybean, mustard, groundnut, and potato (Saseendran et al. 2000). But the leguminous pulse will be less affected in the changing climate scenario because it was established that higher CO_2 level rises the N_2 fixation. Moreover, the pulses can be grown under resource scare condition. The similar impact has followed in oilseed crops. Additionally, the sensitivity of crops towards climate change has differed with their growth stages such as maize is extremely thoughtful to night temperature during pollination and to the shortage of available water.

Environmental change is considered as a foremost cause of weed flora shifting from the tropical and sub-tropical zone to temperate climate and enhances the number of weed species presently limited to the temperate climate of higher altitude (Sarkar 2015; Silberg et al. 2019). Weeds are highly responsive to a small increase in temperature in the tropical region and several reports are available for a substantial increase in weed growth with an increase in temperature. Agricultural intensification through higher input use to get better yield without concern about sustainability is considered as a serious threat to building up some obnoxious weeds, as a glaring example heavy infestation of *Phalaris minor* in rice–wheat cropping system in SA countries (Banerjee et al. 2019).

In the perspective of higher temperature, it would also influence the insect pest population in a complex way under changing climate. Changing the flowering time in the temperate countries due to global warming leads to the addition of different insect species and reaching of a pest status by non-pest insects. Host plant and insect interaction will alter in reaction to the consequence of CO_2 on nourishing superiority and secondary metabolites of host plants. Both direct and indirect effect of moisture stress on field crops make them more susceptible to be damaged by the pest, more precisely in early stages. Precipitation also influences the insect pest infestation, i.e. in winter cereals, aphid population rate could lower under the drought stress condition. However, higher rainfall area may be affected by severe disease pest infestation because of the presence of more relative humidity. Along with climatic variability, intensive farming involves the utilization of excess amount of insecticide without considering the economic threshold level (Saha et al. 2016). Integrated pest management is also negligible in intensive farming. When these chemicals are used, they not only destroy their intended target pests and parasites but also kill beneficial insects which contribute to biodiversity loss.

2.3.6 Occurrence of Extreme Events on Human

Fluctuations in the climatic distribution in the larger area will enhance the frequency of extreme events like drought, floods, heat waves, torrential downpour, and cyclonic events. The occurrence of uncertainties like an extreme growth in temperature (of 6 °C and beyond) is a consequence of higher CO_2 emission suddenly, due to a forest fire. However, the causes for occurring of extreme events are closely related to each other like occurrence flooding mostly depends on heavy rainfall (more intensified) and glacier melting. Globally, the number of severe flooding is being doubled during the last decade and among the extreme events, droughts are taken into consideration as the most detrimental one. The drought is resultant of erratic rainfall distribution, drastic use of groundwater, lowering moisture storage capacity, or the combination of all factors. Modern intensive agriculture aims to produce higher yield per unit area with the adoption of the mechanized farming system. This makes very hard for traditional farmers to compete. Also, this mechanized intensive farming does not create a lot of job per unit of food produced which likely to increase joblessness and farmers have to migrate from agriculture for searching a better livelihood.

2.4 Natural Resources and Footprints in South Asia (SA)

Natural resources of South Asia (SA) comprise mainly of land and water, which must be used sustainably with advanced resource conservation technologies. Coming over to land resources increased population and urbanization had adverse effects on the land resources. Further, problems of water logging, soil salinity, alkalinity, erosion, brick making put an adverse effect on the land resources as they are shrinking, while on other hand, there is a need to produce more from the less land as world's population.

2.4.1 Natural Resources of South Asia

Seven countries of SA including India, Bangladesh, Pakistan, Sri Lanka, Afghanistan, Nepal, and Bhutan are contributing to 23.7% of the population across the globe, but they comprise merely about 4.6% of world annual renewable water resources. At certain locations, conditions become quite serious as in Punjab, India where more than 114 blocks out of total 142 blocks declared as dark zone which means that farmers of those block will have to think seriously by adopting resource conservation technologies. Agricultural contribution continuously decreased in the gross domestic product (GDP), even because of extensive research and the highest share of people to this sector for earning their livelihoods (FAO 2016). That might be because of many sustainability issues, viz. shrinking water resources, the outbreak of insect pest attack, deteriorating soil vigour, arising micronutrients shortage, etc. (Bhatt et al. 2016). From the last few decades, water demand in the other competitive sectors, viz. household, industrial, and hydropower shaping the way the upper reaches of major river systems in SA. Downstream parts of basins facing severe pressure because of escalating water demands particularly under environmental flows and species biodiversity. Shallow water trends showed decreasing trends in Asia as a whole (Fig. 2.2), where experts of NASA, highlighted the drought in each week concerning groundwater and soil moisture; which is derived from GRACE-FO satellite data. In Fig. 2.2, the drought pointers labelled existing wet or dry situations, articulated as a percentile presentation the possibility of incidence for that specific locality and period of a year, where inferior standards (warm colour) sense dryer than regular, and greater standards (blues) sense damper than standard.

The information of the satellite data confirmed that the shallow water trends in Asia are a decreasing trend as a whole. The interactions of climate, topographical, land-use, and socio-economic factors are responsible for the water availability in the South-Asian countries per capita water resources abundant in Bangladesh, Bhutan, and Nepal, whereas rest observed stressed conditions. Total water extractions in SA signify about one-quarter of the accessible renewable freshwater. Experts already

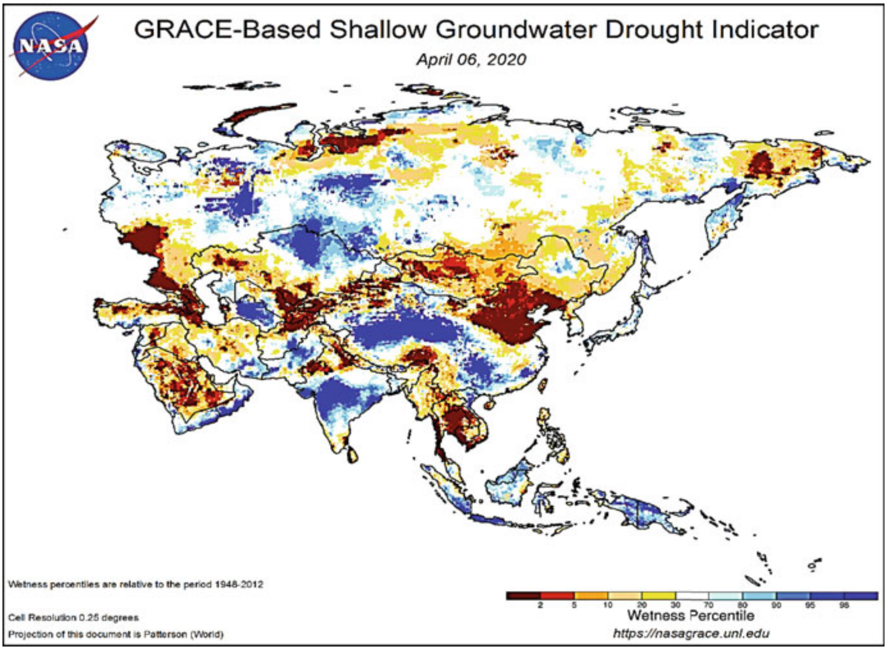

Fig. 2.2 NASA highlights the drought in each week concerning groundwater and soil moisture; which is derived from GRACE-FO satellite data (Source: https://nasagrace.unl.edu/)

predicted that SA is a hot-spot of water-related threats, secretarial for some 40% of natural calamities documented worldwide predominantly under global warming including floods, drought, hike in sea-water level, landslides, and land destruction, specifically in hilly and semi-arid areas. There is a need to predict future climatic conditions, to reduce their impacts as far as possible.

Besides drought, salinity is an additional difficulty in >60% of the area of the Indus-irrigation system, while soil erosion is also detrimental to soil quality in the sub-mountainous tracts where highly intensive rains on the soil with poor organic matter de-attach soil particles. However, eight SA countries, namely India, Bangladesh, Pakistan, Sri Lanka, Nepal, Afghanistan, Bhutan, and Maldives are possessing almost identical land resource and crop types (Fig. 2.3). Different crops cultivated in the South-Asia depending upon the different factors, viz. soil texture, climate, underground water status, availability of the better cultivars, etc. During the recent decades, land productivities of RWCs systems decreased in the IGPs due to numerous problems such as shrinking underground water, deteriorated soil health, micronutrients insufficiencies and wide-spread insect pest infestations, and climate change (Bhatt et al. 2016).

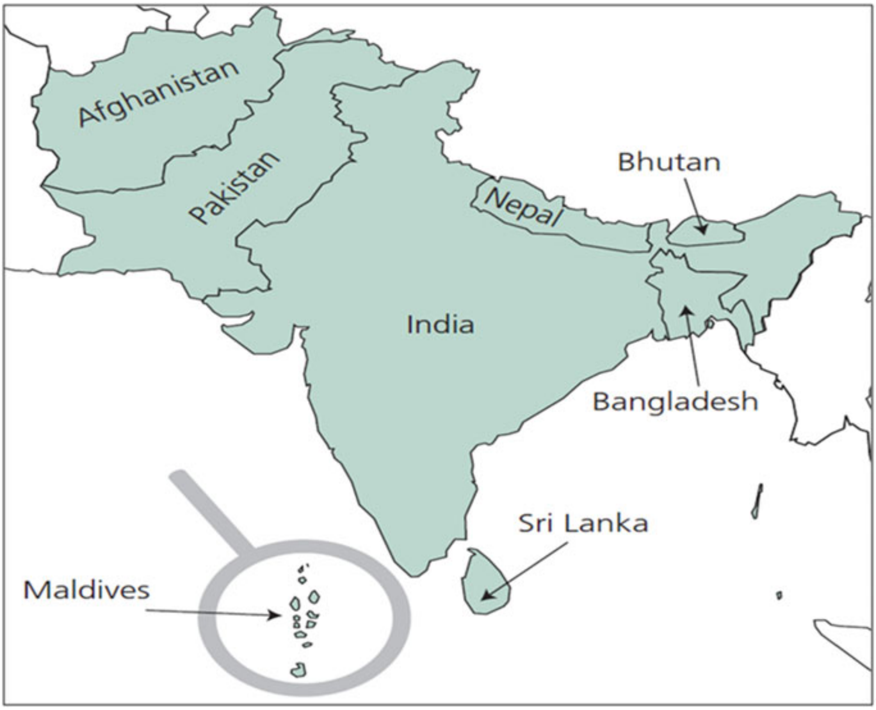

Fig. 2.3 Geographical distribution of these crops in South Asia

2.4.2 Different Footprints

Different footprints (Fig. 2.4) have been recognized and discussed in the following sub-heading:

2.4.2.1 Carbon Footprint

Carbon footprint (CF) from the last few years represents one of the most important environmental protection indicators (Lam et al. 2010; Galli et al. 2012) which deals with CO_2 quantities and other GHGs, viz. CH_4, N_2O, etc. released during a particular procedure or produce (UK POST 2006; BSI 2008). The global warming potential (GWP) (European Commission 2011) used as a pointer for quantifying the CF which is directly linked with climate change leads to global warming (Høgevold 2003). As per another definition shared by European Commission (2011) , CF is because of 'Life-Cycle-Thinking' is linked to global warming. Further, based on land area utilization, CF might be represented by the area prerequisite to confiscate released CO_2 by fossil-fuels through afforestation from the atmosphere (De Benedetto and Klemeš 2009). However, CF related to the estimation of direct and indirect emissions of CO_2 in an action/over the lifespan of a product and delineated in units mass (Wiedmann and Minx 2008).

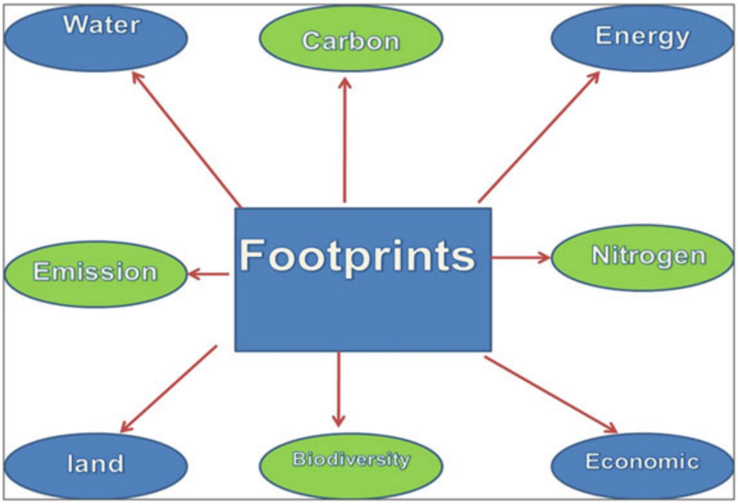

Fig. 2.4 Different footprints which are linked to the agroecology

2.4.2.2 Water Footprints

Water footprints (WFs) represent the total volume (direct and indirect) of freshwater used, consumed, or polluted and are closely linked to the concept of virtual water (Hoekstra and Chapagain 2006; Galli et al. 2011, 2012). Further, WF consists of green, blue, and grey water footprints (comprises of surface and underground water, rainfall consumption, water volume required to dilute polluted water to standards) (Mekonnen and Hoekstra 2010; Klemeš et al. 2009).

2.4.2.3 Energy Footprint

Energy footprint (ENF) may be well-defined as the total amount of lands utilized to afford non-food and non-feed energy; for example, the sum of the land including land for fuel crops, forest land, C uptake land, and hydropower land (European Commission 2011). Further, ENF may be delineated as the total land required for sequestering CO_2 produced for energy usage (Palmer 1998; De Benedetto and Klemeš 2009), without the fraction involved by the oceans, and the part employed by hydroelectric barriers and lakes for hydraulic-power (WWF 2002). ENF also includes fossil (Stoeglehner and Narodoslawsky 2009), wind (Santhanam 2011) nuclear (Stoeglehner et al. 2005), solar (Brown 2009), and renewable ENF (Chen and Lin 2008), as its sub-footprints.

2.4.2.4 Emission Footprint

Emission footprint (EMF) might be termed as product or service quantity-wise responsible for creating emissions, viz. SO_2, CO, CO_2, water (e.g., nitrogen and phosphorus, demand for chemical oxygen), and soil (through emission in the soil) in the atmosphere. Normally, calculations of EMF were done, based on per unit of land required. Lower land intakes' emanations may be degenerate without disrespectful the standard that anthropogenic mass movements must not change the potentials of indigenous sections (De De Benedetto and Klemeš 2009).

2.4.2.5 Nitrogen Footprint

The nitrogen footprint (NF) is an indicator for the measurement of the quantity of volatile compound, which is freed into the environment as a consequence of anthropogenic actions. It is articulated in entire units of Nr (Nr express all types of nitrogen species excluding N_2) (N-Print Team 2011; Leach et al. 2012). The NF symbolizes the disturbance of the provincial to universal N succession and its penalties. NF mainly covers the following Nr emissions: NOx, N_2O, NO_3, and NH_3 which are inter-exchangeable since one Nr form to a different (Galloway et al. 2003). Lack of data and its uncertainty is the major weakness of the NF (Leach et al. 2012).

2.4.2.6 Land Footprint

The land footprint (LF) comprises sub-footprints, including forest (WWF 2002), agricultural land (Kissinger and Gottlieb 2010), the built-up land (Chambers et al. 2004), the grazing land (WWF Japan and GFN 2010), and the crop-LF (Van Rooyen 2005).

2.4.2.7 Biodiversity Footprint

Biodiversity losses such as the result of the land renovation, land convention fluctuations, the unjustifiable usage of carbon-based possessions, the over-misuse of oceanic ecological capitals, and the invasion of unfamiliar living organisms are being measured by biodiversity footprint (BF) (Oteng-Yeboah 2009; Burrows 2011).

2.4.2.8 Economic Footprint

Economic footprints might be conferred by financial footprints (FFs) and economic footprints (ECFs). Clear definitions of both till now not available. Further, FF represents the expenditures made by a human, while ECF represents over-all straight and incidental economic influences of particular procedures, produces, or actions, an area or a whole nation. The FF emphasizes withdrawal, reserves, assurance, duty, and plantations (BMFG 2008) and is well-defined in terms of the financial components solely, business, nation, or period, while ECF signifies the extent.

2.4.2.9 Composite Footprint

Composite footprint is dealing with composite evidence in a particular index and permitting establishments or nations to be categorized in terms of their overall sustainability. These basic assessments are mass-media sociable and are utilized rather likewise to an educational score (OECD 2008). The complex footprints are discussed details in the following sub-sections:

Ecological Footprint

The EF is a compound pointer associated with numerous footprints (Toderoiu 2010; Galli et al. 2012). Humankind's anxieties on surroundings nature, viz. land and water bodies determined by EF (Wackernagel and Rees 1996) which further used to measure environmental sustainability. EF also compares resource consumption behaviour of humans with waste absorption with the environmental capability to rejuvenate (GFN 2010). EF delivers an amassed valuation of numerous anthropogenic forces (Wackernagel et al. 2006; Galli et al. 2012).

Sustainable Process Index

The defensible economy solely depends on solar-radiation as the natural revenue. This solar-radiation is the basic assumption of the Sustainable Process Index (SPI), which is associated with the EF (Kettl et al. 2011) and dealings the over-all region indispensable to implant human actions sustainably within the environment. The whole area is divided by the system units known as a specific area which measures sustainability. Lower the SPI, lesser is the effect of given properties or facilities on the ecosphere (Sandholzer and Narodoslawsky 2007). Further, SPI and EF have the same limitations. Limited data, unsurely of data, time intensiveness related to SPI when results of suitable provincial/regional data achieve a comprehensive intention (Hall 2008).

Despite above footprints, there are also some important footprints recognized and discussed by several researchers including phosphorus footprint, which is dealing with the unevenness of phosphorus in relation with growing crops (Lott et al. 2009); the footprint of fishing-grounds, which linked to catching the various fish species (WWF Japan and GFN 2010), also explained the sea area essential to harvest appropriate fish and sea-food for human beings (Van Rooyen 2005); the footprint of human, which deals the quantity of energy, properties, and harvests inspired by human being throughout the lifespan (National Geographic Channel 2011); the footprint of waste, which deals with the quantity of waste formed by obtaining constituents and ingredients, industrial and processing, and carriage (United Soybean Board e Thinking Ahead 2011).

2.5 Management of Footprints for Sustainability

Footprints management is an advanced concept and its proper management is particularly important for environmental sustainability. The foregoing overview of environmental footprint indicates that they are not yet consistent. Environmental footprints definition often varies, as per their measurement units. From the definition point of view, Hoekstra (2008) delineated that a 'footprint' is a measurable quantity that labelling the assumption of natural assets through human beings. He also endorsed how human actions execute diverse categories of problems and effects on inclusive sustainability. Life Cycle Assessment (LCA) used to outline the environmental influences which highlight the 100% utilization of all kinds of left-over materials (Zaman 2013). Normally, LCA is linked to ecological impressions

(Von Blottnitz and Curran 2007) , while maintainable improvement (MI), also taking care of financial and communal apparatuses. Ilskog and Kjellström (2008) reported five-dimensional design which comprises practical, financial, social, ecological, and organizational sustainability. Further, as per Ilskog and Kjellström (2008), MI goal is to come out with a balanced approach among all the objectives, viz. socially equitable, social multiplicity respect, environmentally comprehensive, frugally conceivable, science-based, technologically suitable and intended to authorize and extend capacity and potential of human beings. Sustainability valuation considered into three major groupings, viz. pointers, assessments connected to products, and cohesive valuation implements. Over recent years, tools have emerged known as footprints or individual contribution which further used for appraisal of sustainability along with its components. The present section entitled, 'footprints management for sustainability' covering with footprint definitions, measurement units, and management of various footprints, which are described details in the following sub-heading:

2.5.1 Management of Carbon Footprints

For reducing/managing the C-footprints from individuals, assessment of CF from individual contribution i.e. a farmer, industrialist, politician or even a student is very important. Pre-industrial Revolution near to about 1750, the CO_2 and other greenhouse gas concentrations were 270 ppm to 280 ppm which further increased to 405 ppm in 2017. Not only GHGs concentrations but annual growth dynamics are also escalating. Further, as per Bartoli et al. (2011), today's CO_2 concentration is highest than the last 2.1 million years. Fossil fuel burning worldwide is the largest source of GHGs generation, which increased from 6.8 PgC in 2001 to 9.8 PgC in 2015 (National Oceanic and Atmospheric Administration 2017). Further, deforestation, urbanization, and natural fires are responsible for 1/5th of global emissions (Smith et al. 1993). Oceans are the biggest sink for the C as absorbed 1.8 PgC year^{-1} to 2.9 PgC year^{-1}. Thus, 4 PgC to 6 PgC of emissions stay behind in the atmosphere each year. The research conducted by Gifford (1994) shows that non-deforested terrestrial ecosystems store 2.5 GtC year^{-1} $\pm$ 2.7 GtC year^{-1}. Already many recommendations there, viz. agroforestry, afforestation, minimum tillage, changing of dietary habits from non-vegetarian to vegetarians, use of gypsum with fertilizers, usage leisurely of relief manures, viz. neam-coated or poly-coated urea, intermittent irrigations instead of continuous flooding, DSR, incorporation of crop residues as mulch materials or biochar on the soil-surface, green manuring, use of short duration cultivars, etc. will resolve the determination. Subsequent are discussed other practices for management of CF, though C management is a significant concern for alleviating the adverse effects of global warming.

2.5.2 Crop Residues as Mulch

For the management of the CF, crop residues after crop harvesting must be integrated into the soil or spread on the soil-surface as mulch. Crop residue hinders hot sun-rays to penetrate the bare soil-surface which further lessens the soil-surface temperatures, vapour-pressure gradient, wind speediness and ultimately reduces the soil moisture evaporation. Application of crop residue mulching is indirectly helped to reduce the diesel or electricity consumption by lessening the irrigation demand by the crops. Thus, an efficient crop residue mulching practices are not only helpful to reduce the CF but also beneficial for managing water footprint. (Bhatt and Khera 2006; Arora et al. 2008; Busari et al. 2015; Bhatt and Kukal 2017).

2.5.3 Tillage Modifications

Earlier, tillage rather intensive tillage is done to prepare seed-beds and to get ride-off from the weed seed bank. But later, scientists revealed that conventional intensive tillage as intensive tillage breaks the aggregates and thus makes the organic matter once protected available to the soil micro-organisms, which oxidizes it to CO_2, which is not good for carbon footprints. Therefore scientists across the globe recommended ZT as an important resource conservation technology (Bhatt 2017; Bhatt et al. 2017), but its performance too decreased if all the mulch loads of the previous crops removed from the soil (Bhatt and Kukal 2015a, b).

2.5.4 Need to Change Dietary Habits

In the current era, there is a significant change in nutritional lifestyles as from vegetarian nourishment to a non-vegetarian diet. Further, attention on animal stuff is possibly going to jump to >70% globally between 2005 and 2050. In animals, enteric ageing is an abdominal connected process in herbivorous living being, viz. cow, wild oxen, goat, and sheep have a rumen, a huge four-compartment stomach with a multifaceted microbial population which procedures compound sugars with a final product as CH_4. The discharges decrease potential in Brazil, India, the USA. Additionally, the EU solely increases up to 350 Mt CO_2 per annual. There are several recommendations, viz. enlightening the nature of scrounges, fixing feedstuffs to recover absorbability, and adding grain-based essences to domestic animals, enrichments and addition of substances which could shrinkage CH_4 emissions and manage CF.

2.5.5 Reduces Wastage of Food

Globally, if nourishment production target is reduced anyhow, then the pressure on the food producers will be significantly decreased and that is possible through decreasing the wastage of food which is a vital, but typically un-attended concern. Harvest more by using minimum agricultural lands, pressure anyhow decreased and thereby implementations of different approaches of conservation agriculture seem to be practical which further reduces the emissions of the GHGs. As per FAO measures, about 33% of all human utilization diets is projected to lose. The C imprint of nutrition surplus is measured at 3.3 Gt CO_2. Cereals comprise the greatest share of hardships by calorie and ejections (individually 53 and 34%), whereas green-vegetables comprise the top percentage of hardships by weightiness (44%). In the UK alone, 64% of nourishment wastage is 'avoidable' (Parfitt et al. 2020). Therefore, reducing food wastage will help a lot in managing the C-footprints.

2.5.6 Reducing Methane Emissions from Rice Cultivation

Certainly, there is a role of paddy cultivation particularly conventional paddy cultivation conditions, viz. under puddle standing water conditions (Matthews et al. 1991; Gaihre et al. 2013). Around 55% of the yearly CH_4 emission comes from the paddy growing areas from July to October (Matthews et al. 1991). The average CH_4 discharges varied from 0.65 to 1.12 mg m^{-2} h^{-1} (Mitra et al. 1999) and >90% of which to the atmosphere is through rice plants (Banker et al. 1995). Around 100 g of CH_4 is discharged for producing 1 kg of rice grains. The defaulting CH_4 zero-emission factor is 1.3 kg CH_4 ha^{-1} day^{-1}, in non-stop flooding rice cultivation (IPCC 2006). The decay of fertilizers and crop residues in inundated rice farming mainly responsible for CH_4 emissions (Aulakh et al. 2001). Therefore, preventions submerged conditions by DSR or through alternate wetting and drying or using tensiometers helped in the management of the C-footprints.

Further, in general, WHO (2008) also recommended some practices for daily life as prefer walking, cycling, car-pooling, public transport. On average, every litre of fuel burnt in a car produces >2.5 kg of CO_2. Drive slowly as driving quicker >120 km h^{-1} escalations of fuel in gestation by 30% compared with driving at 80 km h^{-1}. Upper gears (4th, 5th, and 6th) are the greatest cost-effective in the relation of fuel ingestion. Further, reduce, reuse, recycle environmental and health benefits also serve the purpose. Waste is a vital donor to C discharges. The dropping waste can lead to huge emission reserves which help in the management of the C-footprints.

2.5.7 Management of Water Footprints

In the South-Asian countries, except for Bhutan and Nepal water resources are limited and shrinking because of overloads of population pressure. Agriculture sector consumed around 90% of all water available for South-Asia, whereas the rest world used 70% for irrigation. Further, out of these total requirements, around 60% depends on the surface water, while the rest 40% explored from below the ground using submersible pumps. Moreover, paddy cultivation adds to it as around

4000 l of irrigation water used for producing 1 kg of rice. As water is declining throughout the SA and that particularly true where rice-based cropping systems being practiced. Hence, researchers recommended certain resource conservation technologies for the better utilization of the water resources for enlightening the water utilization and hence water use efficiency in the South-Asia. Amongst them, the short lifespan of crop cultivars, timely replacement of rice seedling, use of laser land levelling, judicious application irrigation on the based on tensiometer and adoption of inproved crop production techniques like DSR, mechanical transplanting, crop residue mulching, raised beds, double ZT, etc. are improving water as well land productivity. But, there need to rethink as these RCTs are not universal and are in reality are site and situation-specific. As in the case of DSR, under light-textured soils, it is a great failure. Light-textured farmers often seen to till their DSR crop because of the severe Fe insufficiency and considerably greater weed-pressure, though it is a success under heavy textured soils. Even there is lack of location specific recommendations of the RCTs depending upon the texturally divergent soils and divergent agro-climatic conditions (Bhatt and Kukal 2017). Rapidly declining groundwater quality causing severe health issues needs to be identified, e.g., south-western parts of Punjab, where special rivers diverted for providing irrigation water and people used only filtered water for drinking.

2.6 Natural Resources Intensification for Agroecology Sustainability

The term 'sustainable intensification' is used to define the forthcoming path of development of crop cultivation, to meet the requirement of ever-growing food demand vis-à-vis maintaining the food security and combating the adverse effect of global warming (Pearce et al. 2015). Despite this magnificent progress in the agriculture sector during the last few decades, we cannot ignore the forbidding-side of the story as well. The SA countries occupy miserably a low place in respect of yield in contrast with other countries. Organizers, policy-maker, scientists, and economists are seriously concerned about the sluggish development rate of the crop production in current years. The population has been escalating at an alarming level, while the average growth level of total food grain production is not at all satisfactory. So, there is no other option except to produce more and more (Ghosh et al. 2017; Meena and Lal 2018). There is, therefore, an urgent need for massive well-planned action programme for improving input use effectiveness and output to sustain the tempo of agricultural growth in this region. Increasing productivity with a decrease in production cost for the advantage of the agricultural community as a whole and maintenance of soil health are newly emerging challenges for the agricultural scientists (Ray et al. 2020). Modern agriculture practice is highly inputted intensive agriculture. This input-intensive agriculture uses a considerably higher amount of agricultural input such as plant nutrients, seeds of high yielding crops variety (HYV), plant protection chemicals, irrigation, etc.

On the other hand, with the increasing cost of cultivation in the modern input-intensive agricultural practices and no appreciable additional benefits in income, the growers in overall and small and marginal in specific are finding it extremely difficult to earn their livelihood and a large number of them are below the poverty line. Thus, it must be kept in mind that at this juncture we should not emphasize on our production need alone; we must have to consider the ecological health as well to keep the sustainability of our production unaffected.

As sustainable ecological intensification and production maximization are directly related to the efficient utilization of the precious natural resource, thus there is essential to reflect ecological conservation such as the maintenance and regeneration of natural assets and the possible output of the ecosystem services (Lampkin et al. 2015; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). Agroecology, an approach for sustainable farming, creates the best use of natural resource to meet the present demand without hampering the future need (AGF 2020). The farmers maintaining agroecological sustainability not only improve food yields for balanced nutrition but also maintain soil and environmental health vis-à-vis healthy ecosystems. Natural resources can be intensified for agroecology sustainability in different ways. Scientist used number of agroecological indicators (Lampkin et al. 2015). We also identified such five agroecological indicators as suggested by (Lampkin et al. 2015; Pearce et al. 2015) (Fig. 2.5).

In Table 2.2, we have summarized the different practices that are directly related (synergistically antagonistically) to agroecological sustainability. Integration of input-intensive agriculture with organic and natural low input-intensive agriculture practices is the most efficient and eco-friendly natural resource management techniques for agroecological sustainability. This system can supply enough plant nutrients in the available form to crops and recover the quality of the agricultural products.

But sole adoption of such organic natural resources intensification strategy alone cannot meet the high nutritional requirement of the crops. For this reason, in the recent past, it has been a convention of applying different sources of nutrients, e.g. chemical fertilizers, organic manures, green manures, crop residue, bio-fertilizers, different soil amendments, etc. in combination to the similar crop in the similar piece of land; that means in an approach of INM (Kesavan and Swaminathan 2008; Balasubramanian et al. 2017). Besides this practices, adoption of integrated pest management, biological pest control, the introduction of legume-based diverse cropping system, livestock-based integrated farming system, and agroforestry system has a direct positive impact by optimizing the use of natural resources intensification for agroecology sustainability and environmentally friendly.

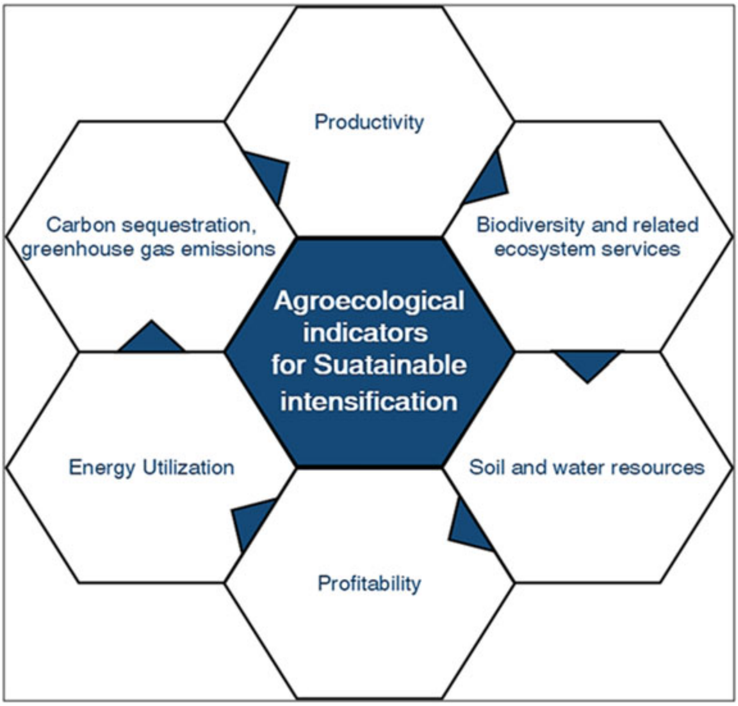

Fig. 2.5 Indicators of performance relevant to sustainable intensification

2.7 Agroecology for Food Security

The demand for food is continuously rising with growing population and farmers are adopting conventional farming practices for augmenting the food production by using higher amount of agro-chemicals as a form of fertilizers and pesticides. However, due to repeated intensive farming practices and higher application of external inputs, the production system showing its limit as the ecosystems have reached saturation and degradation level (Lecomte 2012). The reducing food production capability of the agricultural lands results in a risk to food safety. For most of the major crops, the average yields have improved over the past 50 years (Tilman et al. 2011); nonetheless, the improvement is not equal across the world. The productivity is lower than its need in the poorest provinces of the world particularly in developing countries (Vijikumar 2010) due to insufficient agricultural development models in addition to higher population densities that led to dreadful condition of the natural resource base in SA. Besides, climate change and its consequences have also affected food production and made it difficult to eliminate the food insecurity in this region (European Commissions 2011; Wickramasinghe 2014). In agroecology, simple farming techniques such as traditional practices of the agricultural system linking

Table 2.2 Involvement of diverse agroecological performs and methods to distinct and viable crop diversification. Source: Lampkin et al. (2015) and Pearce et al. (2015)

Practice	Productivity	Non-renewable energy use and GHG emissions	Biodiversity and related ecosystem services	Soil and water resource protection	Profitability
Improve soil fertility through the inclusion of legumes	+	+	+	++	−
Carbon-based soil improvements	+	+	++	+	0
Zero-tillage	+	+	+	+	+
Fewer usage of synthetic fertilizers and pesticides	−−	+	++	++	−−
Rotations	+	0/+	+	+	+/−
Poly-cultures	++	0/+	+	+	+/−
Variety-mixtures	+	0/+	+	0	0/−
Field margin and other refugia	+/−	0/+	+/++	0/+	+/−
IPM	+	0/+	+	0	+
Various grasslands	+	0/+	+	+	0/+
Diversified crops and livestock	+	0/+	+	+	+/−
Mixed livestock species	+	0/+	+	0	+/−
Integrated crop/farm management	0	+	+	+	0/+
Organic farming	−−	+	++	++	0
Agroforestry	+	++	++	++	+/−

− = worse than conventional, 0 = similar to conventional, + = better than conventional

with biodiversity are adopted to increase the crop yield and to promote natural interactions among crops, soil, nutrients, pollinators, and livestock (Tittonell 2014). Additionally, these techniques and practices are less costly and improve the soil health and fertility which reduces the dependency of farmers on external inputs and state subsidies; therefore, that will help to alleviate poverty and will contribute to food security. However, for effective transformation to the agroecological farming active participation of farmers with their own experiences as well as initial investment by governments for rural infrastructure and expanding existing projects are very crucial (European Commissions 2011).

Agroecological practices reintegrate the food production system with the natural growing course of plants and manage the nutrient cycling in soil with dead plant parts of the same ecological unit persistently. Besides this, it increases carbon sequestration, conservation of soil as well as water and its efficiency, thus restore the agricultural biodiversity and reduce biotic and abiotic stresses on crops (Vijikumar 2010; Sharma and Hansen-Kuhn 2019). Therefore, different approaches to sustain agricultural diversity include crop rotations, intercropping, cover crops, polyculture, mixed and/or integrated farming, ZT technology, agroforestry systems, organic farming, green manuring, and composting, integrated nutrient and pest management, and so on and these have several common and positive influences on agroecosystems and food production (Carrol et al. 1990; Tolentino and Tolentino 2019). Regeneration of the natural ecosystem through these agroecological practices is the sustainable way to long-term food security because it will satisfy several needs of farmers as well as society at large.

In SA, most arable and permanent croplands are lowlands situated at arid- and semi-arid zones and these have higher potentiality for increasing agricultural productivity (Devendra 2012; Tolentino and Tolentino 2019). Though intensive monocrop cultivation particularly rice is more prevalent in lowlands, integrated cropping systems and different mixed farming approaches should be adopted by the farmers to improve the biodiversity (Viczianya and Plahe 2017) and to maintain agroecology which ultimately increases food production as well as whole resource efficiencies. Now it is established that if rice is grown along with *Alzola*, fish, duck, and/or other boarder plants in a complex agroecosystem, it will reduce the application of external inputs but augment the production of rice and other components of the system and the farmers' income along with the empowerment of farming family (Xie et al. 2011; Khumairoh et al. 2012; Liang et al. 2012; Long et al. 2013).

Food sovereignty is also a vital context to directly improve the food safety and its sustainability and it can be attained by considering food sovereignty strategies such as localization of food production by allowing the involvement of the producers in innovations because they know the micro-environment in which the crops are grown, avoidance of dependency on international market and trades and improvement of immunity of populations (Lecomte 2012; Viczianya and Plahe 2017). Hence, agroecology is an approach to maintain diversified agroecosystems and this is the vital time to choose the suitable strategy for ecological resource management of SA for sustainable agricultural productivity which results in long-term benefits and food security to the poor populations.

2.8 Adaptive Measures for Soil Ecology

Soil is the unique essential natural assets for agriculture and can improve livelihoods of agricultural communities when it is managed effectively as it is the main regulatory centre of natural as well as managed ecosystem processes (Barrios 2007;

Bukari 2013). It also acts as a prime reservoir of carbon along with different plant nutrients, buffering medium of precipitation extremes and habitats for several living organisms (Montanarella 2015; Coyle et al. 2016); hence, soil health is very crucial for sustainable agriculture. However, in spite of the continuous application of different agricultural inputs, soil health is gradually deteriorated and the agricultural productivity is being affected after intensive use of it during several years. Due to intensive cultivation reduced soil fertility, soil compaction, erosion, and salinization are also being prominent which result in unstable soil ecology and depreciation of the environmental sustainability and food security (Lal et al. 2011). In SA, crop straws are commonly used as fodder and fuel, not as a basis of carbon-based substance; hence, soil organic carbon is continuously decreasing (FAO and ITPS 2015). Now, higher chemical fertilizer application although does not show higher yield but it is also destroying organic matter and population of organisms in the soil; therefore, it is very important to take measures for maintaining soil ecology for the long run and this is possible only through adopting agroecological practices (Lecomte 2012).

During selection and adaptation of agroecological approach, characteristics of the practice and the target environment should be considered and then the suitable management practices for carbon sequestration, nutrient cycling from the deep soil profile, maintenance of soil structure, and biological population should be allowed to impose along with desired crop species and inputs (Barrios et al. 2012; Wade 2014). The C repossession is the imprisonment and storing long term of atmospheric CO_2 in soil (Jain et al. 2012). Generally, the atmospheric CO_2 is converted into different inorganic carbon compounds by chemical reactions in soil and the quantity of C deposited in soil shows the equilibrium between the mechanisms of C fixation in soil and release from soil (Benbi and Senapati 2009). The soil C sequestration directly depends on climate, vegetation, soil parent material, soil water content, and land management methods of the particular location (Jimenez et al. 2007; Lal et al. 2007; Ontl and Schulte 2012; Abdullahi et al. 2014).

Higher C sequestration improves and maintains the soil physicochemical properties and soil quality and also increases microbial growth and activity (Hu et al. 2001; Chakraborty et al. 2014) which outcomes in enhanced soil structure, the water-holding capacity of soil, infiltration and reduction in soil erosion, and leaching loss of nutrients (Ontl and Schulte 2012). Mainly conservation agricultural practices along with different agroecological strategies can raise the C stock in soil and induce soil stability. Hence, different agricultural technologies such as ZT, crop rotation, mixed cropping, cover crops, crop residue management, mulching, agroforestry system, ley farming, contour farming, grazing management, organic farming, green manuring, integrated nutrient management, etc. have the efficiency to effectively increase the soil C sequestration (Benbi and Senapati 2009; Gami et al. 2009; Nayak et al. 2012; Ontl and Schulte 2012; Sapkota et al. 2017). Therefore, the aforementioned strategies also directly influence the nutrient cycling in soil, plant nutrition, organic matter decomposition, soil aggregate formation, soil erosion, and nutrient loss (Bhojvaid and Timmer 1998; Kaur et al. 2000; Mishra et al. 2003; Nosetto et al. 2007; Jarvie et al. 2017) by increasing the microbial activity due to higher C content in soil (Hu et al. 2001). This microbial biomass mineralizes the soil nutrients for plants and maintains the nutrient cycle (de Deyn and Van Der Putten 2005); besides, it neutralizes toxins, maintains gas and water flow in the soil around the plant roots, and stimulates soil aggregation (Reynolds and Skipper 2005; Kibblewhite et al. 2008) as the soil organisms like bacteria can produce cementing agents among the clay particles and fungal hyphae and its metabolites enmesh the soil aggregates (Reynolds and Skipper 2005; Kibblewhite et al. 2008; Totsche et al. 2018). Additionally, the addition of pulses in cropping system has several positive impacts on soil ecology such as it fixes atmospheric nitrogen, increases the soil phosphorus mobilization, acts as a cover crop and reduces soil erosion, uptakes nutrients from the deeper layer of soil due to its deep root system which results in less leaching loss (Wade 2014).

About 52 Mha areas in SA are salt-affected (Sharma and Singh 2015) and in coastal areas of India and Bangladesh, salinity along with inundation is inherited problem (Burman et al. 2013). Therefore, utilizing these areas for food production after reclamation sustainable food security can be enhanced and in this situation, different land shaping practices can be useful. It was found that crop yield and soil nutrient status have enhanced as compared to non-land shaping situation due to rainwater harvesting, improved soil drainage, salinity reduction, less leaching loss of nutrients, and cultivation of several plantation crops as well as fish (Burman et al. 2013). Besides this, phytoremediation can also be adopted for salinity situations as it is environment friendly and cheaper than chemical reclamation procedures (Sharma and Singh 2015). *Eucalyptus tereticornis*, *Populus deltoides,* and *Tectona grandis* in saline soils; *Acacia nilotica*, *Casuarina equisetifolia*, *Leptochloa fusca, Prosopis juliflora,* and *Tamarix articulata* in sodic soils; *Acacia farnesiana*, *A. nilotica*, *A. tortilis*, *Casuarina glauca*, *Parkinsonia aculeata*, *Prosopis juliflora,* and *Tamarix articulata* in waterlogged saline soils can be planted in agroforestry based cropping system for phytoremediation and for increasing the land productivity (Singh et al. 1994; Dagar and Tomar 2002; Qadir et al. 2007).

2.9 Adaptive Measures for Crop Ecology Under Changing Climate

At present, the changing climate is the primary intention for biodiversity loss which leads to insecurity in food production (Raza et al. 2019). In SA, the crop production system is very sensitive to periodic weather inconsistency, mainly in rainfall and temperature dissimilarities (Aggarwal et al. 2009; Knox et al. 2012; Pitesky et al. 2014; Ali and Erenstei 2017; Khatri-Chhetri and Aggarwal 2017) because 70% of total production directly depends on monsoon rains (Wickramasinghe 2014). Due to climate change, most of the rice and other cereal varieties can lose up to 15–30% of its yield potential across the SA (IFAD 2008) and by the end of twenty-first century, the total cereal production will face around 4–10% reduction (Khatun and Hossain 2012). Therefore, different adaptive measures at farm level are very crucial for sustained crop production system by alleviating the consequences climate change and it depends on the adaptive capability of a particular farming community (Rosenzweig and Parry 1994; Mendelsohn and Dinar 1999; Smit and Skinner 2002; Gbetibouo 2009). Furthermore, combined strategies of adaptation along with mitigation have more impact in declining climate change vulnerability. Some useful crop adaption strategies which can be taken against global warming at the farm level are as follows:

2.9.1 Adjustment in Sowing Time and Method

Altering the sowing as well as harvesting time of crop, detrimental impacts of changing climate can be alleviated (Challinor et al. 2014; Ali and Erenstei 2017; Raza et al. 2019). This approach saves the crop from unpredictable climate before sowing and after harvesting as well as during crop growth. In this state, contingency crop planning according to stress can also be very beneficial for crop adaptability. SA shares the highest methane emission in Asia and yearly emission of methane only from rice cultivation takes third position globally (IRRI 2018; Aryal et al. 2020). But simultaneously, the rice production needs to be augmented for the increasing population of SA. Therefore, replacing the conventional flood rice method with DSR, the system of rice intensification (SRI), and other alternative wetting and drying (AWD) approaches of rice cultivation where puddling is not needed can be adopted. These alternative rice cultivation methods not only reduce greenhouse gas emissions and crop duration but also increase input use efficiency, yield and make rice cultivation possible in water scarcity condition (Siopongco et al. 2013; Sapkota et al. 2015; Aryal et al. 2020).

2.9.2 Stress Tolerant Cultivars

In addition to alteration in sowing time, selection of suitable crop species and cultivar scan also decrease the influences of changing the global climate in crop ecology. Under different climatic stress, drought-tolerant crops like millets instead of other cereals, short duration and/or early maturing crops, salinity tolerant crops, and their varieties can be grown (Raza et al. 2019). This approach is very useful to diminish the impacts of climatic erraticism on the crops (Aggarwal and Mall 2002; Smit and Skinner 2002; Howden et al. 2007; Ali and Erenstei 2017).

2.9.3 Cropping System

Mono-cropping is very popular in SA and this conventional cropping system is very sensitive to climate variability. Therefore, the adaptation of crop rotation, mixed cropping, intercropping, cover cropping, the addition of pulses in the cropping system, etc. is essential to reduce the crop loss and increase the production and farmers' income (Kassam et al. 2009; Ali and Erenstei 2017; Duku et al. 2018).

These adaptive practices also reduce the crop loss due to pest-attack which is also exaggerated due to the changing global change and improve the soil health (Bradley et al. 2010).

2.9.4 Conservation Tillage

Climate change can also reduce the production of food capacity of soil through erosion and declining soil productivity and fertility (Lal et al. 2011); hence, conservation measures should be adopted to minimize these threats (Pitesky et al. 2014). Implementation of conservation tillage such as ZT along with residue management rises the SOM content which improves the soil aggregation and its water-holding capacity and reduces the soil erosion (Sapkota 2012; Pitesky et al. 2014). Besides this, ZT improves soil quality and nutrient status which ultimately increase crop production and decrease the influences of global warming on crops (Lal 2004; Gathala et al. 2011).

2.9.5 Nutrient Management

Application fertilizer is very critical for food production next to the selection of crop varieties (Aryal et al. 2020) but in SA, fertilizer use efficiency is very low (30–40%) (Farnworth et al. 2017; Tewatia et al. 2017). Additionally, intensified use of synthetic fertilizers significantly affects the environment and only crop production system contributes over 60% to nitrogen pollution (Sapkota et al. 2016). Thus, the rational use of fertilizers is very important for reducing pollution and improvement of crops' adaptability to climate variations (Challinor et al. 2014; Raza et al. 2019). Besides, the optimum application maintains soil as well as food quality (Aggarwal and Mall 2002; Raza et al. 2019). In this context, possible adaptation actions such as integrated nutrient management involving both organic and inorganic nutrient sources and/or SSNM potentially can diminish the effects of changing climate which results in increased fertilizer use efficacy, crop yield, and growers' income (Majumdar et al. 2000; Pitesky et al. 2014; Aryal et al. 2020).

2.9.6 Water Management

Under the changing climatic situation, water management is one of the further most indispensable adaptive practices in the agricultural production system (Smit and Skinner 2002; Challinor et al. 2014; Ali and Erenstei 2017) as numerous crops are very subtle to drought during their certain growth stages. Hence, water management practices are crucial techniques to handle the special effects of changing climate on crop ecology. Several adaptive practices of water management are harvesting of water, watershed management, lifesaving irrigation, on-farm water storage, soil water conservation through crop residue management, micro-irrigations, groundwater recharging, contour farming, land levelling, etc. (Aggarwal and Mall 2002; Howden et al. 2007; Gleick et al. 2011; Aryal et al. 2020). Moreover, effective transportation of water to drought-prone areas and management of water erosion and water logging at heavy rainfall areas are also essential for regulating crop ecology (Howden et al. 2007).

However, these adaptation strategies are highly confined to specific locations or crops, i.e. all practices may not be directly adaptable in all regions and/or agricultural fields (Tiwari et al. 2008; Porter et al. 2014; Ali and Erenstei 2017). But, selection and adaptation of suitable practices that enhance crop yield yet deal with climate variability will potentially mitigate the negative effects of global warming as a consequence of the changing climate and sustain the crop ecology (Howden et al. 2007).

2.10 Conclusion

From the discussion of the present study, it is well-noted that food production and increasing the poverty level are the major difficulties to meet the food and nourishing safety of the developing world. At the same time, climate change also creates a great barrier to improve farming productivity. Traditional agricultural technologies are not environmentally friendly and cost-benefit where farmers use imbalanced synthetic fertilizers and pesticides. Hence, it is crucial to improve ecologically friendly technologies for preserving crop productivity. The sustainable food production can be achieved through management of agroecology; since agroecological based agricultural production system generally emphasizes on RCTs, reworking small farm enterprises, consider the participation of more farmers' and their traditional knowledge, include improved plant genetic multiplicity, and avoid to over-use of imbalanced synthetic fertilizers and pesticides.

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Agroecology for Sustainable Food System and Footprint Mitigation

3

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Abstract

Farming is widely acknowledged as a significant driver of climate alternation, as well as being forced to respond to its consequences. The main issue of agricultural system is the rising of different footprints related to different components of agrosystems; it may be carbon footprint (CF), or it may be resource footprint (soil, water, and land). The energy utilized to generate nutrition that has been lost or discarded is around 9.5% of the overall energy intake in the planet, whereas the footprint of food waste is equal to about 4 gigaton (Gt) of greenhouse gas emissions (GHGs) per annum. Agroecological activities greatly lead to farms' CF close to 365% related to land cover region and close to 580% related to food volume, indicating a substantial sequestration of GHGs at farm size. The principal contributors of GHG on farm scale seemed to be surface nitrous oxide (about 26%), rice firm-generated methane (about 25%), animal waste (about 25%), and bacterial fermentation (about 24%). By 2030, agricultural GHG emissions are projected to be approximately 60% greater in comparison to 1990. The estimated dynamics in Indian agriculture's GHG emissions would rise up to 18% by 2030 as opposed to 2010 emissions. Agroecological strategies include implementing combined ecological, economic, and environmental concepts in order to turn smallholder agricultural structures into more sustainable ones. Agroecology is indeed the implementation of ecological principles and conceptual development to boost and control soil quality and efficiency in agriculture on a long-term basis. This offers a plan for increasing the diversification of agroecosystems. It therefore benefits the impact of the integration of flora and fauna biodiversity, resource recycling, the production and development of biomass by the utilization of natural input depend on legumes, plants, and livestock establishment. These together form the rationale for sustainable farming and strive to boost the food supply and the sustainability of society. Agroecology encourages the cultivation of a variety of quality food, fabric, and medicinal plants. Sustainable farming practices must address biodiversity conservation, enriched ecological processes, social sensitivity, self-reliance, equality, better quality of life, and crop and livestock economic productivity. This chapter seeks to provide a summary about the status of footprint in agriculture framework and potentiality of agro-ecology towards reducing footprint, sustainable farming and also try to highlight the drawback in Indian farming system towards the journey of agroecology. This chapter also discusses about the optimal conditions for best farming practices and the effects of agroecology towards sustainable agriculture and food production in India.

Keywords

Agroecology · Agroecosystem · Biodiversity · Food · Sustainable farming

Abbreviations

AER	Agro-eco-regions
AESR	Agro-eco-sub-regions
BNF	Budget natural farming
CF	Carbon footprint
CH_4	Methane
CMSA	Community managed sustainable agriculture
CO_2	Carbon dioxide
CSE	Centre for Science and Environment
EF	Ecological footprint
EFA	Ecological footprint analysis
FAO	Food and Agriculture Organization
GDP	Gross domestic product
Gg	Gigagrams
GHG_S	Greenhouse gases
GM	Genetically modified
Gt	Gigaton
ha	Hectare
ICAR	Indian Agricultural Research Council
ICT	Information and communications technology
LCA	Life-cycle assessment
LPG	Liquid petroleum gas
LVC	La Via Campesina
NAPCC	National Action Plan on Climate Change
N_2O	Nitrous oxide
NGOs	Non-governmental organizations
NMSA	National Mission for Sustainable Agriculture
PKVY	Paramparagat Krishi Vikas Yojana
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana

R&D	Research and development
RIS	Rice Intensification System
SDGs	Sustainable Development Goals
SRI	System of Rice Intensification
ZBNF	Zero budget natural farming

3.1 Introduction

Farming is highlighted among the most important human behaviors correlated with depletion of the habitats. The vast volume of resource used in terms of water use and soil depletion is a significant driver of environmental damage from farming. About 70% of the total water available is used in irrigation, and 24% of the ground surface is protected by agricultural systems as per the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005). In addition, even in the previous 100 years, farming has changed dramatically from a resource-based livelihood operation to a highly technical and resource-intensive market-based process. This accelerated industrialization of production creates waste that surpasses the assimilative capabilities of habitats and contributes to shifts in the global environment and the emergence of ecological footprint in various resource bases (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). Furthermore, contemporary farming and irrigation methods lead to high footprint and create pollution (Yannopoulos et al. 2015). Agrarian growth has increased substantially in the past 50 years and is expected to rise by yet extra 50% or higher during the twenty-first century, with global populace edging beyond about 10 billion and increasing incomes pushing per capita consumption (Alexandratos and Bruinsma 2012). Two-thirds of global food requirement is projected to emerge from Africa (sub-Saharan) and Asia (South) (U.S. Environmental Protection Agency 2012). Specific farmland emissions are projected to rise as quickly as possible in sub-Saharan Africa (~29.5% around 2030). Emissions are projected to rise between 20 and 25% during the same timeframe in America (except for Brazil) and Asia (Southeast). Over this time, China and India would both have significant levels of growth in emissions (about 15% each). In contrast, emissions are projected to increase slowly in the European Union (EU) (about 3%) and about 7% in Brazil (U.S. Environmental Protection Agency 2012). Typically speaking, GHG emissions are forecasted to rise due to higher food demand as populations expand and communities in developed countries become prosperous and meat intake grows. By 2030, agricultural GHG emissions are projected to be approximately 60% greater in comparison to 1990 (Pathak et al. 2014). The estimated trends in GHG emissions from Indian farming have shown that emissions would rise by about 17% in the industry-as-usual scenario by 2030 compared to 2010 (Pathak et al. 2014; Meena et al. 2020). South Asia releases approximately 4900 gigagrams (Gg) of methane (CH_4) every year from rice farming alone, which would be the third largest amount of CH_4 through rice farming worldwide (IRRI 2018). The main issue of agricultural system is the rising of different footprints related to different components of agrosystems; it may be CF, or it may be resource footprint (soil, water, and land). The amount of energy utilized to generate food that is discarded is around 10% of the overall energy intake in the planet (FAO 2014). The footprint of wasted food is equals to 4 gigatons (Gt) carbon dioxide (CO_2) of GHG emissions annually (FAO 2014). Consequently, in science, emphasis should be granted to determine the feasibility of agricultural practices to maintain a healthy food supply.

The ecological footprint (EF) is basically used as an indicator focused on consumption of natural resources and is widely used as indicators for the sustainability in using biophysical resources. Wackernagel and Rees (1996) introduced the method as a predictor of environmental sustainability that evaluates human load on nature by determining how often biologically viable area is required to preserve a community with a specific consumption level at a given point in time. The EF approach provided a modern form of assessing impacts of the human being on climate by evaluating the consequences of food intake and food production networks (Ropke 2005). If the EF exceeds the available biocapacity, then this indicates a so-called ecological deficit which is an important measurement of the extent to which a population exceeds sustainable limits. The reverse condition indicates "ecological surplus" suggesting a more sustainable state of human habitation. Agroecology has emerged as a discipline that provides the basic ecological principles for how to study, design, and manage agroecosystems that are both productive and promote natural resource conservation (Altieri 1995; Meena et al. 2020a). The connection between climate and agroecology is two-way—agroecological systems have the potential to contribute to reduce greenhouse gas emissions and offer management practices to adapt to climate change (FAO 2018). The function of agricultural sector in Indian financial system can be considered through its contributions to gross domestic product (GDP) and employment. This sector also contributes significantly to sustainable economic development of the country. Any nation's sustainable progress in agriculture depends on a prudent combination of their available natural resource. In this way, if farming turns out badly, it will be actually awful for the economy as the falling of agricultural boom influences not only employment but also GDP too. The bigger target for improving the agricultural sector can be reached by rapid agricultural development, which relies on rising the zone of production, crop depth, and productivity. Putting that aside, increasing productivity is a greater priority for a country like India than the rest of the two. This is essentially a natural consequence of the expansion of population growth, industrialization, and the nation's limited land size. Productivity could be accelerated through two methods. The primary approach is to recognize and move from productivity to sustainability. However due to increasing population, this technique cannot provide an everlasting answer. Therefore, we can move for the second approach, which can also lead to environmental degradation inside the financial system and have an effect on its sustainability. Therefore, it is important to tackle the issues associated with the creation of a sustainable agriculture.

Agroecology is a rising ecological idea and precept for designing and the control of agricultural features even as supplying a methodological framework to correctly execute this venture. It applies less to farming and their administration practices and progressively about environmental frameworks and their supportability notwithstanding abuse (Oteros-Rozas et al. 2019; Meena et al. 2020b). Throughout the world, small farm holding families support agroecological cultivating framework. It can remodel the food framework, pass on pay to farmers and healthy nourishment to clients, and decrease environmental changes. The urgency of the sustainable agriculture to satisfy the developing interest of food has been acknowledged by India and numerous other developing nations. The Indian government integrated sustainable agriculture into the corporate sector for profitable business activity in late. Sustainability of agriculture could be kept up through two key factors: the diminished costs and expanded soil ripeness. Agroecology is rising as a potential choice to assess longevity, since it does not require the customary cultivating rehearses, rather is a steady procedure to step by step advance the cultivating methods in a more astute manner with improving livelihood. Apparently the agroecological activities are also environmentally friendly. Farms are progressively adaptable to environmental change and stuns, for example, tropical storms, dry spells, food, or raising the price of compost. In India, developments for sustainable farming have been driven generally by the non-governmental organization (NGO) segment and urban white-collar class activists (Brown 2018). Hence, fruitful cases in economical farming and their significant accomplishments are remained as an island of progress and have not arrived at a mass scale (Gregory et al. 2017).

The intent of this article is to highlight the prospects and status of agroecology towards sustainable agriculture and food production while mitigating footprint in agrosystems. Likewise, it seeks to assess the sustainable agriculture method throughout the biological, financial, and social sustainability scale with the long-established system.

3.2 Agricultural Issues

World agricultural sector faces the first and ongoing challenge of producing sufficient food to nourish growing global population. The second issue facing world farming is the creation of innovations, institutional arrangements which contribute towards igniting the best extent of agriculture as a growth driver. Farmers would need exposure to both domestic and global markets to face this task. In this new century, the third challenge for farming is to establish a range of innovations, opportunities, and policies that promote smallholder farmers to be cautious about the long-term governance of the natural capital they operate. New research on the status of the world's food safety and health is soothing. Food security circumstance has exacerbated particularly in some of the parts of sub-Saharan Africa and Asia. Such declines have arisen more notably in conventional situations and are aggravated by shifts in the climate, a condition that is expected to cause exile movements. Several reports highlight an indication that understanding the need for a world to devoid of desire and ailing health by 2030—as the Sustainable Development Goals (SDGs) portray—will be challenging. The main issues that need to be addressed are tireless undernourishment and lack of healthy sustenance but others are corpulent and overweight, natural corruption and contamination that compromise the asset base that agribusiness is reliant on the reduction of biodiversity that is basic to encourage sustainability, great quantity of ozone depleting substance discharges add to atmospheric change, imbalances in access to nourishment; and arrangements and laws that minimize little ranchers, their habitual, authority and learning frameworks (Smith et al. 2014). However, the prevailing industrial food and farming framework may be exemplified desirably by input-concentrated and traditional monocultures, has empowered expanded yields and nourishment generation, leads to incredible expense to the earth and human wellbeing, but performs very little to highlight the underlying drivers of neediness or to manage inborn vulnerabilities towards environmental change (IPES-Food 2016). Agriculture bears a substantial share in affecting the climate alternation situation with a higher CF. From the research, it is evident that both pre-farm and post-farm practices in different components of agrosystems contribute to various types of footprint. Asia has a large share of gross agriculture pollution of about 44%, led by America and Africa (FAOSTAT 2019; FAO 2014). Fossil fuel energy used in livestock adds supremely to GHG pollution (Yadav et al. 2018). Pre-farm methods including the manufacturing of fertilizers, pesticides, diesel, and electric power for cotton cultivation in Australia made a significant contribution of about 25%, while post-farm procedures like liquid petroleum gas (LPG) cotton drying, electric cotton ginning machinery, and transportation account for about 26% (Hedayati et al. 2019).

3.2.1 Indian Perspective

India is a global agricultural powerhouse. The Indian agriculture has transformed significantly over the last few decades (Goyal et al. 2016). Several factors, such as average income development, food processing acceleration, and the rise in agricultural exports, have encouraged development in this sector (Table 3.1), but the agricultural sector in India is not in decent shape. There are several questions for those explicitly or indirectly associated with the growth and advancement of agricultural sector in India. Agriculture contributes a huge role in the economic development of India. However, this role would be to be re-oriented in the light of changing climate and requirements and to meet the new challenges and also to harness new opportunities (Goyal et al. 2016). The main challenges are:

Table 3.1 Growth rates in agriculture (Source: GOI 2017; Kumar 2019)

Periods	Growth rate of GDP (%)
1960–1969	1.04
1988–1996	2.24
1968–1976	2.47
1975–1989	2.76
1995–2005	2.28
2004–2015	3.72
2014–2018	2.55

- Approximately three-fourths of India's families rely on agricultural production.
- The bulk of the people in India stay in remote regions.
- India's food safety relies on the growth of cereal crops and on increasing its fruit production and vegetable and milk supply to satisfy the needs of the growing population.
- Low yield is one of the main challenges confronting India's agricultural sector. India's farm yield is 30–50% lower than developing nations (Goyal et al. 2016).
- Farming is hugely dependent upon rainfall, particularly the summer's monsoon in the larger regions of the world. Summer monsoon's activity is sadly extremely unpredictable.
- In India, farming is a labor-based industry where most farming activities, such as slogging, levelling, seeding, sorting, watering, slathering, planting, and threshing, are primarily carried out by human.
- Inequality and the ranchers' obligation.
- Insufficient farming research and literacy, training, instruction, and expansion.
- Average farm capacity, weak facilities, limited utilization of farming technology and best farming strategies, decreased soil quality attributable to overfertilization, and persistent usage of pesticides contribute to weak agricultural output.

Additionally, microscale surveys have clear proof of young people not engaging in research linked to agriculture (Jha and Rodgers 2016). Agricultural production is necessary to increase the incomes of farm-dependent citizens. There are important correlations between the agricultural and non-agricultural sectors.

3.2.2 Worlds' Perspectives

- The higher-input, commodity-intensive farming processes resulting in significant forest degradation, water shortage, soil degradation, and GHG emissions will not produce nutritious food and sustainable agricultural output (FAO 2017).
- The world food network even has a significant impact on the climate. In addition, agriculture consumes almost 40% of the surface of the planet, much more than any other human occupation. Additionally, farm field irrigation accounts for 70% of global water consumption, and cultivation leads directly to about 11% of total GHG emissions (Brooks et al. 2019).
- Combating severe poverty and guaranteeing that poor people leaving in deprivation will not slip back into it need measures to limit inequality (FAO 2017).
- Poor food systems and governance (FAO 2017).
- Lack of interdependency among the nations (FAO 2017).
- Higher agricultural footprint and emissions.
- Specific farmland emissions are projected to rise as quickly as possible in sub-Saharan Africa (about 29.5% around 2030). Emissions are projected to rise between 20 and 25% during the same timeframe in South America (except for Brazil), the United States, and Southeast Asia (U.S. Environmental Protection

Agency 2012). Yousefi et al. (2017) documented about 79% CF output from electricity. Electrical power used for rice irrigation in China accounted for about 4% of overall carbon emissions, while wheat and maize added about 37% and 19%, respectively (Zhang et al. 2017). In Thailand's soybean oil production, 6% of the overall CF was due to electricity (Patthanaissaranukool and Polprasert 2016).

3.3 The Paradigm Shift Needed

The 2030 schedule regarding sustainable improvement identified that the intense and transformative advances are critically expected to move the world onto a sustainable and versatile way. For this to fulfill the SDG of minimizing hunger, accomplishing nourishment safeguard, enhanced sustenance, and advancing reasonable horticulture, a change of our agricultural and food structures is wanted. Agroecology applies scientific ecological standards to the agroecosystem management. Its developments expand farms and cultivating landscapes, enrich biodiversity, support soil biodiversity, upgrade recycling, increase environmental benefits, and animate collaborations between various species to such an extent that the farmer can accommodate their own issue (Gliessman 2014).

The structure of agroecological cultivating frameworks depends on the utilization of the accompanying standards (TWN and SCOLA 2015).

- Improve reuse of biomass, maximize the supply of nutrients, and regulate the flow of nutrients.
- Secure optimum soil quality for vegetation growth, particularly through the management of organic matter and the improvement of soil biotic activity.
- Minimize losses from solar radiation, air, and water flows through microclimate control, water extraction, and management of soil through expanded soil coverage.

3.4 What Is Sustainable Agriculture?

By 2050, the need of nourishment, fuel, and fiber for the necessities of 9 billion individuals will be increased, while simultaneously managing the impacts and difficulties presented by environmental change will also be a serious challenge (WBCSD 2020). The progressive climate alternation observed throughout the world overspeaks to a tremendous risk to profitability, agrarian worth chains, and the welfare of billions of individuals who rely upon them. Simultaneously, agrarian creation contributes straightforwardly to almost one-fourth of the worldwide ozone depletion (WBCSD 2020). The fundamental test for sustainable agriculture is to utilize accessible biophysical and human resource. This should be possible by limiting the utilization of outside contributions, by streamlining the utilization of interior assets, or by mixes of both. This guarantees the proficient and successful utilization of what is accessible and guarantees that any upgrades will persevere, as conditions on outer frameworks are kept to a sensible least. Sustainable agriculture looks for the incorporated utilization of a wide variety of supplement, agroforestry, advanced soil, and water management techniques (Jhariya et al. 2015; Singh and Jhariya 2016). By-products or squanders from one component or venture become contributions to another. As normal procedures progressively substitute for outer information sources, the effect on nature is diminished. Extensive sustainable agriculture seeks:

- An intensive incorporation of natural procedures, for example, supplement cycling, nitrogen fixation, and nuisance predator relationships
- To reduce utilization of external and non-sustainable resources that harm the earth or mischief the soundness of harmers and purchasers
- Cooperation of farmers and rural people in all procedures of problem investigation, innovation improvement, adaptation, monitoring, and evaluation
- More equal access and incentives to productive resources
- Better use of local knowledge, traditions, and tools
- Integrating a diversity of herbal assets and businesses inside farms and a boom in self-reliance among farmers and rural communities

3.5 What Is Sustainable Food Production?

It relates non-polluting technologies and methods, conserving non-renewable natural assets, being economically efficient and healthy for ecosystems and customers, and not sacrificing the needs of successive generations (Foresight 2011). A major challenge is to maintain a sustainable food provision for the growing demand of the world. Production of food is among the crucial areas of policy, in addition to food intake and food safety. The total population of world is likely to arrive at 9.1 billion by 2050 (34 million higher than today) (FAO and WHO 2017). In order to feed these growing populations, food production would have to increase by 70% (FAO 2009). It will be required to produce enough food using less space. Water and power will also become restricting variable. The quest is that food items will have to be nutritious for maintaining and promoting good health.

3.6 Sustainable Intensification

In basic terms, intensification can be characterized as delivering more units of yield per units, everything being equal and through new mixes of sources of information and related advancements. Expectedly, intensification has planned to raise yields as well as profit per unit of land, through more prominent speculation of work and higher utilization of information sources, for example, manure or pesticides (The Montpellier Panel 2013).

Sustainable intensification provides a down-to-earth pathway towards the objective of delivering more nourishment with less effect on the earth, heightening nourishment creation while guaranteeing the characteristic asset base on which farming depends, and in reality for people in the future (The Montpellier Panel 2013). Sustainable intensification has also been utilized to describe the strategic course of food production development for resolving the challenges of increasing globalization, food stability, environmental issues, and resource sustainability. While others view about sustainable intensification as increasing production, with more productive yet possibly expanded use of inputs and technology, environmental protection needs to be considered, along with the preservation and renovation of natural assets and the development of ecological facilities. It involves addressing consumption problems, waste, habitat preservation, and resource utilization while guaranteeing that overall production rates are sufficient to satisfy people's needs. Scientists recently surveyed sustainable intensification efforts globally and reported that 29% of all farms implement any sort of revamped sustainable intensification systems on 9% of the world's farming land (Pretty et al. 2018). They predicted that the implementation of sustainable technologies will quickly reach a turning point for change globally.

3.7 Footprints in Agroecosystem

Agriculture is the prime economic activity which is directly related with the supply of food (FAO 2011). Rapid growth of the world increases the disparity between food demand and food supply. By 2050, to feed about 2.3 billion, the global food demand will need to grow by 70%, and simultaneously agricultural methods could decrease the carrying capacity of agricultural land (Bennett 2000). Therefore, the assessment of sustainability of agricultural activities should be given priority in research to back sustainable supply of food.

The ecological footprint (EF) is a measure of natural resource use, and this is one of the most commonly used measures of sustainability by utilizing biophysical tools. The methodology was created by Wackernagel and Rees (1996) as a pointer of ecological sustainability that quantifies the human burden on nature by surveying how much naturally beneficial territory is expected to keep up a given populace with a given utilization framework at a given point of time. The EF approach has developed a modern way to the assessment of human influence on the environment by quantifying the consequences of food intake and food supply processes (Ropke 2005). If the EF exceeds the available biocapacity, then this indicates a so-called ecological deficit which is an important measurement of the extent to which a population exceeds sustainable limits. The reverse condition indicates "ecological surplus" suggesting more sustainable state of human habitation.

Ecological footprint analysis (EFA) relates the EF to the bio-capability available. It measures the biological potential utilized on a sustainable basis to what is accessible. It is necessary to differentiate between EFA and footprint. The footprint itself teaches us nothing regarding asset utilization; it's only a metric that increments or diminishes as our natural requests increment or lessen without asking us whether such prerequisites are sustainable. Conversely, EFA is intended to reflect sustainability. As stated by Wackernagel et al. (2002), EFA offers a means of balancing the use of sustainable natural capital with the biologically efficient capability of nature. The main issue of agricultural system is the rising of different footprints related to different components of agrosystems; it may be CF, or it may be resource footprint (soil, water, and land). The resources used to generate food that is wasted or discarded are around 10% of the overall energy intake in the planet (FAO 2014), while the footprint generated from food waste equals about 4 Gt CO_2 of GHG emissions annually (FAO 2014).

The CF definition originally refers to the word "EF" provided by Rees (1992). The biologically productive area needed to sustain a given human population is known as an EF, expressed in terms of global hectare (ha). In the same way, Wiedmann and Minx (2008) clarified CF as a certain volume of gaseous pollution related to climate change and connected to human development or consuming operation. Therefore, CF emanates GHGs from all outlets and procedures, from production to dumping, relating to a specific product or personal or framework. Only CO_2 was historically known for CF calculation, but all big GHGs released, such as CO_2, CH_4, and nitrous oxide (N_2O), are now taken into account in terms of CO_2 equivalent (CO_2-e) (IPCC 2014).

Carbon footprint is a part of life-cycle assessment (LCA) which calculates GHGs. According to the FAOSTAT (2019) report, total emissions from the agricultural sector have risen (Roy and Sahoo 2020). One-fourth of gross anthropogenic GHG emissions come from livestock and land use transition (IPCC 2014). With global population growth of about 36%, farm land has risen by 43% from 1990 to 2014, and livestock, forestry, and land use pollution have risen by 1.2% (FAO 2015). In India, the growth in population and cultivated region was about 46% and 51%, respectively, with a rise in pollution from livestock, forestry, and land usage of about 12% (FAO 2015). Livestock carbon emission is almost twice that from livestock. GHGs are emitted by the livestock sector mostly through enteric fermentation, feed manufacturing, transport, and implementation of manure. Livestock energy use added about 21% of the overall pollution (Gerber et al. 2013). Pre-farm methods including the manufacturing of fertilizers, pesticides, diesel, and electric power for cotton cultivation in Australia made a significant contribution of about 25%, while post-farm procedures like LPG cotton drying, electric gin machinery, gin waste treatment, and transportation account for about 26% (Hedayati et al. 2019). Rest was emitted by 48.4% during on-farm processes. Electric power used in farming has made a significant contribution the most to CF (Yousefi et al. 2017). Electric power used for rice irrigation in China accounted for about 4% of overall carbon emissions, while wheat and maize added about 36% and 19% separately (Zhang et al. 2017). About 3% of India's electricity use emissions for the 2000–2010 time span (Sah and Devakumar 2018).

The CF of rainfed cultivation is smaller than the arable fields, because the agricultural emissions are minimized and the regions are smaller, meaning that the activities are performed manually (Devakumar et al. 2018). For increasing population requirement, machinery usage is rising, and the power supplied to machines is met by fossil fuel that is accounted for GHG emissions. Rice's contribution to total CF was stated to be about 13% due to fossil fuel utilization in China (Zhang et al. 2017). Approximately 25% and 21% fuel emissions from machinery are used in wheat and maize cultivation, respectively, in China (Zhang et al. 2017). Hedayati et al. (2019) measured the CF of machinery for cotton processing in Australia and reported that it accounted for approximately 7% of overall CF across pre-farm, on-farm, and post-farm operations. Between the three systems, machinery contributed about 16% of on-farm pollution. Production, transportation, and implementation of fertilizers add considerably to overall GHG emissions (Rao et al. 2019). In overall agricultural GHG emissions, chemical fertilizer is responsible for about 13% (FAO 2014). CF of various crops differed as per fertilizer requirement and fertilizer conservation activities. Farm emissions generally rely on how much fertilizer is being used (Gan et al. 2011).

Rice is thought to be the principal contributor to the most GHG production (Rao et al. 2019). Rice had the largest CF of about 1.61 kg CO_2-e per unit production owing to CH_4 pollution contributing about 45% of overall CF (Zhang et al. 2017). The research reported by Rao et al. (2019), Zhang et al. (2017), and Benbi (2018) in various regions have shown that rice produce the largest CF owing to large-scale production of CH_4. The Comparative assessment of CF value of various crops (wheat, millet, soybean, and maize) in all Indian states indicates that rice crops have a greater energy demand, particularly for irrigation purposes (Rao et al. 2019).

3.8 Concepts and Principles of Agroecology

Bensin (1930) first used the term "agroecology" in two scientific publications and perhaps most recently in Gliessman (2014) and Warner (2007) books. Agroecology is a trend, a science, and a practice. It is based on knowledge of science and tradition. This is a science that bridges the socioeconomic and environmental aspects. It can operate at different levels—farming, group, national, regional, etc. (Fig. 3.1).

Agroecology is a systematic analysis that includes all of the ecological and human components that focus on the structure, fundamentals, and processes of their intra- and interrelationships. It could also be described in the view of ecological strategy to agriculture that considers agrarian regions as biological systems and the natural impact of cultivating rehearses (Fig. 3.2). Agroecology offers a broader scientific knowledge of agriculture since it integrates ecological concepts to food production systems, considering the connections between the various components of the agroecosystem, along with the human community. It instructs us to be in harmony with nature while making a variety of healthy, nutritious, and delightful foods, using natural sources (FAO 2017). Agroecology, generally, is the way of thinking of savoring all edibles that nature produces and, simultaneously, of supporting nature to permit it bloom with its biodiversity (FAO 2017). Agroecology additionally conveys the social advantages related with neediness decrease and network strengthening, on the one hand where it lessens the probability of natural

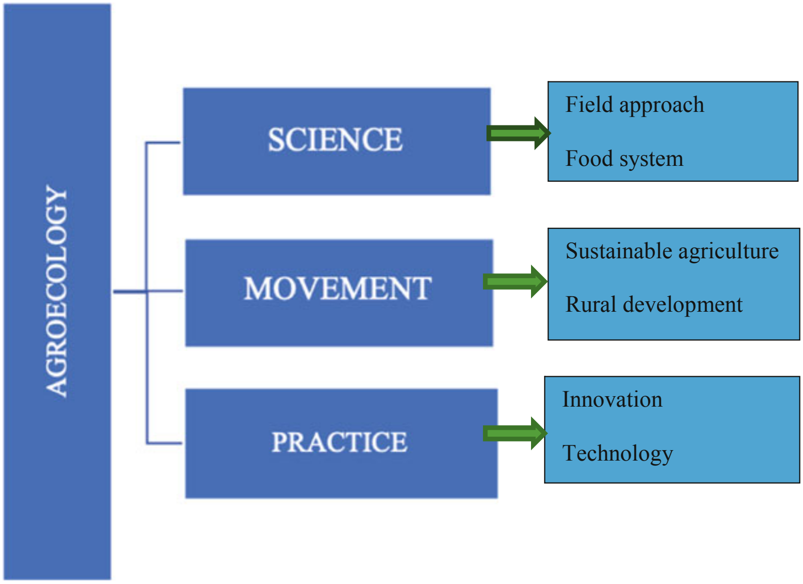

Fig. 3.1 Diversified form of agroecology (FAO 2018)

debasement and on the other hand where it is equipped for conveying the ecological advantages through effective use of resources and decreased natural effects. It additionally helps to ensure biodiversity and improves the flexibility against the stuns related with quickening environmental change. Agroecology is the developing logical worldview dependent on the acknowledgment of the environmental principles when applied to agrarian frameworks. Few of these ecological values are applied in traditional farming, and some of them came through recent findings in ecological studies like biodiversity and soil food web (FAO 2017). Agroecology is dependable and demonstrated customary method for cultivating that was developed by farmers fitting to their assorted agro-climatic conditions. The experience of farmers around the globe utilizing agroecological strategies has given enough proof of its financial, social, and ecological advantages (Meena and Lal 2018). Agroecological methodologies have conveyed expanded food generation and improved profit for farmers and upgraded food security and sustenance for the networks they feed. The information expenses go down with time, and farmers decrease the expense of development as well as build the yield. Agroecology is inescapable to give adjusted situations, continued yields, organically intervened soil richness, and characteristic pest regulation guideline through the structure of enhanced agro-biological system and the utilization of low-input advancements (FAO/INRA 2018). Agroecology gives us the ability to understand the agroecosystems and also to design and manage for food production in a holistic way. Since decades, farmers have protected, conserved, and increased natural resources like woodlands, grasslands, forest biodiversity/agro-biodiversity,

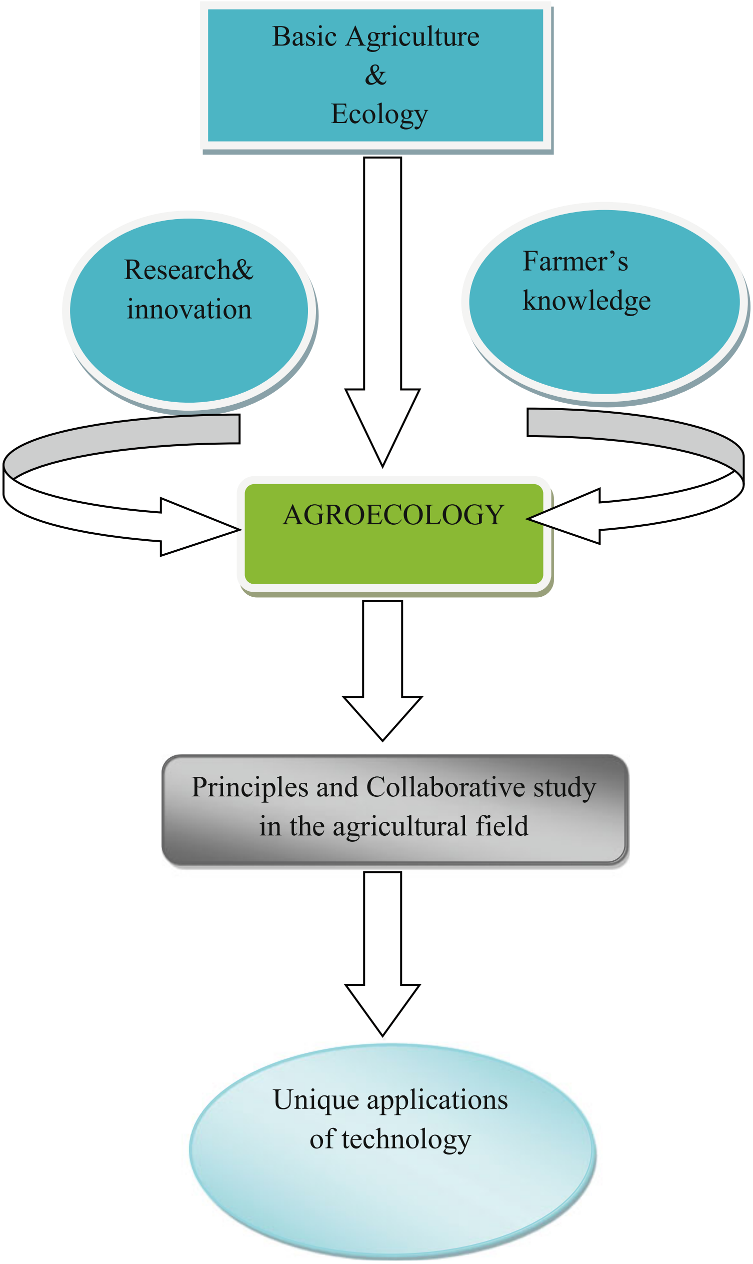

Fig. 3.2 Basic concept of agroecology (FAO 2018)

livestock, soil, water resources, and overall agricultural crops by introducing the concept of agroecology.

Agroecology allows us in a holistic way to explain and sustain critical resource cycles, natural phenomena, energy transitions, and socioeconomic relations. Agricultural strategies based on agroecological principles examine regional geological and socioeconomic particularities and ecological and cultural peculiarities and abide the rituals of people, such as dietary habits, celebrations, and their moral and esthetic principles (Singh et al. 2014; Meena et al. 2018). Agroecology is a heterogeneous and multidimensional idea which encourages space for transdisciplinary and multi-on-screen character exchanges. Asymmetries in agri-nutrition systems have been considered to affect the way agroecology is translated into processes and strategies (Oteros-Rozas et al. 2019).

3.8.1 Principles

Several articles have outlined agroecological concepts in various forms, simplified by Nicholls et al. (2016) and late by the Food and Agriculture Organization (FAO) and by the International Cooperation for Development and Solidarity (Nicholls et al. 2016). These principles spread agricultural and environmental administration of agri-nourishment frameworks, just as some more extensive extending financial, social, and political rules that have developed as of late from the action of social developments. Agroecology is a discipline that combines economic, biological, and agricultural disciplines with traditional knowledge of farmers. This inevitably leads to fundamental principles that eventuate in different forms of technology. The possibility that an agroecosystem ought to mirror the functioning of local ecosystems is at the heart of the agroecology strategy, thereby displaying stiff nutrient cycling, complex system, and increased biodiversity. The underlying assumption is as such agricultural imitates can be profitable, pest-resistant, and nutrient-conservative, the same as their biological model (FAO 2018). The overall ecological performance and protection of the environment are thus enhanced. The main agroecological technique is to reincorporate assorted variety into the agricultural fields and encompass biological systems in the development of sustainable agriculture. Throughout diversified agroecosystems, emerging ecological properties evolve, allowing the system to operate throughout ways that sustain soil health, production of crops, and pest management. Agroecology has its origins in ecology, implementing natural ecosystem knowledge and contrasting it with armored agroecosystems. There are six principles of ecology (FAO 2018):

- *Networks*: Nature is a web of biological processes that are interconnected within other living systems.
- *Cycles*: Continuous material cycles through the ecological system, so habitats do not produce waste.
- *Solar energy*: This is the basic energy source that powers all the cycles of the world.

Table 3.2 Scientific database about agroecological principles

Year	Scientific resources
2020	Anderson et al. (2020)
2019	HLPE (2019)
2018	HLPE (2018), FAO (2018)
2017	FAO (2017)
2016	Brym and Reeve (2016), Nicholls et al. (2016), Hatt et al. (2016), Dumont et al. (2016)
2015	Snipstal (2015), Colin et al. (2015), Pimbert (2015)
2014	SOCLA (2014), Parmentier (2014)
2013	Rosset and Martinez-Torres (2013)
2012	Stassart et al. (2012)
2011	De Schutter (2011)
1995	Altieri (1995a, b)

- *Partnership*: Energy and resource exchange in the environment are maintained by widespread cooperation and not by rivalry.
- *Diversity*: By the richness of diversity, all ecosystems derive stability and resilience.
- *Dynamic balance*: An ecosystem is indeed a changing, versatile network.

Agricultural frameworks are planned based on the following five ideas:

- Increase biomass reuse, increase the supply of nutrients, and regulate the distribution of nutrients.
- Ensure favorable soil conditions for growing plants, especially by manipulating organic material and boosting biotic soil behavior.
- Reduce losses from solar, air, and water flows through microclimate administration, water collecting, and soil management by means of improved soil spread.
- Spatiotemporal diversification at species and genetic level in the field.
- Improve good organic cooperations and collaborations between components of agro-biodiversity, in this way advancing key biological cycles and administrations.

To establish this collection of concepts, we attempted to formalize and synthesize the practice from various perspectives inside the agroecological community (Table 3.2).

3.9 Elements of Agroecology?

The following ten elements come from national agroecology workshops, coordinated by the Food and Agriculture Organization (FAO) in steering nations to mutate their agrarian and food systems and to achieve zero hunger and many other SDGs (FAO 2017, 2018; Altieri 1995a, b; Gliessman 2014). The ten agroecology components are interconnected and interdependent.

3.9.1 Diversity

Diversification is essential for agroecological shifts in order to make food safety and nourishment while also preserving, safeguarding, and improving natural resources. Agroecological applications maximize species diversity and biological resources in multiple ways. Rotations of crops, often with legumes, boost temporary diversity (FAO 2011). When the biodiversity is increased, it leads to lots of benefits in terms of environmental, socioeconomic aspect and productivity. Agroecological strategies increase the delivery of ecosystem services that rely on agricultural production, such as pollination and soil quality. Diversification may improve productivity and productivity in the utilization of energy by maximizing the production of biomass and water. Agroecological diversification further reinforces socioeconomic and environmental sustainability, including through generating new market opportunities. For instance, the threat of disappointment even with environmental change is minimized by plant and animal diversity (FAO 2018).

3.9.2 Synergies

Synergy development strengthens essential functions around agricultural systems and promotes output and various ecosystem services. If biological synergies are increased, agroecological strategies improve ecological functions, resulting in increased effectiveness and resilience in the use of resources. Integrated rice systems in Asia incorporate rice growing with many other commodities such as birds, ducks, and plants. Integrated rice frameworks dramatically increase nutritional variety, weed management, soil profile, biodiversity protection, and pesticide management by improving synergies (FAO 2018).

3.9.3 Efficiency

Creative agroecological rehearses produce more. Agroecological frameworks improve the utilization of natural assets, particularly those that are inexhaustible. Eventually, decreasing reliance on external assets engages makers by expanding their self-rule and strength to normal or financial stuns (FAO 2018).

3.9.4 Resilience

Diverse agroecological processes are much more robust, more capable of recovering from abnormalities, along with extreme weather conditions like drought, floods, and resisting disease attacks. Agroecological activities preserve the biological nature of farming processes and encourage the required population of species to auto-regulate pest outbreaks (Perfecto and Vandermeer 2010). Agroecological methods may boost socioeconomic stability in the same way.

3.9.5 Recycling

Further recycling means reduced economic and environmental costs of crop production. Agroecological methods promote biological processes which push nutrient, biomass, and water recycling, thus further enhancing the use resource effectively and lessening damage to the environment. Recycling may occur both on the farm and in the countryside, by diversifying and constructing synergies between various elements and practices. Recycling offers many advantages through shutting down nutrient chains and eliminating waste, resulting in less reliance on foreign input, raising the flexibility of farmers, eliminating their vulnerability to financial sector and environmental disturbances. Recycling of organic products provides great opportunity for agroecological developments (FAO 2018).

3.9.6 Co-creation and Sharing of Knowledge

Once co-created via collaborative procedures, agricultural technologies react better to regional difficulties. Co-creation and information exchange play an important role to develop and apply agroecological technologies to tackle problems through food systems, particularly climate alternation mitigation. Agroecology combines conventional and native understanding, practical idea of producers and traders via the co-creation framework (FAO 2018).

3.9.7 Human and Social Values

It is crucial for food production and agricultural systems in a sustainable way to protect and improve rural living standards, equality, and cultural wellbeing. Agroecology puts great importance on human and cultural values like integrity, equity, incorporation, and fairness, all of which contribute to the SDGs' aspect of improved livelihoods. By generating employment opportunities, agroecology aims to solve gender inequalities. Globally, women represent roughly half of the population in farming. They are also crucial in food safety, in nutritional variety and wellbeing, and also in biodiversity conservation and sustainable use. Nevertheless, women are truly socially disadvantaged and exposed to abuses of their freedoms, although their efforts are often overlooked (FAO and Asian Development Bank 2013). In community agriculture, agroecology may help rural women to develop greater levels of independence through awareness development and marketing opportunities. Agroecology can create opportunity for elder female to be more independent, for example, via engagement in groups of producers. Women's cooperation in agroecology is extremely important, and women often lead agroecology projects. As a model of sustainable rural development from the ground up, agroecology encourages individuals to be their own innovators.

3.9.8 Culture and Food Traditions

Through promoting nutritious, diverse, and ethnically suitable food, agroecology adds to food safety and nutrition through preserving ecosystem health. Agroecology is crucial in reshaping traditional and current farming practices, assembling in a cohesive fashion that helps to promote food production and consumption. In this manner, agroecology tries to foster a healthy human-food partnership. When humans and environments grow cooperatively, conventional and aboriginal expertise provides a great deal of real-life experience that could really motivate to adopt agroecological alternatives. India, for instance, has an approximately 50,000 native rice variants—grown over decades for their particular flavor, nutritional and pest tolerance characteristics, and ability to adapt to a variety of ailments (NBPGR 2013).

3.9.9 Responsible Governance

Sustainable food production and farming needs processes of accountable and good governance at various levels—from regional to international. Effective, accessible, and integrated monitoring frameworks are required to establish a supporting atmosphere that encourages producers of agroecological principles and practices to change their processes. Prominent examples involve programs for school nourishment and public logistics, economic regulations that permit distinguished agroecological products to be branded, and ecosystem service incentives and inducements (FAO 2018).

3.9.10 Circular and Solidarity Economy

Agroecology strives to link consumers and producers by building positive loops via circular and stable ecosystem that organizes neighborhood markets and encourages local economic growth. Agroecological strategies are promoting reasonable alternatives based on local requirements, assets, and capacity, producing fairer and much more sustainable markets. Improving short food channels can increase producers' earnings whereas keeping reasonable rate for the consumers. This would include new innovative economies in addition to much more conventional regional markets, in which majority of smallholders sell their goods (FAO/INRA 2016, 2018).

3.10 Need of Agroecology

It is commonly acknowledged that farming is considered as a significant factor of environmental changes. Agroecological methods include the use of incorporated biological, monetary, and social standards to the progress of smallholder cultivating frameworks which brings more versatility (Sinclair et al. 2019). Agroecology includes transdisciplinary science, supportable horticultural practices, and social developments that are encouraging far-reaching conduct change. Agroecological standards map near the principles of adjustment with the outstanding special case that while they frequently display versatility benefits, these are accidental as opposed to speaking to an unequivocal reaction to atmospheric signals (Sinclair et al. 2019). Agroecology techniques, developments, and methods have repeatedly proven reliable of sustainably increased productivity, restoring soil quality and maintaining yields over period, and ensuring stable livelihoods, particularly for small-scale farmers. It can also assist with a number of diets to ensure proper nutrition. Considering the uncertainties of climate change for agriculture and associated technologies, developments and rehearses are especially significant as they expand species farms and ecosystems, create essential ecosystem services, ensure better soil profile, and boost water retention which allows ranchers with a way to distribute threats and adapt to climatic alternation.

The technology, inventions, and rehearses are data escalated as opposed to capital-concentrated and are focused on strategies which are not applied top-down but built based on the knowledge and experiments of farmers and collaborative strategies of farmers and researchers. Technologies, developments, and practices in agroecology are capable of meeting key criteria for assessing technology. These are in fact practical, economical, accessible, publicly acceptable, locally compatible, and eco-friendly. Agroecology can make a significant contribution to fulfilling the SDGs in an inclusive, systematic, and comprehensive way that might directly concern and support those aiming at uplifting the 2030 Agenda. It also has a robust potential to meet the specific objectives of SDG like terminating hunger and lack of healthy sustenance, doubling agricultural output and small-scale farmers' income, guaranteeing supportable nourishment generation frameworks and executing flexible cultivating rehearses, and keeping up the hereditary decent variety of seeds, developed plants, and cultivated and trained domesticated animals (FAO 2018).

3.11 Traditional vs. Agroecological Approaches

In comparison to industrial agriculture's external input-driven approach, agroecology is information-intensive, ability-based, and regional commodity-driven, incorporating minimum-cost technologies which use local knowledge and innovation from farmers as a basis. The efficient and long-term understanding of agroecological approaches has meant that they obtain little assistance from agriculture and wide-scale planners who are often interested in quick, quick-return remedies. Most financing to be spent in the war against hunger goes to support for agrochemicals and vast-scale projects which in the end excludes small farmers (Vidal 2014). On the other side, agroecological systems are built to provide farmers' minor and major autonomy from the use of expensive externalities and make both the communities and ecosystems long-term resilient, self-sufficient, and safe (Table 3.3).

Table 3.3 Traditional vs. agroecological approaches (TWN and SOCLA 2015)

Current approach	Agroecological approach
Segregation	Integration
Reductive perspective	Systemic perspective
Short-term perspective	Long-term perspective
More external and artificial inputs	More local and natural inputs
Declining biodiversity	Promoting biodiversity
Degeneration	Regeneration
Input intensive	Knowledge intensive
Measures single crop yield	Measures whole farm yield
Mono-cropped	Multi-cropped
Low resource use efficiency	High resource use efficiency

3.12 Agricultural Production in India

Agriculture is one of the Indian economy's most influential industries. Agriculture provides livelihood for nearly two-thirds of the rural population. India's farming sector accounts for approximately 15.9% of the nation's $2.7 trillion economy and 49% of overall employment (2018–2019). A recent international economic opinion for the 2019–2020 financial year projected India's gross domestic product (GDP) rise at 6.6% (Report on Policies and Action Plan for a Secure and Sustainable Agriculture 2019). Even today, however, most Indians are dependent on agriculture directly (farming) or indirectly (business with agricultural goods). In India, agricultural output is lower than its capacity due to restricted use of recent farming techniques, climate instability, inadequate farm services and support, and a lack of economy-oriented output. Even natural factors are also a part of agricultural distress in India. It thus becomes a daunting challenge to feed a rising population and ensure food security in the forthcoming days, particularly with regard to rapid climate change (Report on Policies and Action Plan for a Secure and Sustainable Agriculture 2019).

Agriculture is a key area which requires re-looking and re-inventing. It is the exact moment for India to move towards a millennium agrarian metamorphosis, moving from conventional (employment-intensive) agricultural practices to modern agribusiness processes. Recently, the Government of India has put an adventurous benchmark of doubling farmers' incomes by 2022–2023, which correlates to aimed yearly agrarian prosperity of over 14% per year (Report on Policies and Action Plan for a Secure and Sustainable Agriculture 2019).

3.12.1 Agroecological Zones in India

The agroecological zone is indeed the unit of land created from the agro-climate zone that is imprinted on the soil and functions as a climate change and the duration of the growth period. The categorized agroecological zones are going to be very effective in supporting sustainable agriculture, improving the economic system, and retaining food safety. The nation has been clustered into 20 agro-eco-regions (AER) and 60 agro-eco-sub-regions (AESR) (Table 3.4), based on the soil and bioclimatic variation and physiographical conditions. That agroecological sub-region has been further categorized as district-level agroecological units to establish long-term land management approaches.

Table 3.4 Brief description of the agroecological zones in India (Source: Ahmad et al. 2017)

AEZ No.	Agroecological region	Physiography
1	Cold arid eco-region	Western Himalayas
2	Hot arid eco-region	Western Plain, Kachchh, and part of Kathiawar Peninsula
3	Hot arid eco-sub-region	Deccan Plateau
4	Hot semiarid eco-region	Northern Plain (and Central Highlands) including Aravallis
5	Gujarat plains and Kathiawar Peninsula eco-region	Central (Malwa) Highlands
6	Hot semiarid eco-region	Deccan Plateau
7	Hot semiarid eco-region	Deccan Plateau (Telangana) and Eastern Ghats
8	Hot semiarid eco-region	Eastern Ghats and Tamil Nadu Uplands and Deccan (Karnataka) Plateau
9	Hot sub-humid (dry) eco-region	Northern Plain
10	Hot sub-humid (dry) eco-region	Central Highlands (Malwa and Bundelkhand
11	Hot moist/dry sub-humid eco-region	Chhattisgarh/Mahanadi Basin agro-eco-region
12	Hot sub-humid eco-region	Eastern Plateau (Chhota Nagpur) and Eastern Ghats
13	Hot sub-humid (moist) eco-region	Eastern Plain
14	Warm sub-humid (to humid with per-humid) eco-region	Western Himalayas
15	Hot sub-humid to humid eco-region	Assam and Bengal Plain
16	Warm per-humid eco-region	Eastern Himalayas
17	Warm per-humid eco-region	North-eastern Hills (Purvachal)
18	Hot sub-humid to semiarid eco-region	Eastern Coastal Plain
19	Humid-per-humid eco-region	Western Ghats and Coastal Plain, Hot
20	Hot humid to per-humid island eco-region	Islands of Andaman-Nicobar and Lakshadweep

3.12.2 Agroecology for Sustainable Agriculture and Food System in India

India is overwhelmingly focused on the agro-economy, with 70–75% dependent on agriculture (Mandal and Ghosh 2000). Nonetheless, the advantages of farming are not completely bridled in Indian situation, and a large number of individuals have no entrance to food consistently because of the accompanying two most obvious reasons: lack of utilization of current logical strategies, instruments, and actualities combined with restricted rural land assets and quickly expanding population.

As a result, despite launching a green revolution (GR) in major regions of the country, a large population is suffering from malnutrition. Public policies for the use of pesticides to increase crop yields were implemented in the 1960s, but negative effects and adverse environmental and environmental impacts were recognized much later. While the GR has improved productivity, it also has detrimental consequences on the ecosystem (Tripathi and Singh 2007, 2009, 2013). Therefore, the implementation of technological advances was rendered with special emphasis.

In the context of degradation, it is less about farms and their administration rehearses; it is all about ecosystems and their sustainability. The decreased profitability could be substituted or recovered using the method agroecology which helps to improve productivity. It can improve the food system, provide farmers with income and consumers with healthy food, and minimize climate change. India and many other developing nations have recognized the need for sustainable farming to fulfill the expanding need for nourishment. The government recently includes sustainable agriculture in the private sector for successful business activity.

3.13 Agroecology Improves Production

Shifting away from a structure of highly intensive and inequitable chemical farming are whether alternative solutions that can yield enough and sustain them should be evaluated very carefully. Evidence to date has shown that agroecological strategies not only can achieve the same outputs as conventional approaches but in many instances improve them significantly over a period of several years, surpass traditional methods, and provide the environment and community with various added advantages (Hine et al. 2008).

3.13.1 Achievement in India

In India, there are a developing number of agroecology examples of overcoming adversity at different scales, every one of which show the potential for agroecological practices to support or improve yields, yet to give a large number of extra natural and social advantages. There are various examples where the take-up of agroecological practices has had an especially clear effect on continuing or improving yields. Using the Finger Millet Intensification System, yields boosted to 3–4 t/ha from

750 kg to 1 t/ha. Production costs per kilo have also been dropped by up to 60%, contributing in a rise in farm revenue from Rs. 5628/acre to Rs. 8110/acre (SRI-Rice 2014; Bhalla 2010). The Rice Intensification System (RIS), which shattered global records for rice yields in Bihar and Tamil Nadu in 2012 (Vidal 2013), is yet another example of how to increase the productive capacity of irrigated rice through naturally improving the root system's wealth. Despite the fact that at first the Rice Intensification System did not get so many acknowledgements, the System of Rice Intensification (SRI) has created sensational rice yield increments in India. A farmer from Bihar reaped a record breaking 22.4 ton of paddy rice/ha in 2012 utilizing SRI strategies, while a farmer in Tamil Nadu gathered another record yield of almost 24 tons of paddy rice/ha utilizing these techniques (Vidal 2013). As per the Bihar government, over the millions of ha in which rice is now grown using SRI, average rice yields are at least 40% higher than traditional rice cultivation. SRI's advantages have now been demonstrated in over 50 countries. SRI International Network and Resources Center (SRI-Rice) mentioned increased yields of 20–100% or greater, a reduction of up to 90% in seed demands, and water savings of up to 50% (SRI-RICE 2014). This method can also be implemented to a wide variety of crops, and while it is not limited to natural or synthetic-free systems, the use of chemical inputs is often minimal in action (Vidal 2014). Bio-villages are established in every block in West Bengal (Ganguli 2009). Due to the presence of pesticides, samples of Darjeeling tea have been refused by Germany and some other European countries far beyond the allowable limit (Mohanty 2003). Afterwards tea growers transformed organic and arranged several workshops by institutions such as Organic Ekta that support small tea farmers to switch over to organic farming. An NGO, Vikramshila, too is trying to put attempts into this path and assisted Bigha, a village in the district of Bardhaman, attain a pesticide-free kharif crop (Mukherji 2015). These instances serve to advise us that plant hereditary qualities have just one impact in deciding yields and, at last, food security. The manner by which harvests are developed is basic. Agroecological cultivating strategies that feed soil, safeguard water, and limit outer information sources guarantee not just that there is sufficient nourishment for the ebb and flow populace but also that the land remains gainful for who and what is to come.

3.14 Agroecology Boosts Living Standards

Agroecology boosts local communities' living standards, including increased economic feasibility and employment, nutrition welfare, and empowerment at social and political scale, thus producing more reliable and adequate outputs (Chappell and Bernhart 2018). Simultaneously, the reliance on yield as a key indicator of agricultural success could blind critics to the full cost of agroecological approaches. Besides amazing outputs per unit area, when it comes to much more detailed conservation, sustainability, and ecological services, agroecology stands out dramatically (Altieri 2009). Agroecological activities are therefore aimed at achieving optimum sustainable outcomes instead of optimizing production (Parrott and Marsden 2002).

3.14.1 Achievement in India

In addition to the introduction of organic markets, the implementation of agroecological practices such as zero budget natural farming (ZBNF), community managed sustainable agriculture (CMSA), and sorted out duck rice cultivating was already revealed to get a beneficial impact on family income in India across a range of geographic scales. ZBNF is both a collection of agricultural practices and a revolutionary farmer campaign raised in Karnataka, India. It is projected that 100,000 families in the area in Karnataka, and thousands of families throughout the nation, use ZNBF practices. In 2015 Andhra Pradesh's government declared its goal of touching 500,000 peasants with ZBNF by 2020 (Khadse et al. 2018; Saldanha 2018).

Zero budget, which implies not being dependent on loans, and not purchasing materials, aims to end tremendous debt by dramatically rising cost of output. Natural cultivation involves cultivating with nature and even without the artificial products obtained. ZBNF approaches involve mulching, guided irrigation, contour bonds, usage of native earthworm organisms and fermented bacterial livestock, mixed cow dung, and soil therapy. At the regional level, ZBNF works predominantly by volunteers, representatives of farmers' groups, and local leaders, inspired by the movement's founder, Subhash Palekar, an agricultural researcher who has published various ZNBF process publications. By using as many on-farm options as possible, farmers are reducing the need for monetary loans needed to modernize agriculture, thus the zero budget. According to La Via Campesina (LVC), numerous farmer families across India recently followed this trend, shifting away from monoculture cash crop cultivation to locally resourced practices of agroecological farming (Rosset and Martínez-Torres 2012).

In Andhra, CMSA models have been especially successful among local farming groups and have been implemented by an approximate 500,000 farmers on a large scale over 3,500,000 acres as of 2011. Farmers are instructed over a time span of four seasons in anti-pesticide monitoring and sustainable farming strategies. Public control and procurement ensures the performance and reliability of goods for customers, instead of formal validation. The CMSA model was created and implemented by the Centre for Sustainable Agriculture, while the state government's financial support is thought to have significantly accelerated the scope of such endeavors. Pest threats have reduced dramatically, and soil quality has recovered to its normal higher levels. Whereas relevant agricultural productions have not increased, the lower production costs achieved by adopting these practices have enabled several farmers to grow paddy twice per year, increasing the overall productive capacity of the land and its subsequent earnings (Kumar et al. 2009).

In the southern part of India, substantial numbers of farmers have implemented a special agroecological technique known as "Aigamo process." While it was first introduced as a pest control tool in Japan, it concurrently doubled the quantity of protein content in farmers' diets and adding to their family income (Wijeratna 2012). The incorporation of ducks and fish onto rice paddies was found by smallholder farmers to provide an effective strategy of insect control. The ducks consume grass, seeds, bugs, and other pests and do the weeding work, while the duck and fish feces provide valuable plant nutrients (De Schutter 2010). The farmers consume the ducks and fish, which boost their intake of protein. As a consequence of these initiatives, the International Rice Research Institute reported 20% greater crop production and also 80% increment of net profit (Khan et al. 2005). A 2-year comprehensive analysis of 120 cotton farms in Madhya Pradesh demonstrates that organically grown areas incurred conventionally grown Bt cotton yields, whereas nutrient and other production costs have been lowered by 50%. The market related to organic food market in India is developing quickly (India Organic Food Market Forecast and Opportunities 2019). This market could be targeted and supported by many Indian farmers while rising sustainability on the farm.

3.15 Agroecology Develops Resilience to the Ecosystem

Agroecological practices alleviate the risks involved with ecological seasonality by increasing the resilience of farmland to extreme weather conditions, pest invasions, as well as other ecological shocks. This is especially relevant at a period when changing climate is causing ever-more strange weather trends worldwide (IPCC 2014). Certainly, the agriculture industries would have to face any degree of climate change in all nations, rendering mitigation essential (Howden et al. 2017). Securing ranchers and their families to deal with both the danger of climate instability and the threats that climate change may bring to the potential livelihood prospects is a very vital prospect. There are various agroecological methods listed in Tables 3.5 and 3.6 which may be implemented to minimize climatic vulnerabilities. The first main phase is the comprehension of the agroecological characteristics of conventional and other agroecological farming technologies that have been studied (DeWalt 1994). The second option is to distribute with greater intensity the concepts and strategies of resilience extracted from active farmers and also the findings of research studies documenting the efficacy of agroecological approaches that boost the resilience of agroecosystems to severe climate events (Stigter et al. 2005).

Table 3.5 Role of agroecology to enhance ecological resiliency (Modified from Altieri et al. 2015)

Agroecological services	Methodology
Biodiversity restoration	Polyculture, crop rotation
Biodiversity and natural resource conservation	Riparian buffers, vegetated ditches, hedgerows
Ecosystem services	Water and soil conservation, plant health and productivity
Ecosystem function	Pollination, nutrient cycling, erosion control, and biological control

Table 3.6 Agroecological criteria for establishing robust agricultural practices (Modified from Altieri et al. 2015)

Agroecological principles in actions	Working framework
Enhance the recycling of biomass	By enhancing the breakdown of organic substances and the nutrient rotation over period
Offer the best suitable soil conditions for crop growth	By enhancing the biotic interaction in the soil
Reduce the resource loss	By enhancing conservation and regeneration of different natural resources
Strengthen immunity of agricultural production	By improving effective biotic diversity and introducing biological enemies, antagonists, etc.
Enhance advantageous biotic interactions	By synergizing with various elements of agro-biodiversity

3.15.1 Achievement in India

India seems to be a global plant diversity hub. Millions of Indian farmers today can use these resources to establish ecologically sustainable farming systems and also as a strategy to mitigate climatic alternations (NBPGR 2007). A few of the increasing handful of examples that occur throughout the nation are discussed below.

An agroecological campaign began in the 1970s in the Zaheerabad area of the Medak district, which now comprises more than 5000 female farmers. After the Great Drought of the 1970s compelled thousands of small farmers to starve because of the failure of certain modern crop varieties, farmers in the area began to adopt agroecological techniques to improve ecological resilience with the help of the Deccan Development Society. Such strategies included seeding and preserving a range of land-based food crops, agroforestry, soil preservation, organic farming, and the development of local independent-made biopesticide remedies, as well as rejuvenating local markets. The outcome is that thousands of farmers today grow robust farming technologies that improve their seed and food safety (Satheesh 2010).

Farmers led by the Tamil Nadu Organic Farmers' Movement (TOFarM) used agroecological practices in Nagapattinam and neighboring coastal districts in Tamil Nadu to revive devastated farmland after the 2004 tsunami. Traditional technological assessment teams estimated that cultivating on salt-soaked soils could require up to 10 years. Farmers using organic as well as other agroecological methods, however, succeeded in crop growth after only 2 years, by intelligently desalinizing the soil with particular plant species and restoring the soil microbiology previously wiped out (Samuel 2015).

3.16 Agroecology Enhances the Reliability of Smaller Farms

Economists have long argued that, in order to boost agricultural output, one should increase the size of the farm in order to obtain economy of scale. This is expressed in Giampietro's (1997) seminal study, "Socio-economic Constraints on Biodiversity Agriculture," when he noted that contemporary farms are being built with huge capital expenditures in equipment, chemical inputs, irrigation, and land expansion, which must be justified on an on-farm basis by increasing profits generated by monoculture production (Giampietro 1997). There is growing evidence that the future food security of the planet is in the possession of small-scale ranchers, as they are more profitable and delivering more food/ha (Altieri 2009). Such results are particularly relevant for India. About 83% of farmers in India are classified marginal with less than 2 ha of land each and 42% of India's operational area (Chand et al. 2011). These small ranchers carry about 41% of India's total grain and cover more than a quarter of India's vegetables and fruits (Agarwal 2010, 2018; Agrawal et al. 2010).

Sustainable intensification, advocated as a remedy for small-scale producers in industrialized nations, is viewed as a significant transformation in terms of crop production. Combining sustainable farming with intensive farming leads to environmentally sound agricultural methods and better productivity (Collins and Chandrasekaran 2012). Several other regional evaluations affirm agroecological farming's ability to raise yields, as illustrated in Table 3.7.

Table 3.7 Selected assessment supporting the ability of agroecology to enhance the reliability of smaller farms (Modified from De Schutter 2010; Altieri et al. 2012)

Selected assessments	Main reported yields or food security outcomes
Pretty et al. (2003)	Rising in the productivity in the area of 29 m ha, with about 10 million families gaining from improved food system and protection
Badgley et al. (2007)	In advanced countries, organic agriculture systems produced 80% more than traditional farming
IAASTD (2009a, b)	The study presents and relates to an increasing variety of indications that investment in agroecological solutions can be relatively successful in enhancing productivity and food safety
The Government Office for Science (2011)	Food production from agroecology through the use of modern and enhanced strains was important as agricultural production grew by 2.13-fold on average The majority of households dramatically increased food quality and food stability in the home
Bachmann et al. (2009)	For organic ranchers, food quality was significantly higher. The study showed that on-farm diversity was substantially higher for complete organic farmers, increasing an average of 50% more crops than traditional farming

3.17 Role of Agroecology Towards Reducing Ecological Footprint

Agroecology includes scientific foundation for manufacturing through a biodiverse agroecosystem that can support its own structure and function. In seeking to enhance agricultural productivity, most researchers have ignored a crucial factor in creating an independent and productive farming methods, a thorough knowledge of the essence of agrosystems and the concepts for action. Agroecology has developed as a methodology that lays out the fundamental ecological concepts for the research, layout, and management of both efficient and natural resource protection agroecosystems (Altieri 1995a, b). Rather than concentrating on one single feature of the agrosystem, agroecology stresses the interrelationship among all agrosystem elements and the diverse nature of ecosystem cycles (Vandermeer 1995). Furthermore, agroecology gains from natural cycles and positive experiences on-farm to the usage of off-farm products and increases the performance of farming processes (Reinjtes et al. 1992). Agroecology includes various technologies which are likely to promote the responsive biodiversity of agrosystems and the preservation of established on-farm assets. The innovations which may serve as an environmentally sustainable by enabling and influencing agroecosystem process, such as:

1. Biomass recycling, resource distribution, and supply management.
2. Providing optimal fertile requirements for the growth of plants by increased organic substances and biotic development.
3. Reducing food, water, and resource losses by microclimate protection, soil conservation, and water recycling.
4. Spatiotemporal enhancement of different species and biological diversification.
5. Improve advantageous biological relationships and synergies among elements of agro-biodiversity, promoting key biological functions and facilities.

Agroecological systems use natural resources more sustainably and efficiently and reduce the release of chemicals to air, water, and soil. Through the enhanced proximity between producers and consumers, agroecology helps raise awareness and reduce food waste, e.g., by redistribution of un-usable crops (Beausang et al. 2017) or by repurposing urban organic waste as fertilizer (Sonkin 2017). Agroecology puts an emphasis on maintaining soil fertility and ecological processes, which can improve agricultural efficiency over the long term. Studies have shown that through diverse and heterogeneous agroecological approaches, it is possible to preserve and increase wild and domesticated biodiversity by up to 30% (FAO 2018). The connection between climate action and agroecology is two-way—agroecological systems may lead to GHG reduction and offer management practices to adapt to climatic alternations (FAO 2018).

The academic studies and paradigm review paper offer evidence of the hypothesis that agroecological strategies would boost efficiency, thus reducing the CF, delivering useful ecological resources, improving social sustainability, and enhancing the economic and ecological resiliency of the farmers. The flow-on effects lead to the regional food allocations and regional development and eventually boost the wellbeing of the munities (Pretty et al. 2011). Many results, though, are already regional, mostly owing to a lack of suitable policy climates. Agriculture was identified as one of the most important human activities linked to environmental degradation. The vast volume of capital used in terms of water use and land erosion is a significant cause of environmental impacts from farming. Agroecological concepts are very useful in developing sustainable farming systems to enhance relationships among different plant species, livestock, and humans and the ecosystem sustainability.

The goal of agroecology is to implement ecological concepts to plan and maintain agroecosystems in a much more sustainable manner. With fewer from the earth, there's a need to create more for the world. Even so, we need to have a set of best practices, coordinated approaches, strategies, and innovations to reduce the EF of farming. In particular, agroecology is often used as a science and empirical tool which actually explains the long-term profitability and local environment effects of different practices. Agroecological and other creative solutions will help farmers address increasing environmental problems, like climatic change, water supplies, and biodiversity depletion. It is necessary to consider the need for enhancing the fundamental research on all sustainable agricultural strategies centered on science and facts. This involves designing benchmarks to quantify outcomes at the agricultural production and establishing suitable measures and promoting the capacity of countries to monitor their enforcement, instruments, and protocols to determine the contribution of such activities to sustainable agri-based agriculture (Oteros-Rozas et al. 2019). Agroecology is interesting in that it provides both supply-side and demand-side reduction incentives. Sustainable escalation, reduction of pollution from enteric fermentation, reduction of CH_4 emissions from rice cultivation, and enhancement of the use of fertilizer constitute the supply-side prospects. The demand-side prospects are emission mitigation in farming processes and food waste reduction. The following mitigation strategies were established by the IPCC (2014) via agroecology: usage of specific varieties or organisms, improvement of agro-biodiversity, modern crop development activities, plant control (increased selection, recycling, nutrient control), water management, land usage reform, and biochar implementation. The research by Rakotovao et al. (2016) emphasizes that the introduction of agroecological activities on a pasture scale provides substantial GHG reduction and sequestration of carbon in the sense of Malagasy, thereby offering an option to combating climate change. Improving development performance by implementing sustainable farming methods not just reduces GHGs from agrosystems but also helps to reduce pollution levels (Sapkota et al. 2017a, b, 2019). Organic farming reduces total CF by sequestrating carbon into soil (Hedayati et al. 2019; Skinner et al. 2019). For organic cultivation, the production of N_2O may be decreased by about 50% and the output of CH_4 by about 70% (Skinner et al. 2019).

3.18 Challenges of India's Agroecology Scheme

Agroecology has enormous potential to improve Indian agriculture to provide sustainable food security, poverty reduction, rapid economic expansion, and restoration of the ecosystem (Banerjee et al. 2018; Jhariya et al. 2018a, b). The agricultural sector has the most challenging sector economically, environmentally, and socially. The Indian agricultural sector faced various traditional as well as new global challenges, such as the preservation and upgradation of biological establishments for economical agribusiness, including land, water, biotic diversity, and natural assets. The urban development and the utilization of non-agricultural land should be evaluated critically before agribusiness (Kamble and Chavan 2018; Khan et al. 2020a, b). The 80% ranchers in India have little size of land. They are not financially solid, and there is absence of market connection. The overall gain from agribusiness of little and negligible rancher is very low, or sometimes it becomes negative due to huge expenses in farming segment (Kamble and Chavan 2018). The agribusiness profitability is low and hampers profit of the ranchers. The per unit region efficiency is likewise low if there should be an occurrence of significant harvest creating in nations. The fall in the groundwater level produces more weight on other water system offices and makes jumps in the method for farming improvement in India. Absence of seriousness in Indian ranchers is another obstacle ascending in the middle of agribusiness advancement. The ranchers are less hazard bearing and incompetent which antagonistically sway on their pay from agribusiness. The farming protection plans are wasteful to beat different hazard in agricultural sector (Kamble and Chavan 2018). Low gainfulness is a primary driver behind the ranchers' obligation, and suicide issue existed in much territory of India over the most recent couple of years. The spending on farming sponsorship has expanded step by step; however, the issue stays the same and constantly grows up (Kamble and Chavan 2018).

3.18.1 Policy Environment

In terms of subsidies, research and development (R&D) priorities, innovation drive, and farmers' aid structures and organizations, the current policy environment tends to favor proven chemical alternatives to agricultural production.

Subsidies are linked to production and facilitate the agrochemical sector in many cases (through well-organized business promotion as well as many other accepted avenues of communication), for instance, food and fertilizer subsidy quantity over Rs. 2 lakh crore which is nearly tenfold of public agricultural expenditure (Gulati and Saini 2015).

Priorities for R&D are primarily focused on traditional intensive farming, which encourages the utilization of external inputs and chemicals and focuses on certain chosen crops (e.g., corn, wheat, mango, and banana). This takes place at the behest of many other crops like coarse cereals and conventional indigenous legume, fruit, and vegetable varieties.

In rural areas, agrochemical industry and seed suppliers are marketing their products extensively, occasionally gaining from associated policy aid. Low-input, minimal-cost agroecological practices and services are being promoted on a small scale (Wibbelmann et al. 2013).

A significant reassessment of the excessive policy emphasis (by providing production aid, incentives, facilities, and investment) onto the GR areas is required. Most of India's states have been gaining (or are proximate to acquiring) self-sufficiency in contexts of the production of food grain for their own population. The distances transported by food grains via the public distribution system (PDS), predominantly from the northern states, to satisfy food safety require enormous transportation and environmental costs. Rather, it might make better sense to encourage neighboring states to allocate their excess, improve the agricultural markets of these poorer states and their inhabitants, reduce the gap between consumers and producers, and endorse a much more socially acceptable food system. In such a situation, India's road to agricultural affluence could then shift away from the inefficient cereal-based cropping processes that are presently destroying their social and ecological health, a big segment of Punjab or Haryana's agriculture.

The PDS method which intends to supply food grains to some of India's poorest people while at the same time providing guaranteed markets to farmers has been under dispute in terms of performance, distribution, usefulness, and targeting. Approximately a quarter of the subsidized food distribution is not entering target audiences because of limited visibility of the program, administration, and facilities (Purohit 2011). Research and development focuses on a few grains and some other products (e.g., rice and wheat) with few introduction of coarse cereals, like bajra and millet, which are sometimes more nutritious, but often part of many societies' regional food package (Devakumar and Chhonkar 2013). As mentioned above, it is highly integrated with close to 80% of transactions historically clustered in Punjab, Haryana, and Uttar Pradesh; however, there has been notable shifting towards increased purchases of these crops in non-green revolutionized areas through the PDS. Because most of India's poorest end users are mostly part of the production system, much can be done to improve direct interoperability here between the two.

Public organizations, like cooperatives and regional NGO, are sometimes poorly resourced, restricting their vital role in recognizing, studying, educating, promoting, and linking with agricultural communities (Wibbelmann et al. 2013). There seems to be limited recognition of the function that forest, native, and uncultivated crops can perform in establishing food security and subsistence for rural and especially poor tribal communities in India.

There seems to be weak gender auditing in agriculture (Wibbelmann et al. 2013). Females account for 43% of the world's farming workforce and provide up to 70% of total agricultural labor in India along with their regional practices, as per some reports (Rao et al. 2019). Yet, they are frequently marginalized (FAO 2011; Dev 2012).

Pricing externalities leads to neglect agroecological activities. As reported by De Schutter and Vanloqueren (2011), failure to completely incorporate external costs into agri-food price mechanisms has allowed industrial farming to grow despite significant economic and social consequences and has prevented a rigorous assessment of the advantages of agroecology. The thriving of huge populations is inferable from the reality that food prices do not portray the actual societal costs arising from their activities (De Schutter and Vanloqueren 2011).

3.18.2 Market Structure

As the price of external inputs including fertilizer, pesticide, and seed rises, the extremely important aspect for farmers is to find out the ways to secure greater net profits from their goods. This raises the value of farmers' exposure to equal and competitive markets that can help them achieve a higher net income (Chand et al. 2011). In general, smallholders are faced with the following competitive challenges.

Low accessibility to resources and appliances: seeds, fertilizers, and facilities that are essential to boosting output (especially in the absence of agroecological inputs) are in so many instances expensive, of inferior or questionable value, or simply inaccessible to small farmers. There is also no access for farmers to threat management resources like protection and credit facilities. Small farmers in India face serious challenges such as climate, growth, disease and pest outbreak, and advertising. Such instruments are keys to reduce a few of these threats (Chand et al. 2011).

3.18.3 Retailers Find It Hard to Indulge Small Farmers Reasonably

Operating with major farmers and the APMC network with its intermediaries is one of very few viable alternatives for cost-effectively buying products currently for retailers who need large quantities. Attempting to access small holders directly introduces serious risks and transaction costs that are often unsustainable. These costs result in a preference for working with the existing, inefficient market system, large manufacturers, and intermediaries and dealers in order to achieve the correct quantities and rates (Chand et al. 2011).

3.18.4 Medium-Sized Farmers Are Benefiting Unequally

For these infrastructural inequalities, much of the advantages of the growing, globalizing sector have come to such medium- and large-scale farmers who have formed direct links with producers and retailers. Due to volumes, the implementation of innovation guarantees quality and consistency, and they have constructed-in strength in market access. Few minor and moderate farmers have succeeded in doing the same and engaging with corporate players, a finding that has enormous implications for most farmers in India (Chand et al. 2011).

Efficiency gains, simplicity of manufacturing, and strain of globalization also lead in a specialization of manufacturing trends that limit farmers' options for cultivation in a variety of ways (Joshi et al. 2006). They are often characterized by huge markups, even though there is little scanning engaged.

Certification systems are expensive, ineffective, and extremely complex for organic and natural products, preferred by large and influential growers. Certification organizations are working with mixed results and trust.

3.18.5 Information and Technology

Data and innovation has been a noteworthy supporter of development and financial improvement in business parts, nations, and locales where they are all around embraced and coordinated. The broad scale of information and communications technology (ICT) adoption and incorporation has reduced knowledge and processing cost, increased service quality, provided new employment, developed new business opportunities, and saved assets. Lack of adequate information, understanding, and technology hinders productivity and improved livelihoods: as a consequence, the techniques and methods used are frequently biased towards those private enterprises capable of promoting their own goods to farmers (fertilizers, pesticides, seeds, etc.) and discouraging farmers from using local and agricultural inputs, cultural knowledge, and procedures. Exposure to weather data, new or restored innovations, and market pricing would not only allow better farm planning and fair market access, but often instruction and ability developing around good practices would significantly improve farmers' ability to maximize their procedures. Subsistence agriculture often occurs if farmers are unable to maximize their resources. This could be especially true in rainfed regions, which address for 65% of India's agricultural land and are habitat for a large percentage of poor and working-class people in India (Joshi et al. 2004).

Extension facilities and platforms are not readily available to women, who are the majority of farmers: the statistics available indicate that only 5% of extension resources are provided worldwide to rural women, whereas none more than 15% of extension representatives worldwide are female. Over 60% of agricultural exercises are done by female farmers in specified states. However, the fact that in India most of the farmers are women is certainly not represented in the procurement of extensions or education (Dev 2012).

Lack of consumer data, both explicitly via distributors and implicitly via the media, on the advantages of agroecological farming practices (nutrition, health, and livelihoods) means customers are unable to make informed decisions easily to endorse farming practices promoting health and food security.

3.19 Future Research and Developmental Activities in Agroecology

The quest for economic advancement of agribusiness and of food system frameworks is right now being organized in numerous pieces of the globe. Among the benchmarks of success is a rapid advancement in agroecology to address the worldwide problems in food production and sustainability, biodiversity restoration, changes in climate, and economic justice. Study and awareness are significant constituents of agroecology worldwide and are also a link between its research and action embodiments. A growing number of scientific initiatives worldwide use the word agroecology in their designation of organizations, departments, and meetings for study. While most of them are more genuinely established in agronomy and biology, there were more gatherings and divisions operating on the economic and social perspectives, as well as for agroecology.

In India, increasing demand for agroecology is to be extended from different divisions—multilateral entities such as the FAO, societal movements such as LVC, researchers, and institutions of the popular society (Parmentier 2014; La Via Campesina 2013). Agroecology isn't only a lot of farming rehearses, or a logical order dependent on environmental hypothesis, yet additionally a developing social development (Wezel et al. 2009). Examining the society-related components of agroecology may contribute fundamental information for achievement at larger scale. By and large, laborer developments have had a significant influence in taking agroecology to scale, yet their job has not been adequately broke down up until this point. The international farmer campaign LVC has embraced agroecology as potential instruments for contributing food independence and has proven a significant area for its expansion (Rosset and Martínez-Torres 2012; Rosset and Martinez-Torres 2013). LVC seems to have different types of agroecological interactions, like traditional methods, collectives, and over 40 agroecology educational institutions, and gained some advantageous public policies in different regions of the globe (La Via Campesina 2013). Another farmers' campaign that brought the potentiality of agroecology in scale is ZBNF, in South India. The ZBNF, also known as the Zero Budget Spiritual Farming Campaign, has expanded in many other Indian states at various rates (Khadse et al. 2018; Palekar 2006). It was particularly widespread in Tamil Nadu state, Andhra Pradesh state, and Kerala state, but it was in the Karnataka territory that it initially became prevalent. ZNBF is situated by its supporters as an answer for the farming emergency and increased pattern of suicides of farmers in India (Palekar 2005, 2006).

3.19.1 India's Initiative at Government Level

The quality and consistency of natural resources like soil and water depend on preserving agricultural output. Agricultural development can be maintained by effective location-specific measures to encourage sustainability and sustainable use of these limited natural resources. In India agriculture continues to remain principally rainfed. Therefore, in combination with the growth of rainfed farming, conservation of natural assets holds the main factor to meet the country's growing demands for food grain. For this purpose, the National Mission for Sustainable Agriculture (NMSA) has been devised to boost crop yields, particularly in rainfed regions based on sustainable agriculture, water quality, managing soil health, and synergizing the conservation of resources. NMSA has been intended to converge, consolidate, and subsume all continuing and freshly implemented activities related to sustainable agriculture with a particular concentrate on soil and water protection, management, and advancement of soil quality in rainfed area (https://nmsa.dac.gov.in). NMSA's priority would be to use society-based approach to incorporate the sensible use of common resources. Developing farmers' and stakeholders' potentiality in combination with other continuing missions would be implemented, e.g., the National Mission on Agricultural Extension and Technology, National Food Security Mission, National Innovations on Climate Resilient Agriculture (NICRA), etc., in the field of mitigation measures for climate changes (https://nmsa.dac.gov.in).

Agroecological food creation frameworks can convey equivalent or better yields and monetary comes back to the farmers than transcendent types of synthetic and biotechnology-based agriculture, while additionally upgrading farmers' occupations, improving general wellbeing, and restoring environment flexibility (IAASTD 2009a, b).

There is no uncertainty that food security, alleviating poverty, and ecological sustainability are national needs of foremost significance for India. There is additionally no uncertainty that today, with quickly developing paces of obligation and farmer suicides, critical decreases in soil and water quality, and worries around access to sheltered and nutritious food, India's rural segment is in emergency. Notwithstanding, a huge and developing assemblage of logical proof recommends that the utilization of genetically modified organism (GM) innovation can't be an answer for these mind-boggling and interconnected issues. Rather, the huge-scale usage of agroecological practices can furnish India and her developing populace with enduring nourishment security, upgraded jobs, improved general wellbeing, and a protected, assorted, and versatile farming system. In 2013, India passed the National Food Security Act. The 2013 Act attempts to supply people with food and nutrition safety by guaranteeing full rights to a sufficient quantity of healthy food at reasonable costs (The National Food Security Act 2013).

National food conclave held in New Delhi on March 15, 2019, called for policy changes aimed at promoting sustainable food production, particularly sustainable farming, and regulations to reduce the abuse of antibiotics and pesticides. The consultations coordinated by the Centre for Science and Environment (CSE), a non-profit research and advocacy center based in New Delhi, highlighted the need to control junk food and bring about a strategy-level change in junk food advertisements. The experts highlighted the links between the country's way of producing and promoting nutrition and the rising burden of diseases. The specialists also concentrated on the strong and powerful pesticide bill, antibiotic legislation, and bad food control (Bhaduri 2019).

The Indian government is adopting the National Mission for Sustainable Agriculture, one of the eight missions led by the National Action Plan on Climate Change, in order to predict the potential threats of climate change. At the same time, the Pradhan Mantri Krishi Sinchayee Yojana contemplates "One Fall More Crop," i.e., micro/drip irrigation for water conservation. There is additionally a drive through the Paramparagat Krishi Vikas Yojana to cluster-based organic farming. The aim of these programs is to use climate-smart approaches and innovations effectively in collaboration with the Indian Agricultural Research Council and state authorities (FAO-WFC-IFOAM 2018).

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3.20 Conclusion

Agroecological practices can convey equivalent or better yields and financial comes back to the farmer than synthetic and biotechnology-based agriculture, while upgrading farmers' employments, improving general wellbeing, and restoring ecosystem resilience. There are various examples over the world that obviously show the potentiality for agroecological practices to accomplish a flourishing agriculture. Notwithstanding the natural capability of agroecological practices, there are various moves that should be defeated for their far-reaching appropriation and scale. When it comes to mitigating climate change in farming, an evaluation of possible mitigation and adaptation solutions and their efficiencies and trade-offs and main obstacles to scaling up is important. To this end, this chapter emphasizes the many agroecological activities and innovations that have low to great potential to mitigate the footprint of the agricultural methods and foster sustainable food systems. This chapter also argues that basic improvements in agronomic techniques, like practices of tillage, water management, and food control, will dramatically reduce various forms of agricultural land footprint, in addition, the improvement and encouragement of conventional agricultural methods and the introduction mixed farming method to minimize significant volumes of GHG pollution without limiting the production of agricultural crops. This chapter also stresses that, given mitigation criteria and the involvement of farmers in adopting improvement and solutions, socio-cultural attitudes and non-availability of opportunity from different policy framework hinder the implementation of agroecological approaches and innovations.

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Carbon and Nitrogen Footprints Management for Environmental and Food Security

4

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Abstract

To promote the advance food security for the increasing population, environmental security is important to the sustainable future. Agriculture is a major sector to interfere on the planet, and emitting a huge amount of the greenhouse gasses (GHGs) emission to the atmosphere, it is due to the imbalance and excessive use of chemical substances, electrical energy and high consumption of the fossil fuel. Various agricultural activities including ploughing, irrigation, crop cultivars, livestock rearing, application of synthetic fertilisers and pesticides and associated equipment also emit a significant amount of GHGs. The Indo-Gangetic Plains (IGPs) of the South Asia (SA) are a food basket of the world population. It is due to harvesting of the number of diversified cropping systems/crops in a year in same land with higher crop productivity. Where the rice–wheat cropping system (RWCS) is covering ~26 M ha in the IGPs of SA, and it is solely the major contributor to anthropogenic GHGs productions, particularly methane (CH_4) and nitrous oxide (N_2O) emission, and volatilisation of ammonia (NH_3). The excessive production of GHGs is directly linked to carbon (C) and nitrogen (N) footprints, which are the key element for balancing the many components in the nature directly and indirectly. Therefore C and N of various forms regulate the fauna and flora activities, soil and crop productivity, energy consumption, atmospheric gaseous concentration, etc. Among them, N_2O is responsible for ozone depletion and global climate change and has a global warming possible to 265 times than that of carbon dioxide (CO_2). To reduce the GHGs emissions, it is important to users of balanced chemical fertilisers particularly N-fertilisers, improvements of the operation efficiencies of farm machinery and changes in regional allocation the RWCS. The present study is concentrated on the aspect of C and N footprints in the farming systems, which are linked to the GHGs-emission through pre-, on- and post-farm activities. Several alleviation approaches concerning to the agricultural practices are also suggest a roadmap to the policymakers, land managers and researchers, and help to the modeling for footprints of C and N for environmental, food, nutritional and economics security under the changing climate.

Keywords

Agriculture · Carbon · Greenhouse gasses emissions · Nitrogen

Abbreviations

BNF	Biological nitrogen fixation
C	Carbon
CA	Conservation agriculture
CFT	Cool farm tool
CH_4	Methane
CO_2	Carbon dioxide
EF	Ecological footprint
FAO	Food and Agriculture Organization
GHGs	Greenhouse gasses
GWP	Global warming potential
HCFCs	Hydro-chlorofluorocarbons
IGP	Indo-Gangetic plain
INCCA	Indian Network on Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
N	Nitrogen
N_2O	Nitrous oxide
NFs	Nitrogenous fertilisers
NH_3	Ammonia
NOx	Oxides of nitrogen
O_3	Ozone
RWCS	Rice–wheat cropping systems
SA	South Asia
SSNM	Site-specific nutrient management
UN	United Nations

4.1 Introduction

Presently, changing climate is an alarming topic globally, as it influences the climatic arrangements such as uneven precipitation, life-threatening high temperatures, flood, salinity, water and storms, and incidence of abiotic and biotic stresses including fauna and flora, etc. (Jaiswal and Agrawal 2020). As the demand of food is rising with the growing population, the proportion of greenhouse gasses emissions (GHGs) from the farming activity is due to the imbalance and over-use of chemical substances, electrical energy and use of fossil fuels (Xiao et al. 2019; Jaiswal and Agrawal 2020). Various agricultural activities including ploughing, irrigation, various crop cultivars, livestock rearing, application of synthetic fertilisers and pesticides and associated equipment are also linked to the production of a significant amount of GHGs (Xue et al. 2016; Xiao et al. 2019; Jaiswal and Agrawal 2020).

Besides this, land-use fluctuations including alteration of natural environment to agriculture, deforestation and burning of harvesting crop residues are connected to a considerably greater emission of carbon (C). Therefore, decline of C and nitrogen (N) footprints in farming systems has been considered a progressively burning issue, since these are directly linked to global warming and sustainable crop production in modern era. To mitigate the hostile environmental conditions and spread of attentiveness, various inventories are prepared (Khan et al. 2020a, b). Among them, two major elements, i.e., C and N are a key player on the planet. All the ecosystem services depend on the C and N, while all other direct and indirect services have a strong relation with depending on C and N footprints. Hence, the C and N footprints have a major contribution in GHGs, soil, water and air pollution from the different outside and agriculture systems (Xue et al. 2016; Jaiswal and Agrawal 2020; Meena and Lal 2018). Although carbon dioxide (CO_2) was considered earlier only GHGs, but at the modern era scientists informed several GHGs including CO_2, methane (CH_4), and nitrous oxide (N_2O), etc., as a result of anthropogenic activity (Stocker et al. 2013; IPCC 2014a, b; Xue et al. 2016; Xiao et al. 2019; Jaiswal and Agrawal 2020).

The IGPs of South Asia (SA) measured the backbone of food safety due to harvesting of the number of diversified cropping systems/crops in a year in the same land with higher crop productivity. However, the rice–wheat cropping system (RWCS) in the IGPs of SA and China (Saurabh et al. 2020; Meena et al. 2018) is one of the primary providers to anthropogenic GHGs-emission, mainly emission of CH_4 and N_2O and volatilisation of NH_3 (ammonia) (Stocker et al. 2013; Xue et al. 2016). Among them, N_2O is responsible for ozone depletion and global warming than that of CO_2 (Sapkota et al. 2020; Saurabh et al. 2020). N is considered the further most restrictive nutrient that is governing the production of all agricultural crops (Ladha et al. 2005; Meena et al. 2020). Since agricultural soils are liked to emission of global N_2O about 60%, and also other nitrogenous gases NOx ($NO + NO_2$) and NH_3 as a result of the excessive application of nitrogenous fertilisers (NFs) (Mosier et al. 2004; Galloway et al. 2014). Others studies revealed that only 1/3 of the applied N is used by crops and the rest of N is emitted as N_2O (Sapkota et al. 2020; Saurabh et al. 2020).

The agricultural activity in India emits 18% of the entire emission of GHGs; where enteric-fermentation emits about 63.4% GHGs from agriculture, whereas agricultural soils 13%, rice culture accounts for 20.9%, manure application 2.4% and burning of residue contributes 2% (INCCA (Indian Network for Climate Change Assessment) 2010; Chakrabarti et al. 2018; Meena et al. 2020a). Among these GHGs, N_2O emission occurred from soils due to the application of NFs in both rice and wheat systems. C footprint of rice-based systems is greater than that of wheat, it is due to during rice farming both CH_4 and N_2O gases are emitted. It was observed that CH_4 was emitted by rice crop, and wheat emitted N_2O in the RWCS (Sapkota et al. 2020; Saurabh et al. 2020).

The present study is concentrated on the aspect of C and N footprints in the farming systems, which are linked to the GHGs-emission through pre-, on- and post-farm activities. Several alleviation approaches concerning to the agricultural practices are also suggest a roadmap to the policymakers, land managers and researchers, and help to the modelling for footprints of C and N for environmental, food, nutritional and economics security under the changing climate.

4.2 Challenges for Food Security

Food security is a hugely discussed topic over the world in the last two to three decades. All of we very much worried about this, how it is possible to implicate the essence of food security definition, i.e. "*all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life*" (McCarthy et al. 2018). Till today more than 815 million people affected by malnutrition and every year more than five million children under the age of five decreased due to malnutrition-related causes (Prosekov and Ivanova 2018; World Food Day 2016a, b; ERS 2017). Efforts with different policies to cope with the situation are in action from all the nations, several international organisations around the globe. However, till we are far away from achieving the food security and if considering the real facts, it seems to somewhat impossible target. The challenging factors, responsible for food security of the twenty-first century, are summarised below:

4.2.1 Exponential Population Growth

In the developing courtiers, a linear correlation exists in higher fertility rate and the higher number of food-insecure people. This is the reason behind the inadequate nutritional status amongst the population in those areas. Study reveals, even fertility rates decline in Sub-Saharan Africa (area of highest population growth with the largest undernourished population), the projected population in this area may be doubled by 2050 (UNPD 2009). UN reports also predicted the current population of 7.3 billion may reach to 9.3 billion with continuous growth in 2050. Similarly, food demand may be doubled by 2030 in consequence of the increased population. Not only higher demand of the larger population for food but also its impact in the food supply, access, land fragmentation and other associated areas pointed out it as the main culprit for current food crisis (McCarthy et al. 2018).

4.2.2 Rapid Urbanisation

Researchers addressed the phenomenon of how rapid urbanisation becomes a significant cause of food insecurity. Urbanisation the "real people bomb" is an open event of urban dimensions of development, is now getting worldwide concern as half of the world's population residing in urban areas. Global urban population in 2014 is 53.6% of the total human population which is projected to become 67.2% by 2050 (UN 2014). Competition for land between agricultural use and urban settlement due to process of urbanisation, shifting food habit to grain-based to animal food and processed foodstuff is increasing day-by-day (Popkin and Nielsen 2003) and less buying capacity of major slum dwellers to meet the daily need of the food for all family members- all these affect the food access, supply and stability thereby resulting in food insecurity (Szabo 2016).

4.2.3 Increase in Dietary Demand

There is a projection of an increase in food demand lifted to 50% by 2030 and 110% by 2050 for rapid population expansion, urban development, and improved quality of life in most parts of the world. Tilman et al. (2011) in a study used income-dependent dietary choices and estimated that global demand for crop calories and crop protein will increase by 100% $\pm$ 11% and 110% $\pm$ 7% from 2005 to 2050, respectively. As the world experiences exponential demographic change, the demand for dairy products is expected to increase by up to 70% between 2000 and 2050 (Maggio et al. 2015) and for meat product, increase in demand (kg per person per year) will be 40% and 69% in higher and lower income countries between 2015 and 2050 (McCarthy et al. 2018), respectively.

4.2.4 Depleting Natural Resource

To meet up the need of enormous food and other goods for the ever-increasing population, the only base or prime requirements are land, water, minerals and energy which are considered mostly as finite and as depleting resources (Banerjee et al. 2020; Raj et al. 2020; Jhariya et al. 2019a, b). The whole world is experiencing loss of 20 million ha every year mostly from water and wind erosion, sand encroachment, salinisation, compaction, organic matter decline, beside urbanisation and industrial set up (Maggio et al. 2015; Zdruli et al. 2007). Secondly, if we look upon groundwater, another crucial natural resource is also depleting each day for over-drafting. It was also estimated that by 2025 potentially 180 million people would be affected by water problems (UNEP 2009). It is further a matter of grave concern in many Mediterranean countries where water balance will be predicted to worsen for demographic pressures, together with the economic advancement of non-agricultural sectors (Lacirignola et al. 2014; Meena et al. 2020b). Intensive agriculture in the limited land is mostly dependent on the massive application of fertilisers which are mostly relied upon either directly or indirectly in their production on renewable fossil fuel utilisation (Holden et al. 2018). Another matter of concern is that pollution from urbanisation, industrialisation, mining and related activities that further a cause of soil and water quality reduction can undercut both agricultural productivity and the safety of the food produced (Godfray and Garnett 2014).

4.2.5 Climate and Ecological Change

Erratic change in climatic parameters, i.e. so-called climate change is possibly the major environmental challenge in our time considered to be resultant of human activities through fossil fuel burning, deforestation and other practices that raise the concentration of atmospheric GHGs (Godfray and Garnett 2014). The report forecasted by IPCC, in their third assessment, says that earth's surface temperature will rise by 1.4 °C to 5.8 °C by the end of 2100. Not only temperature rise but erratic rainfall and other uncertainties of weather affect all together with the global ecosystems, water resources, food and health (Gornall et al. 2010). This impact is most worsen in the developed countries (like-Bangladesh, the Democratic Republic of the Congo, Ethiopia, India, Indonesia and Pakistan) where still rain-fed agriculture is considered to be the key strategy for maintaining the livelihood of millions of people (United Nations 2010). Though there is controversy exist in the impact of climate change in agricultural crop production, i.e. either it is good or bad. However, the majority of the scientist reflects in their research that finally, climate change will depict a negative impact on the overall productivity of future agriculture. For example, due to elevated temperature and sea-level, the production of winter rice will decline by 3% and 5% by 2030 and 2050s, respectively (Hossain et al. 2014). Climate change also responsible for changes in ecosystem as species shifting from one to another region for habitat fragmentation, invasive species introduction creates negative consequence in the stability of biodiversity. Livestock productivity will be negatively affected both from heat stress and indirectly from reduced quality of their food supply while the fishery sector will also be predicted to be a decline.

4.2.6 Infrastructural Shortage and its Inefficacy

Infrastructural shortage in terms of road, modern structure for crop production in a changing climate, précised irrigation facilities, mechanisation in every step of agriculture and lastly the storage structure to accommodate the considerable quantity of agriculture production are reported to pay attention immediately as a significant concern of present day's food insecurity (Selepe et al. 2014). The report says approximately one-quarter of total global food is lost each year, from harvesting and storage to wastage in the consumer's kitchen. In Africa, out of total food waste of a day (500 calories per person), only 5% are lost with the consumers while more than three-quarters is lost in agricultural production and faulty storage. In South and South-east Asia, more than 18% of all food is wasted than the amount projected to sufficient for feeding an extra 234 million people. Though it is already established that rural infrastructural development is the critical component of rural development and crucial for sustainable reduction of food insecurity (Ahemachena and Chakwizira 2013), but till there is negligence in implementing this aspect in policies of most of the developed countries what further a matter of agony for the global food security.

4.3 Footprints of Natural Resources

Footprints of natural resources are an emerging issue to talk about in present days across the globe. From the time of evolution, human civilisation solemnly depends on nature, particularly on natural resources. So, footprints of natural resources can be easily described as an assessment by which we can measure the dependence of humanity on natural resources (Wackernagel et al. 1997). It generally measures the number of natural resources required to produce goods and services to support different activities of the population. There are various types of footprints (ecological footprints, C footprints, N footprints, water footprints, environmental footprints, etc.) and these altogether helps in forecasting environmental condition overtime (Verones et al. 2017).

4.3.1 Types of Footprints

Worldwide, various types of footprints were recognised in supporting numerous activities of humanity. Different research articles also suggested that these set of footprints (highlighted in Fig. 4.1) were increasing social pressure into the globe. Here we are discussing some of the footprints of natural resources.

4.3.1.1 Environmental Footprints

Different components of the environment and their aggregative effect on the environment are calculated as environmental footprints. The essential components of a healthy environment are considered as air, water and ecosystem. Human-induced pollution has to signal towards an environmental threat. Therefore, measuring the environmental footprints and suggestive policy matters will help to build a proper mitigating strategy for the future generation.

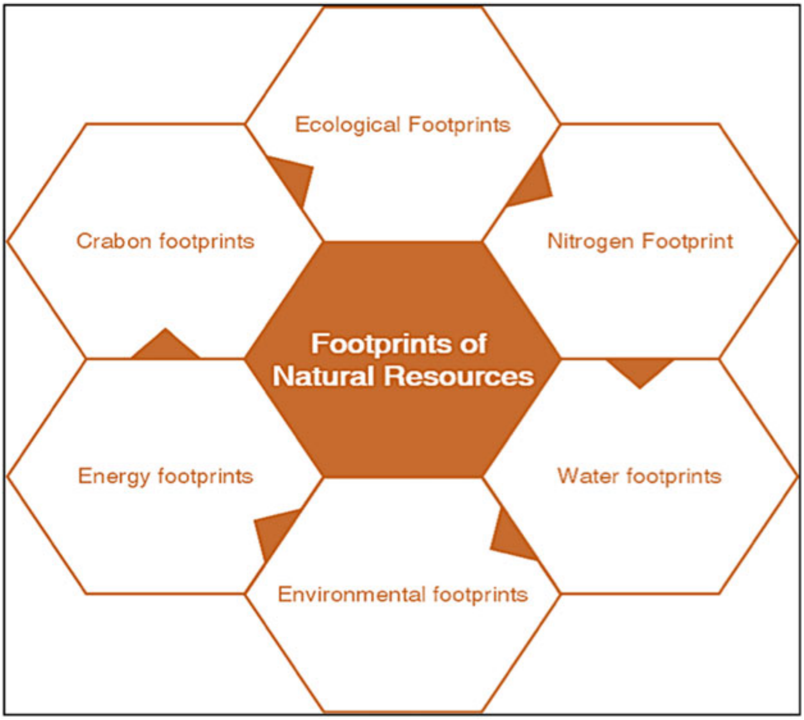

Fig. 4.1 Footprints of natural resources

4.3.1.2 Carbon Footprint

C footprint can be demarcated as the amount of emission occurred through CO_2 and other GHGs during a process or product cycle in a healthy ecology or environment. Recent studies suggested that C footprint is one of the significant indicators amongst the environmental protection indicators and the global warming context. CF is also considered as the greatest threat of the twenty-first century for climate change and enduring temperature hike in the atmosphere and oceans (Abbott 2008). Many researchers assumed that the concentrations of GHGs are increased in the atmosphere due to deforestation and changes in land-use practices, burning of soils, etc. Some GHGs, i.e., CO_2, CH_4, N_2O, hydro-chlorofluorocarbons (HCFCs) and ozone (O_3) were identified as a significant source for creating atmospheric effluence (World Meteorological Organization 2014). It is calculated that CO_2 is the essential human-induced GHG emitter among other gasses and contributing a share of 63% in total GHG emission into the atmosphere (World Meteorological Organization 2014).

It is predicted that the atmospheric temperature also breaks the increasing record in the coming 100 years (Staudt et al. 2008). This warming is also signalling towards drastic changes in sea levels, different ecosystems, glaciers melting, the quantity of precipitation, availability of freshwater and probable expansion of deserts on the globe (Gleick et al. 2014). Some other consequences may include a super hike in maximum temperature, and prolonged colder days along with the devastating change in the agricultural production system and infectious disease increase manifold, etc. Deterioration in public health, unusual flood and drought along with more intense hurricanes were some of the instances may also be included with global warming and climate change in coming decades (Staudt et al. 2008).

4.3.1.3 Nitrogen Footprints

Nitrogen is an indispensable element for life and production of all crops (Smil 1997). It is estimated in many types of research that N plays a significant role in crop production and a large amount of food material for ever-increasing population across the globe was supported by nitrogenous fertilisers (NFs) (Smil 2001). Besides, the raising of field crops needs NFs up to a great extent, but only a small amount is effectively utilised (Erisman et al. 2008). Human activities have been dramatically changed the world's N cycle. The amount of N within the environment has been increased globally since the nineteenth century due to excessive use of NFs (Galloway et al. 2008). It is also portrayed in research articles that worldwide, the main source of active N production is agriculture and solely contributes an amount of 80% to the global environment (Union of Concerned Scientists 2009).

Approximately, it is estimated that 80% of the total N lost is within the food production system and rest amount deployed before human consumption indeed can be mentioned as human waste. N deposition in air, soil and water has some destructive impact on human health and ecosystem also (Galloway et al. 2008). Deposition of N also signalling threats on various aspects like biodiversity reduction, reduction in the global N cycle, deteriorate quality water and considerable human health hazards (nausea, breath shortness, blue baby disease and some extent cancer (U.S. Environmental Protection Agency (EPA 2014; Vitousek et al. 1997). The widespread report on eutrophication of river water and bays, smog formation, ozone layer depletion in the upper atmosphere, formation of acid soils and global warming has been portrayed in numerous research articles across the globe due to deposition of atmospheric N (European Commission DG Environment News Alert Service 2012).

4.3.1.4 Energy Footprints

Worldwide, fundamental driving forces behind the huge energy demand for the service of humanity are rapid growth in population and income. As a result, increasing demand in energy supply coupled with the price hike of per unit energy prices is amongst the vital issues in today's world (Brandi et al. 2011). Besides, the use of natural resources (oil, natural gasses and coal) will increase day-by-day to provide uninterrupted energy supply for human welfare (British Petroleum 2013). Consequently, in a little while, this indiscriminate undermining of natural resources will exhaust the situation of energy supply from natural resources (Maggio and Cacciola 2012). Therefore, calculating energy footprints has immense importance to reduce the negative impact of C and N footprint.

4.3.1.5 Ecological Footprints

The ecological footprint has been defined by Wackernagel and Rees (1998) that the amount of biological capacity of the planet (earth) is to be needed for adequately nurturing the human population (Ewing et al. 2010). Many researchers and environmentalists suggested that the earth can carry a maximum population pressure of four million people (Motavalli 1999). But, currently, the world population exceeds the number of 7.2 million. It is estimated that the population will undoubtedly attain ten million, and after that get stabilised (Worldometers – Real Time World Statistics 2014).

Some researchers are pointed out that humankind had already occupied a large amount of bio-capacity with maintaining their sustenance in this globe during the first decade of this century (Ewing et al. 2010). Nevertheless, human races need 1.5 Earths for providing support to continue their consumption (Galli et al. 2014) has been discussed in different literatures about the threat related to global ecosystem degradation due to excess population pressure. To address these growing problems across the globe, ecological footprint is measured for assessing the demand of humankind from nature (Kitzes et al. 2007).

Ecological footprint has emerged as the primary measurement technique to identify the human needs from nature, but in recent, it is actively used as an indicator to measure the environmental sustainability (Wackernagel and Rees 1998). The ecological footprint generally measures the bioproductive space utilisation of humankind more appropriately the amount of space every individual will get to carry on its bioproductive activities (Ewing et al. 2010). The ecological footprint (in global hectare) measures demand human consumption places on the biosphere and it is actually depend on population and consumption level of the respective countries (Fig. 4.2).

The extent of ecological footprint is directly correlated with the C and N footprint. Globally various anthropogenic activities (agriculture, food processing, etc.) are highly associated C and N footprints, thus efficient management of C and N footprints can significantly reduce the global ecological footprint.

4.3.1.6 Water Footprints

The water footprint is measured to categorise the amount of freshwater availability on the earth surface as well as in groundwater. The quality and quantity of freshwater are deteriorating due to groundwater contamination, growth of population, hike in resource consumption and most important the climate change issues. Over the next decade, many research agencies estimated that two-thirds of the world's population would be suffering from chronic water crisis due to water pollution (Conserve Energy Future 2014). Therefore, evaluation of water footprints and strategies to minimise the pollution are the main priorities for sustainability. The reduction of water footprint up to a sustainable level can be feasible with a change in consumption patterns of the end-users and consumers (Ercin and Hoekstra 2014). Water is the most important input for any types of agricultural and food processing activities—from seed sowing to harvesting and processing of harvests to consumption. All these activities directly associated with C and N footprint and emissions of GHGs. Rice

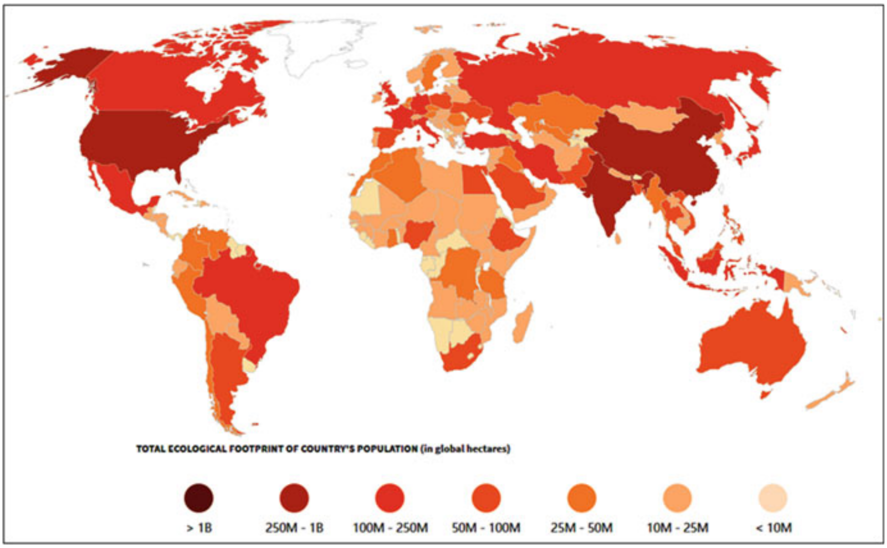

Fig. 4.2 Global ecological footprints by countries (in global hectare) (Data source: Ewing et al. 2010)

and wheat are the most important food grain crops for many countries—especially South Asian countries. This RWCS is the major contributor of GHGs for the agricultural sector with the highest water consumption (Prasad 2005). The global total water footprint for rice and wheat system was presented in Fig. 4.3. The lessening of water footprint not only reduces the C and N footprints but also helps to save the precious water resource.

4.4 Ecosystem Services Role in Footprints

Ecosystem services can be defined as the gifts and services generally the mankind obtained from nature, more specifically from a properly working ecosystem (MEA 2005). Such ecosystems generally include pasture ecosystem, aquatic ecosystem, agroecosystem, freshwater ecosystem, etc. These all afterwards contribute to food ecosystems. Ecosystem services can be separated into four distinct categories, i.e. provisioning services, regulating services, educational services and support services. First three services directly affect the people; supporting services are needed to maintain other services (Notte et al. 2017).

On the other hand, footprints of natural resources can be easily defined as the amount of healthy environment is required to produce the goods and services for supporting the lifestyle of humankind as well as organisms on earth (Belton et al. 2009). Footprints of natural resources generally described as an assessment by which we can measure the dependence of humankind on natural resources (Wackernagel et al. 1997). There are various types of footprints, i.e. ecological footprints, C

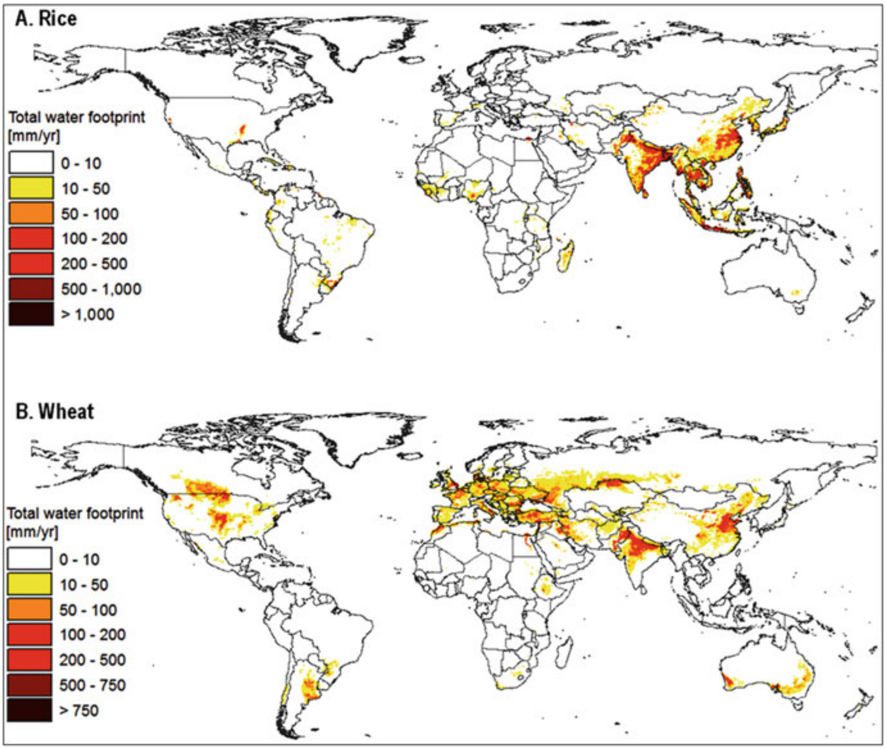

Fig. 4.3 The global total water footprint (mm year^{-1}) by the countries for the production of (**a**) rice and (**b**) wheat (Data source: Mekonnen and Hoekstra 2011)

footprints, N footprints, water footprints, environmental footprints, etc. These altogether help in forecasting environmental condition overtime or more specifically, the deployment and restoration of natural resource base over time (Verones et al. 2017).

In-depth, ecological footprints go through the dimension of activities like area for biologically productive land and the freshwater requirement for producing of consumable goods coupled with the assimilation of generated wastes for calculating the impact on human (Rubin et al. 2002). Environmental components, along with healthy ecology, had been serving humanity since its evolution (Dick et al. 2011). Human activities like biological production, production of goods and services, luxuries in lifestyle maintained through using of different ecosystem services across the globe. Besides, the overexploitation of these ecosystem services tends to limit these natural resources for human welfare (Veach et al. 2017). It is reported from different articles that the extinction rates of these limited resources and biodiversity proneness across the globe decrease many folds due to indiscriminate undermining and unscrupulous utilisation (Pimm et al. 2014). This over-exploitation of ecosystem services drove some negative impacts more especially footprints to the environment (Brown et al. 2013) and many of instances we can easily observe from Fig. 4.4.

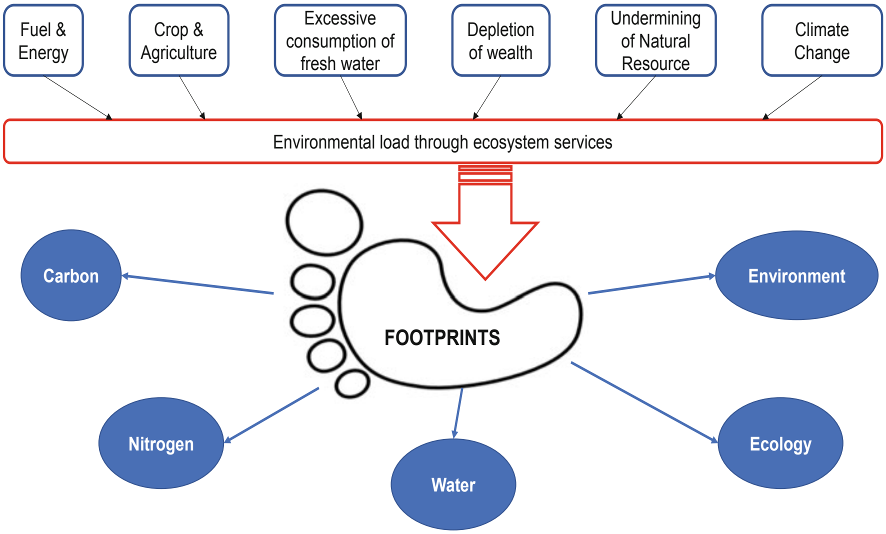

Fig. 4.4 Footprints of natural resources and ecosystem services

4.4.1 Footprints of Agricultural Practices on Ecosystem Services

It is estimated from different studies that the world population will grow four times in the twentieth century and projected over nine billion from present statistics of seven billion people by 2050. However, already a vast population in African and south-east Asian countries are still suffering from malnutrition and hunger (Kanianska 2016). Besides, agricultural ecosystem covers nearly 40% of global surface area and covers the food demand for an ever-increasing population. Growth in human population coupled with boosting food grain production necessitates in altering wild land to agriculture (Kanianska 2016). Last 100 years, there are several evidences in many research articles which pointed out the land conversion and resource depletion due to massive agricultural activities across the globe (Slaughter 2012). Besides, human influence in case of land alteration and natural resource utilisation is accelerating day-by-day to meet up the food demand of an ever-increasing population (Alonso-Pérez et al. 2003). This increasing intensity on agriculture not only generates pressure on land resources but also producing a list of negative impact on the environment (Kanianska 2016). These negative impacts due to ecosystem services in agriculture termed as footprints in a single word. Summation of these undersized factors altogether makes agriculture a prioritised sector in terms of environmental policymaking.

In developing countries, a high proportion of agricultural works found in rural areas. More than 3 billion people across the globe, serving agriculture as their primary occupation, and 2.5 billion among them are maintaining their livelihood status from agriculture. Last 3 to 4 decades of the twentieth century, intensification in agriculture has been seen across the globe (Tilman et al. 2009). Uses of NFs coupled with high-yielding varieties were used indiscriminately to boosting up the production. Unscientific practices in livestock rearing also reported from different article suggested that the intensification in agriculture and livestock rearing is connected with an escalating discharge of greenhouse gasses (CO_2, CH_4, N_2O and ammonia) on the environment due to improper management in these sectors (Kanianska 2016; Paustian et al. 2001). It is accounted that agriculture contributes about 58% and 47% of the total emission of N_2O and CH_4, respectively. Statistics on GHG emission from 2000 to 2010 reveals that the emission from agriculture was also increasing in the current scenario. It is also expected that annual GHG emission from agricultural activities will be increasing in the coming days due to the growing demand for food production (Smith et al. 2014). However, newer promising technologies and improved practices may reduce the amount of emission from farming venture and livestock rearing also (Kanianska 2016).

Soil contamination is one of the major problems along with soil erosion in agriculture. Substances like cadmium, mineral phosphate fertilisers, heavy metals or pesticide components when applied into the soil, it gets contaminated. Soil erosion is also a major problem, mostly created by man and every year, an amount of ten million ha of agricultural land has been lost due to soil erosion (EEA J 2012). Since the last five decades, compaction of agricultural soils due to inappropriate management strategy has been found as a serious issue in environmental degradation (Pimentel and Burgess 2013). Overuse of agricultural machinery increase the cropping intensity, and as a result short duration crops are generally grown and inappropriate soil management is some of the instances (Hamza and Anderson 2005).

It is portrayed in different literatures that agricultural activities are one of the main reasons behind water pollution. A high amount of nitrate and phosphate fertilisers drained in streams and lakes, rivers and increase pollution level in these natural water tanks. Nitrate is the most common chemical contaminant that can be found in the world's aquifers. Mean nitrate level in water bodies also increases up to 36% since 1990 also reported in many articles (Amore 2012). Contamination by pesticides is widespread and in different forms. Surface water contaminated through runoff from treated land or treated area, whereas groundwater contamination is mainly through seepage loss and groundwater recharge (Mateo-Sagasta and Zadeh 2018).

Agriculture releases a huge amount of GHGs and emitted ammonia to the atmosphere. It is also the largest user of freshwater resources across the globe. Besides, intensifying agricultural practices accelerating land degradation rates, soil and water deterioration as well as too some extent lends a hand for climate change. The site-specific negative impact on the environment has been arisen but also has an impact at local to global levels. Changes in the traditional agricultural system, conservation agriculture and modification in agricultural activities have an impact on climate change, C sequestration and losses of biodiversity proneness. From ancient times, humanity depends on agriculture which has an immense impact on natural systems and ecosystem services also.

4.5 Carbon and Nitrogen Footprints in Agricultural Systems

The total emission of greenhouse gasses (GHGs) has increased many folds in the last three decades. GHG emission from the agricultural sector is nearly one-fourth of total GHG emission globally which largely depends on several factors (Fig. 4.5). Change in land use policy, modernisation in agricultural practices, mechanisation of agricultural operation are some of the instances to be incorporated (IPCC 2014a, b). Since 1990 to 2014, Food and Agriculture Organization has estimated that the increase in global population by 36% followed by expansion in agricultural land 42.5% and 1.1% hike in GHG emission due to agriculture, forestry and increase in land use under global scenario (FAO 2015). Nevertheless, in the case of South-East Asian countries, particularly in India population has increased by 45.8% along with 50.8% increase in agricultural land and 11.8% scramble jump in GHG emission (FAO 2015). Further detailed information regarding GHG emission from agriculture sector portrayed that only Asian countries contribute 44% of total GHG emission from agriculture after that America, Africa, Europe and Oceania take place (FAO 2014).

4.5.1 Total Energy

Total energy consumed in farming is the summation of numerous works, i.e., planting, cultivation of lands, intercultural operation, fertiliser application, harvesting, etc. It is reported from a research investigation on sunflower carried out in Iran that most of the renewable energy consumed (79.03%) in agricultural production undergoes within the use of diesel, pesticides, fertilisers, electricity and machinery. Rest of the part (20.97%) used as human labour, planting of seeds and

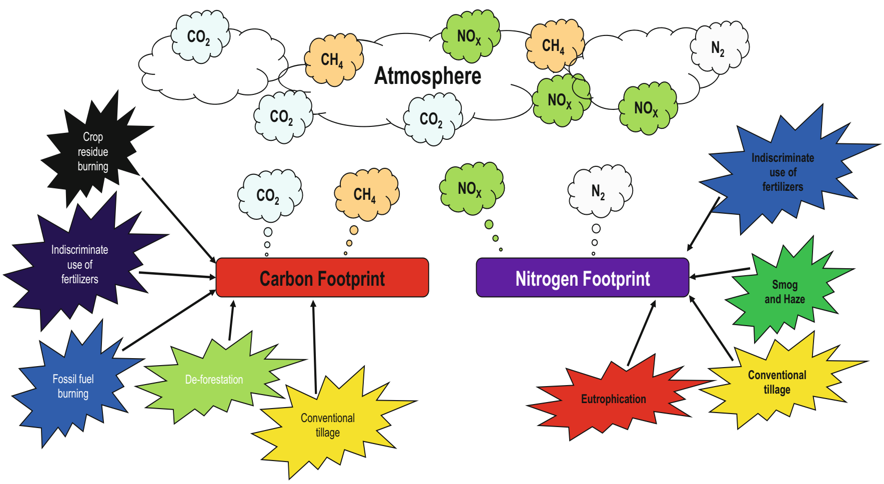

Fig. 4.5 Carbon and nitrogen footprint from the agricultural sector

irrigation purpose (Yousefi et al. 2017). In the year 2010, it is calculated that an amount of 785 million tons of CO_2 was emitted from agricultural production system through an abrupt use of fossil fuel and its transportation (FAO 2014). Different studies also suggested that in semi-arid areas the contribution of input energies only 8% with a comparable statistics of 82% from other agricultural inputs such as pesticides and fertilisers sharing an amount of 9% and 82%, respectively (Devakumar et al. 2018). Another study in Australia estimated GHG emission in cotton cultivation that most of the emission takes place during on-farm processes (48.4%), after that post-farm processes, i.e. cotton seed drying, ginning and packaging contribute 26.2% emission of GHG. Rest 25.3% occurs during pre-farm processes like use of inputs for farming (Hedayati et al. 2019).

4.5.2 Machinery

World population is increasing at an exponential rate and to feed this ever-increasing population, boosting food production is a necessity (FAO 2015). Besides, shrinkage in agricultural land evokes a rising demand for farm machinery in farming operations (FAO 2015). The energy supplied to drive the machinery for crop production to harvesting is in the form of fossil fuel, and different studies have suggested that these fossil fuels in turns contributed to GHG emission and increase the level of C footprint from agriculture (Yousefi et al. 2017). C footprint is estimated in cotton production suggested that up to 7% of the total emission in agriculture takes place from the use of farm machinery (Hedayati et al. 2019).

4.5.3 Diesel

Diesel is used as fuel purpose before, during and after farming activities and considering as a great source of GHG emission. Diesel consumption in farming venture contributes up to 12.24% C footprint among other activities related to farming (Yousefi et al. 2017).

4.5.4 Chemicals

Application of chemical fertilisers in agriculture contributes an amount of 13% of total agricultural GHG emission (FAO 2014). In a research work carried out in India, it was reported that the N fertilisers contributed almost 89% of total C footprint but the share of potassium (2%) and phosphorus (4%) in the total C footprint. Contribution of pesticide in C footprint is calculated as near about 2% (Sah and Devakumar 2018).

4.5.5 Crops

Crop wise nutrient management strategies had an inconsistent effect on C footprint in different crop species. It is reported in many research articles that rice is one of the major input-intensive crops. Therefore, GHG emission from rice field is reported as higher than other crops (Rao et al. 2019). C footprint of oilseed and commercial crops (30% and 29%, respectively) in comparison with legumes and cereals (16% and 25%, respectively) is also reported as much higher (Devakumar et al. 2018). Crops have lower water availability and lowest C footprint. Millet is one of the examples of the lowest C footprint due to the lower energy requirement (Rao et al. 2019).

4.5.6 Crop Residue Decomposition

Rice–wheat cropping system has produced the largest amount of crop residues among all crops produced in the agricultural production scenario. It is estimated that this RWCS shared one-fourth amount of total residue produced in the agricultural production system (Sarkar et al. 1999). Rice residue management is considered as laborious task and burnt in fields to reduce the labour as well as time. Here is the consequence of the enhancement of GHG emission. Several advantages of residue incorporation are also reported in different research articles. Properly incorporation of residue in crop fields helps in conserving soil moisture, maintaining soil organic carbon level, regulating soil temperature and suppressing weed growth in RWCS (Bhatt and Khera 2006; Kukal et al. 2014). It is also reported that alternate wetting and drying irrigation method along with the incorporation of crop residues in RWCS is an efficient strategy to reduce global warming potential (Haque et al. 2016).

4.5.7 Inorganic Nitrogen Fertiliser Used in Crop Production

N is the essential plant nutrients responsible for vegetative and reproductive growth and yield of crops. An increased amount of N fertiliser, boosting crop production is proven in different articles (Spiertz 2010). It is reported in numerous research study that N fertilisers used in cereal production contribute the greatest share of C footprint (averaging approximately up to 65%) (Gan et al. 2011). Many scientists have discussed the intensity of GHG emission due to excess application of N fertilisers. However, the intensity of emission mostly associated with the proportion of precipitation on the land surface along with evapotranspiration at the time of N fertiliser application (Gregorich et al. 2005).

4.6 Carbon and Nitrogen Footprints Calculation and Equations (Rice–wheat System)

C and N are the most important constituents for any living being of the world. Recently, assessment of C footprint and N footprint (NF) in the crop production system has gained extensive popularity, as it helps in evaluating environmental superiority (Tjandra et al. 2016). The energy consumed in different management practices contributes to global warming through emission of GHGs, mainly CO_2, CH_4 and N_2O (Ntinas et al. 2017; Yadav et al. 2017). According to Chen et al. (2011), the C footprint may be described as the total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or is accumulated over the life stages of a product. The various steps involved in estimating the C footprint are presented in Fig. 4.6.

The first step was to define goal and scope by selecting product or activity, defining the purpose of study, and then fixing the boundary accordingly. After defining the goal, inventory analysis is essential. These steps involved to identify all relevant inputs and outputs and qualification of their GHGs emission potentials. Researchers from different parts of the world calculated many GHG emission potentials and kg CO_2-equivalent of all relevant inputs and outputs used in the crop production system. The different steps and activities involved in the inventory analysis of agriculture services have been graphically presented in Fig. 4.7. After inventory analysis, data were further analysed to assess the environmental impacts of various impact analysis. Furthermore, finally, these values were used for judgment to assess the objectives of the study or further improvement of the CF calculations.

The rice–wheat system is one of the most important cropping systems for SA countries. This system was adopted in almost 22.4 million ha throughout the globe under diverse agro-climatic and management practices (Prasad 2005). The GHGs emission from most common farm operations under the rice–wheat system (tillage, sowing, planting, fertilisers and agrochemicals application, harvest, etc.) was generally computed with the corresponding emission coefficients of inputs (Table 4.1).

The environmental impacts of fertilisation practices were assessed by estimating the CF on spatial and yield-scale (Pratibha et al. 2016; IPCC 2013). The N_2O

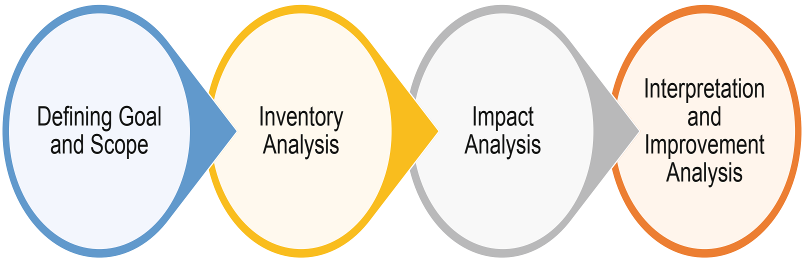

Fig. 4.6 Steps in carbon footprint analysis

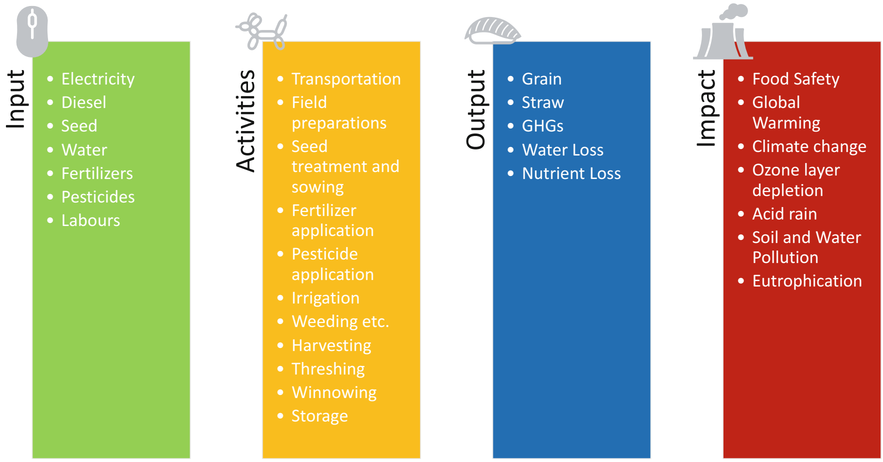

Fig. 4.7 Inventory analysis of agriculture sector

Table 4.1 Carbon dioxide equivalent values for selected inputs relevant to the RWCS

Inputs	Unit	GHG coefficient (kg CO_2eq/unit)	References
Machinery	MJ	0.071	Dyer and Desjardins (2006)
Fuel			
Diesel	L	2.76	
Fertiliser			
N	Kg N	1.3	Lal (2004); Pathak and Wassmann (2007)
P_2O_5	Kg P_2O_5	0.2	
K_2O	Kg K_2O	0.2	
Chemicals			
Herbicides	kg	5.1	Lal (2004), Pathak and Wassmann (2007)

MJ Mega-Joule, *L* Litre

emission from applied N fertiliser, manure and crop residue was calculated by the following equation (Tubiello et al. 2015).

$$N_2O \text{ emission} = \text{N applied through synthetic fertiliser, manure, and crop residues} \times \text{EFI} \times 44/28 \quad (4.1)$$

where N_2O emissions = N_2O emissions from synthetic N/manure, crop residue additions to the managed soils, kg N_2O /year; N = Consumption of N from fertilisers, manure, crop residue, etc., kg N input/year; EF_1 = Emission factor 0.01 for N_2O emissions from N inputs, kg $N_2O - N$/kg N input.

Global warming potential (GWP) computed with data from CO_2 and N_2O emission by fouling using equations as suggested by Pandey and Agrawal (2014):

$$\text{Global Warming Potential (GWP)} = (\text{emission of } N_2O \times 265) + \text{emssion of } CO_2$$

$$CFs = \sum_{i=1}^{n} GWP \tag{4.2}$$

where CF is the spatial C footprint (kg CO_2-e ha^{-1}).

For low-land rice condition (under prolonged submerged condition) where CH_4 emission is widespread, (Xu et al. 2013) proposed another equation to estimate the GWP as follows:

$$GWP = CO_2 + 25CH_4 + 298N_2O \tag{4.3}$$

Finally, CF of rice and wheat crop is calculated by the following equations as suggested by (Mittal et al. 2018).

$$CF_{rice} = GWP_{rice}(CO_{2\ eq.}) / \text{Rice yield (kg)} \tag{4.4}$$

$$CF_{wheat} = GWP_{wheat}(CO_{2\ eq.}) / \text{Wheat yield (kg)} \tag{4.5}$$

Synthetic nitrogenous fertilisers, widely applied in rice–wheat ecosystems, are the main sources of NF (Xue et al. 2016). Excess application of these high analysed crops does not fully utilise in fertilisers (Nr, and all N forms except N_2); this utilised Nr is lost into the environment (air, water, land, etc.). N footprint was used to describe how N was lost to the environment and its resulting impacts due to consumer and producers consumption behaviour (Leach et al. 2017). Under late and early sown rice-ecosystem, Xue et al. (2016) calculated the NF in detail as follows:

$$NF_y = \frac{NE_{total}}{Y} \tag{4.6}$$

where NFy is the total NF for each kg of rice grain yield (g N-eq kg^{-1} ha^{-1} $year^{-1}$).

Xue et al. (2016) also calculated NE_{total} (g N-eq kg^{-1} ha^{-1} $year^{-1}$) according to the following equations:

$$NE_{total} = NE_{input} + NV_{NH_3} + NE_{N_2O} + NL_{NO_3} + NL_{NH_4^+} \tag{4.7}$$

$$NE_{input} = \sum_{m} Q_{used_m} \times \chi m \tag{4.8}$$

NE_{input} is the indirect total amount of Nr emissions related with agricultural input applications acquired multiplying use amount of agricultural inputs (Q_{used_m}) and corresponding emission factor (χm). NV_{NH_3}, NE_{N_2O}, NL_{NO_3}, $NL_{NH_4^+}$ are the ammonia volatilisation, N_2O emission, NO_3 and NH_4^+ leaching, respectively, from the submersed or aerobic rice field at different growing stages. These losses of Nr can be calculated directly or may be estimated by different mathematical equations (Xue et al. 2016).

Nowadays, different software and tools are based on different mathematical and biophysical algorithms to assess and qualify the C and N impacts for the crops of different cropping systems (Lal 2004; Foster et al. 2008; Zhao et al. 2017). These tools/models can be effectively utilised for estimating the CF and NF with minimum input data. The Cool Farm Tool (CFT®), a computer software-based farm-level GHGs emission calculator, used to estimate the yield-scaled GHGs emissions (Whittaker et al. 2013; Hillier et al. 2011). This tool has been successfully validated for wheat (Sapkota et al. 2014) and rice-based cropping systems in SA itself (Ray et al. 2018a, b). CFT calculates emission of CO_2, N_2O and CH_4 in kg ha^{-1} basis from different agricultural and allied sectors (crop, livestock) associated with diverse management factors.

4.7 Reduce Carbon and Nitrogen Footprints for Sustainable Food Production Systems

Global warming and climate change scenario across the globe indicates C footprint as an essential tool for protecting the environment (Wiedmann and Minx 2008). C footprint is also considered as a major threat of the twenty-first century for increasing atmospheric temperature and climate change (Abbott 2008). Different research articles have suggested numerous methods for reducing C footprints from crop fields and agricultural operations (Baldwin 2006). This CFP can be measured by considering the indicators of Global Warming Potential. Global Warming Potential includes the amount of GHGs contributes to global warming as well as in climate change within a particular time frame (usually 100 years) (IPCC 2009). In the last three decades, the average temperature across the globe is increasing constantly (Staudt et al. 2008). This warming situation will create a devastating situation across the globe and the earth will become a desert if we are not ready to mitigate C footprints emitted from agricultural operations soon (Gleick et al. 2014). Therefore, we must focus on numerous sources of CO_2 emission and find out alternative strategies to reduced C footprints to save our environment (Benedetto and Klemeš 2009). Different tools can be used to assess C footprint loads on the environment and must be helped in reducing human inducing emission activities in future (Jones and Kammen 2011).

N footprint is considered as the amount of reactive nitrogen released from numerous human activities across the globe (Sevcik 2010). It is estimated in many researches that nitrogen plays a significant role in crop production, and a large amount of food material for the ever-increasing population across the globe was supported by NFs (Smil 2001). Besides, the raising of field crops needs NFs up to a great extent, but only a small amount is effectively utilised (Erisman et al. 2008). It is reported in different reputed scientific articles that NFP is one of the major causes of N imbalance in the N cycle. Besides excess N released from different activities increases the incidents of biodiversity loss, acid rains, etc. Excess N into the global ecosystem caused eutrophication and enhanced greenhouse effects are some of the instances creating a negative impact on the environment.

It is portrayed in different research articles that CFP coupled with NFP has been increasing significantly due to human activities from the last century. Afforestation, along with the burning of coal, natural gasses and crude oil are some of the instances of CFP association. Whereas NFP increases when artificially N is applied in the crop field, leaching of manure, planting of legumes, etc. (Bakshi 2011). CO_2 emission is mainly the cause of global warming and climate change. Nevertheless, in the case of NPF, excessive uses of N fertilisers lead to groundwater contamination, eutrophication of surface water. In severe cases, emission of nitrous oxide leads towards smog, acid rain and climate change. Both CFP and NFP have created a negative impact on the environment and biodiversity also (Sevcik 2010).

4.7.1 Strategies to Reduce Carbon and Nitrogen Footprints in Rice–Wheat Cropping Systems

Rice–Wheat Cropping System (RWCS) has been considering as world's largest cropping system and input-intensive (water, labour, capital). Due to resource declination, this cropping system also considered as less profitable (Bhatt et al. 2016). Though this cropping system plays a significant role in securing the food grains for a mass population but in many articles potential threat from this cropping system due to GHG emission and risk related to climate change has been reported (Gupta et al. 2016). Rice fields submerged with stagnant water are reported as the highly budding source of methane (CH_4) and on the other hand use of NFs in waterlogged condition mainly helps in formulating nitrous oxide (N_2O) in fertilised soils (Bhatia et al. 2012). Researches on CFP and NFP have been suggested that fertiliser application in RWCS not only possess a major source of N_2O emission but also possess a major threat from CO_2 and CH_4 emission also (IPCC 2007). Tillage/puddling operations in the rice field for proper soil management are mostly responsible for CO_2 emission. Soil aggregates are broken in tillage operations and increase the level of oxygen supply into the soil (Doran 1980). It is reported from different articles that biological C decomposed in crop fields was released as CO_2 after repeated tillage operations take place in rice fields (Chakrabarti et al. 2015). Fuels generally used for numerous operations in rice farming and burning of crop residues also contribute a considerable amount of CO_2 on environment. Different studies also suggested that not only CO_2 but also CH_4 and N_2O emit from rice fields due to crop residue burning. These GHGs also contribute a share of 91.6% of total emission from rice fields globally (Jain et al. 2014). South-East Asian countries generally followed the RWCS cropping system traditionally are playing an important role in GHG emission from rice fields.

Conservation agriculture (CA) based tillage practices in rice–wheat cropping system in the one hand enhance the yield parameters, on the other hand, properly maintain the C sustainability index (Jat et al. 2011). Conservation tillage has been leading towards the enrichment of organic C into the soil (Lal and Bruce 1999). Zero tillage wheat is a proven technology where the earlier crop residues not only helps in input saving but reduces GHGs emission along with enhanced soil C stock (Erenstein and Laxmi 2008; Mileusnić et al. 2010; Abdalla et al. 2013). It is also reported from different studies that the intensity of GHGs emission is efficiently low in zero tilled wheat followed by direct-seeded rice in place of conventionally tilled wheat followed by transplanted rice (Gupta et al. 2016). Besides, excessive application of chemical fertilisers enhanced the release amount of N_2O as well as CO_2 and CH_4. These include environmental load and create a great impact on global warming (IPCC 2007). Therefore, new techniques and strategies are needed for applying chemical fertiliser by reducing GHG emission and boosting crop production. It is reported in different studies that application of urea-based on leaf colour chart can drastically reduce N_2O emission from RWCS (Bhatia et al. 2012). Site-specific nutrient management in RWCS has been proven as an efficient technique in reducing nutrient loss and effective use of fertilisers than the conventional one (Wang et al. 2001). Besides, site-specific nutrient management reduces the amount of GHG emission (Dobermann and Fairhurst 2002). Soil test based fertiliser application replacing summer fallow with grain legumes in RWCS can also be lowering the GHG emission from crop fields (Gan et al. 2014). RWCS has been producing a huge amount of residues, and it is estimated as one-fourth of the total residue produced from agricultural operations (Sarkar et al. 1999). Rice residue management is considered as laborious task and burnt in fields to reduce the labour as well as time. Here is the consequence of the enhancement of GHG emission. Residue incorporation in crop fields is one of the easiest techniques to moisture retention in soil, side by side suppressing weed population and soil temperature regulation (Bhatt and Khera 2006; Kukal et al. 2014). It is also reported that alternate wetting and drying irrigation method along with the incorporation of crop residues in RWCS is an efficient strategy to reduce global warming potential (Haque et al. 2016).

4.8 Carbon and Nitrogen Footprints Management through Best Management Practices

Reduction of C and N footprints in RWCS is one of the main challenges of the present day's agriculture systems. Modern input-intensive agricultural practices are always creating numbers of environmental problems. Current energy-intensive crop management practices very often led to CO_2 and N_2O emissions that contribute to C and N footprints. Hence, effective use through natural resource management in RCWCS would minimise environmental hazards in an economically sustainable

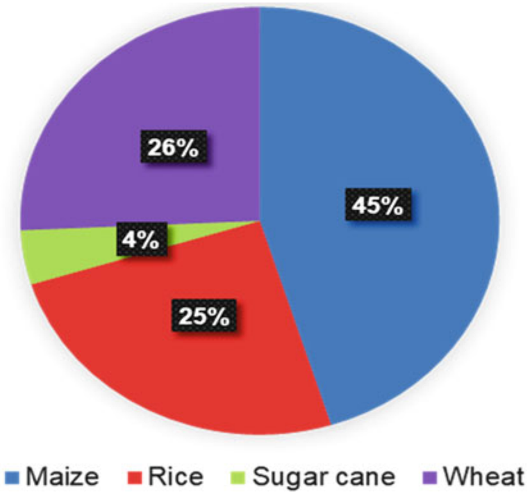

Fig. 4.8 Emissions of total methane and nitrous oxide ($CO_{2\text{-eq}}$ in Gigagrams) by different crops from the on-site combustion of crop residues (average data of 1990–2017) (Data source: FAOSTAT 2019)

production system. So, the adoption of best management practices for the reduction of C and N footprints is essential.

Over the last few decades, C footprints have become an essential indicator for environmental protection (Wiedmann and Minx 2008). C footprint is also considered as the greatest threat of the twenty-first century for climate change and enduring temperature hike in earth's atmosphere and oceans (Abbott 2008). Emission of total CH_4 and N_2O by different crops globally is presented in Fig. 4.8. Maize solely contributes maximum 45% of these GHGs emission followed by wheat, rice and sugarcane with a share of 26%, 25% and 5%, respectively. Burning of in-situ crop residue is one of the major contributors of GHGs and large counties like China, India and the USA are the major contributor of the GHGs (Fig. 4.9).

4.8.1 Reduction of Carbon Footprint

4.8.1.1 Mitigation of Greenhouse Gases Emissions

Tillage operations for land and proper soil management mostly show the way of CO_2 emission from crop fields. Soil aggregates are broken in tillage operations and increase the level of oxygen supply into the soil (Doran 1980). It is reported from different articles that biological C decomposed in crop fields was released as CO_2 after repeated tillage operations take place (Chakrabarti et al. 2015). Conservation agriculture (CA) based tillage practices in rice–wheat cropping system in the one hand enhance the yield parameters, on the other hand, properly maintain the C sustainability index (Jat et al. 2011). Conservation tillage has been leading towards the enrichment of organic C into the soil (Lal and Bruce 1999). Zero tillage wheat is a proven technology where the earlier crop residues not only helps in input saving but reduces GHG emission along with enhanced soil C stock (Erenstein and Laxmi 2008; Mileusnić et al. 2010; Abdalla et al. 2013).

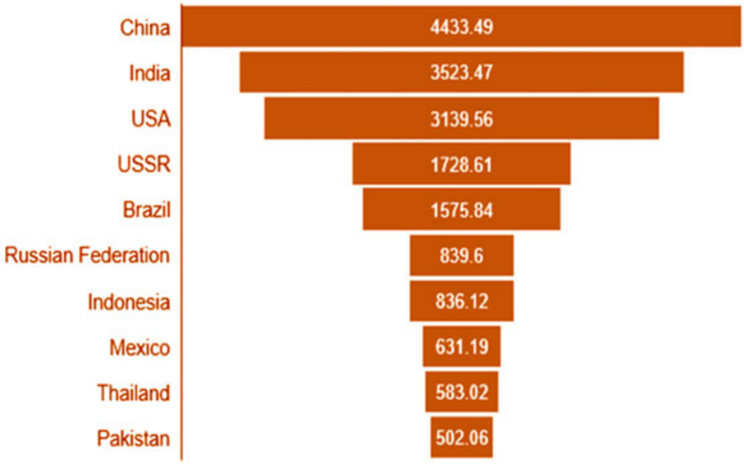

Fig. 4.9 Emissions of total methane and nitrous oxide ($CO_{2\text{-eq}}$ in Gigagrams) from the on-site combustion of crop residues from leading emitter countries (average data of 1990–2017) (Source: FAOSTAT 2019)

Burning of crop residues also contribute a good amount of CO_2 on the environment. Different studies also suggested that CO_2 and CH_4 emit from crop fields due to crop residue burning. Residue management in rice is considered as a laborious task and burnt in fields to reduce the labour as well as time. Here is the consequence of the enhancement of GHGs emission. Residue incorporation in crop fields is one of the easiest techniques to moisture retention in soil, side by side suppressing weed population and soil temperature regulation (Bhatt and Khera 2006; Kukal et al. 2014). It is also reported that alternate wetting and drying irrigation method along with the incorporation of crop residues in RWCS is an efficient strategy to reduce global warming potential (Haque et al. 2016).

Besides, excessive application of chemical fertilisers enhanced the release amount of CO_2 and CH_4. These include the environmental load and create a great impact on global warming (IPCC 2007). Therefore, new techniques and strategies are needed for applying chemical fertiliser by reducing GHG emission and boosting crop production. It is reported in different studies that application of urea based on leaf colour chart can drastically reduce GHG emission from agricultural fields (Bhatia et al. 2012). Site-specific nutrient management in rice–wheat cropping system has been proven as an efficient technique in reducing nutrient loss and effective use of fertilisers than the conventional one (Wang et al. 2001). Besides, site-specific nutrient management reduces the amount of GHG emission (Dobermann and Fairhurst 2002).

4.8.1.2 Increasing Carbon Sequestration

Capturing and storing atmospheric CO_2 in different stable forms are known as C sequestration. It is the most potent method for reducing the atmospheric CO_2 load and reduction of global climate change and CF. Researchers from the different domains already been demonstrated several techniques and strategies for CS in agriculture and non-agriculture aspects (Zhang et al. 2014; Kane 2015). The agriculture sector is one of the major contributors of the atmospheric CO_2 through enteric fermentation, CH_4 emission, residue burning, etc. Soils are the most potential C sequester for the agriculture sector as all agricultural activities directly or indirectly depend on soil (Kane 2015). As agriculture system itself is a soil disturbing process, the primary focus for CS should be confined to maintain soil C pool and C storage. These can be achieved by decreasing the level of soil disturbance, i.e. adoption of CA, reduced tillage and no-tillage, etc., the increment of soil cover by plants and increasing the mass inputs in soil (plant and animal). Soil microbes play a crucial role to maintain the soil biological activity and soil biomass C (Nayak et al. 2019), therefore maintaining soil microbial diversity and abundance is utmost importance for proper CS.

4.8.2 Reduction of Nitrogen Footprint

4.8.2.1 Balanced application of Nitrogenous fertilisers

Nitrogen is the essential plant nutrient responsible for vegetative and reproductive growth and yield of crops. It is a proven fact that increased doses of N strongly enhanced the crop growth and yielded up to a certain point, but after that, it declined due to poor N use efficiency (Spiertz 2010; Li et al. 2014) earlier opined that optimum N application has a crucial role in getting the maximum achievable potential yield. Nevertheless, the use efficiency of the high analysed NFs varied greatly due to the cropping systems, choice of cultivars, growing ecology as well as management practices. In present days, the N use efficiency under RWCS is around 33% irrespective of cultivar and crop management (Sharma and Bali 2017). Rest number of NFs lost in the environment and causing NF in different ways. The estimated GHGs emitted by the significant South Asian countries from synthetic NFs have been presented in Table 4.2. From this data, it was clear that GHGs emissions are directly proportional to the amount of synthetic fertiliser used and amongst the SA counties, India is the major GHGs emitter followed by Bangladesh and Pakistan.

For decades, investigators have endeavoured to develop various approaches to assess optimal and balanced N application rates to unravel the economic and environmental complications associated with over-fertilisation. Such methods include soil-test-based nutrient supply (Russell et al. 2006), plant-analysis-based fertilisation techniques (Olfs et al. 2005), chlorophyll-meter and green seeker based N fertilisation (Huang et al. 2008), farmers' knowledge-based N fertilisation (Cao et al. 2009), response-models-based N rate (Cerrato and Blackmer 1990) and ecologically ideal N fertilisation method (Chen et al. 2011). Dobermann et al. (2003) firstly suggested that managing the location and season-specific variability in nutrient supply was the key strategy to overcome the current mismatch of fertiliser rates and crop nutrient demand. The site-specific nutrient management (SSNM), a plant-based approach to address nutrient differences that exists within/between fields

Table 4.2 GHGs emissions from synthetic NFs from major South Asian countries

Countries	Agricultural use in nutrients ($\times 10^3$ tonne)	Direct emissions CO_2^-eq (gigagrams)	Direct emissions of N_2O* (gigagrams)	Emissions of CO_2^-eq (gigagrams)	Emissions of N_2O (gigagrams)	Indirect emissions (gigagrams)*			
						CO_2^-eq	N_2O leaching	N_2O volatilisation	N_2O emissions
Afghanistan	140.78	685.78	2.21	908.66	2.93	222.88	0.50	0.22	0.72
Bangladesh	1240.44	6042.71	19.49	8006.60	25.83	1963.88	4.39	1.95	6.34
Bhutan	0.79	3.86	0.01	5.11	0.02	1.25	0.00	0.00	0.00
India	16959.30	82616.02	266.50	109466.22	353.12	26850.21	59.96	26.65	86.61
Iran	564.91	2751.93	8.88	3646.30	11.76	894.38	2.00	0.89	2.89
Maldives	0.35	1.71	0.01	2.26	0.01	0.55	0.00	0.00	0.00
Nepal	91.63	446.39	1.44	591.46	1.91	145.08	0.32	0.14	0.47
Pakistan	3446.92	16791.43	54.17	22248.65	71.77	5457.22	12.19	5.42	17.60
Sri Lanka	109.73	534.54	1.72	708.27	2.28	173.73	0.39	0.17	0.56

The direct emissions of N_2O are produced by microbial processes of nitrification and de-nitrification taking place on the addition site and the indirect emissions after volatilisation/re-deposition and leaching processes. They obtained from the various source of FAOSTAT emissions database (FAOSAT 2019) computed following the protocols of Tier 1 IPCC 2006 Guidelines for National GHG Inventories (http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html) by making adjustments in the nutrient application, is considered as a most effective way to reduce the NF by most judicious and optimum use of expensive NFs (Ray et al. 2018a, b). The Nutrient Expert® software, a simple nutrient decision support tool based on the principles and guidelines of SSNM, is very much helpful to develop strategies for managing fertiliser N, P and K tailored to a farmer's field or growing environment.

4.8.2.2 Introduction of Legume Crops in Rice–Wheat Cropping System

An efficient agronomic management approach needs to develop to increase crop productivity under RWCS in a sustainable manner keeping in view the factors of low productivity inherent in the systems (Brahmachari et al. 2019). Pulses are of paramount importance in soil nourishment and eradication of malnutrition, especially for developing countries (Meena and Lal 2018). India is the largest producer (around 25% of global production and 33% of the world area), the consumer (27%) and importer (around 14%) of pulses (FAOSTAT 2019). The inclusion of leguminous crops into RWCS may contribute towards improving the prospects of their long-term sustainability, primarily because legumes can fix atmospheric N (Biological Nitrogen Fixation; BNF) but also due to their diversity which allows them to play a role in various agricultural systems (Sharma et al. 2005). A similar statement was recorded by (Malik et al. 2016; Lal et al. 2017; Garai et al. 2019). They opined that the inclusion of short duration grain legume could effectively improve the system productivity. Grain legumes can be grown without the addition of any synthetic NFs expect starter doses (Meena and Lal 2018). Thus, the addition of grain legumes not only helps to restore soil fertility but also to save the nitrogenous fertiliser. Meena and Lal (2018) reported that farmers could save about 170–-220 kg ha^{-1} of NFs. Nevertheless, the BNF potential of the different pulses varied significantly with the species, soil type, presence of soil microbes and management practices (Schulz et al. 1999; Meena and Lal 2018). The potential N fixing capacity of commonly grown pulse in SA is presented in Table 4.3.

4.8.2.3 Use of Specialised Nitrogenous Fertilisers (NFs)

Efficient use of fertilisers ensures increased crop production per unit area, improved product quality, minimum losses of nutrients through leaching and high profits. In the Indian subcontinent, the use efficiency of N is only 30–40% in rice and 50–60%

Table 4.3 The Potential N fixing capacity of commonly grown pulse in SA

Pulse Crops	Potential N Fixing Capacity (kg ha^{-1})
Groundnut	27–206
Chickpea	23–97
Moong bean	50–66
Black gram	119–140
Cowpea	9–125
Red gram	4–100
Soybean	49–450

Source: Reddy (2017)

Table 4.4 Effect of specialised NFs on plant N uptake and reduction of N losses

SNF	Plant N uptake (% increase)	% Reduction in N loss (NH_3 volatilised; N_2O or NO emitted; NO_3 leached)
Sulphur coating	70	15
Polymer coating	25	40
Urease Inhibition	6	55–90
Nitrification Inhibition	13	26–37
Urease and nitrification inhibition	13–100	13–87
Application of Nanotechnology	34–100	19–30

Source: Dimkpa et al. (2020)

for other cereals with an average value of 33% (Sharma and Bali 2017). To alleviate these situations, researchers have been trying to develop different specialised NFs to increase the use of efficiency and decrease the NFs (Prasad 2005; Dimkpa et al. 2020). These specialised NFs were either following the slow release of N mechanism (Ni et al. 2011) or inhibitory mechanism (urease inhibitor, nitrification inhibitors) (Dimkpa et al. 2020). This SNF not only helps to improve plant N uptake but also reduces the N footprints by the reduction in NH_3 volatilisation, N_2O emission and NO_3- leaching from synthetic N fertilisers (Table 4.4).

The efficiency of these specialised NFs largely depends on the soil type, application method, growing ecology as well as management practices. The main concern for popularisation of these specialised NFs is the cost of production. Specialised NFs production requires complete fertilisers as raw materials. Critical and complex fabrication processes of these fertilisers also append the cost of production. Continuous supply as per the demand is also a big challenge due to the complex production process. Necessary allocation of government subsidy to the end-users and continuous supply of raw material to the produces may be the potential options from augmenting the use of specialised NFs in SA countries.

4.9 Conclusion

From the discussion of the present chapter, it is indicated that climate change is a major issue which is linked with its excessive production of GHGs. To meet the food security of increasing population agricultural intensification across the globe is increasing which lead to influence the GHGs emissions. As various agricultural activities are directly associated with the overall emission of GHGs, therefore, to reduce the GHGs emissions, it is important to users of balanced chemical fertilisers particularly N-fertilisers, improvements of the operation efficiencies of farm machinery and changes in regional allocation rice-based cropping systems.

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Future Transitions to a Renewable Stationary Energy Sector: Implications of the Future Ecological Footprint and Land Use

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Abstract

We investigate the development of stationary energy policy for the national and sub-national ecological footprint. Three carbon emission mitigation scenarios relating to the electricity sector (two different fuel mix scenarios and the rate of technological uptake) are explored. We find that the effectiveness of sub-national policy varies with global uncertainty. To be robust, policy to reduce carbon emissions from the stationary energy sector must be successful irrespective of which future eventuates and/or must be highly adaptable and responsive to different futures. We investigate the impact of emission reduction policy on other parts of the ecological footprint—energy land. Many low carbon energy production methods require large areas of land, and this exacerbates current land use competition, particularly with respect to agricultural land. We find that holistic policy development will need to identify land uses which can operate synergistically with land required for renewable energy to mitigate ecological footprint expansion as renewable energy increases. Our case study using Australia and four of its states provides a framework applicable elsewhere in the world to increase the resilience of the energy sector and agriculture.

Keywords

Ecological footprint · Land use · Policy · Renewable energy · Resilience · Stationary energy

Abbreviations

IPCC	Intergovernmental Panel on Climate Change
CO_2	Carbon dioxide
SRES	Special Report on Emissions Scenarios
STIRPAT	Stochastic Impacts by Regression on Population, Affluence and Technology
IPAT	Impact, Population, Affluence and Technology
OLS	Ordinary least squares
IEA	International Energy Agency
GDP	Gross domestic product
ABARE	Australian Bureau of Agricultural and Resource Economics

MT	Megaton
KWh	Kilowatt-hour
CSP	Concentrated solar power
CCS	Carbon capture and storage
Ha	Hectare
GWh	Gigawatt-hour
NG	Natural gas
Geoth	Geothermal
Bioms	Biomass
PV	Photovoltaic
Qld	Queensland
WA	Western Australia
SA	South Australia
VIC	Victoria
CO2-e	Carbon dioxide equivalent

5.1 Introduction

State jurisdictions in Australia find themselves making policy decisions in a global context of considerable uncertainty. To ensure that policy has the greatest chance of being successful, this variable future global context should not be ignored.

We show how effectively policy decisions relating to fuel mix and rate of technological uptake can reduce the ecological footprint. We use a resilience framework to interpret data from ecological footprint modelling to inform stationary energy policy to minimise the vulnerability of the electricity sector to future threats. Because it is an integrated indicator, the ecological footprint allows us to examine the implications of stationary energy policy for land use.

5.1.1 Research and Development in Ecological Footprint Informed Policy

The use of the ecological footprint to educate and inform has been widely evident throughout the world, largely because of its ability for making the abstract concept of sustainability more concrete. It has been important as a tool to initiate conversations and debate, question assumptions and stimulate future thinking (Barrett 2001). In a number of cases, the ecological footprint has also been used to set targets for reduction of environmental impact (GFN 2013).

Although the ecological footprint's ability to generalise complicated information does allow general policy directives (such as a recommendation that resource consumption should be reduced) (Nourry 2008), it is precisely its generalisation which makes it difficult to identify and rank more detailed policy options and actions (McDonald and Patterson 2004). It is also important to note that in its original form, it was never intended to distinguish detailed policy options, but, instead, provides a snapshot of biotic resource consumption with the intention that other complementary indicators further inform holistic policy for sustainable development.

The development of complementary ecological footprint policy development tools, however, has been limited—especially those that consider the complex systems that decision-makers find themselves making decisions within (Norberg and Cummings 2008). At a most basic level, these tools need the ability to determine if the planet can continue to provide the resources demanded by human populations in perpetuity. To do so they must look to the future to inform robust decisions in the present. At a more sophisticated level, they require the capability to examine the ability of a system to change (and, ideally, improve) upon its current state (Milman and Short 2008). Such tools would enable us to contrast alternative future policy scenarios.

Furthermore, considering ecosystem processes is not sufficient. They must also consider the larger context of the socio-ecological systems in which they are enmeshed. They must be capable of considering the well-being and resilience of both present and future societies. They must be well informed, not only of the symptoms but also of the causes of environmental change (Milman and Short 2008). Such capabilities are critical for policy makers to justify policy change.

Inter-linkages must also acknowledge different spatial scales for three reasons. Firstly, because they are crucial for the study of natural systems which do not often align with jurisdictional boundaries.

Secondly, decisions made at the national scale cannot by themselves be classified as sustainable or not. Countries that use more resources than their domestic land can provide can either import resources or deplete their own natural capital. Although the latter is not considered to be a sustainable practice in the long term, the sustainability of the former cannot be judged without considering the availability/depletion of resources at a global scale.

Thirdly, for the purposes of appropriate policy making at the national scale, it is important to account for the uncertainties at larger and smaller scales which will affect the success of national policies.

5.1.2 Sustainability Issues

The carbon footprint is the largest contributor to the overall ecological footprint, and, in turn, the stationary energy sector contributes the largest fraction of global greenhouse gas emissions that make up the carbon footprint (de Araujo et al. 2007). The consumption of electricity is the most significant component of the stationary energy sector (especially in high-income countries who are the most significant contributors to the global carbon footprint). Therefore, the investigation of footprint mitigation policies which address strategies for reducing the both carbon footprint and the energy land footprint of the stationary energy sector are well justified purely because of the potential this has for reducing the overall ecological footprint.

Here we demonstrate how modelling future stationary energy sector ecological footprint scenarios can be used to reduce the footprint of electricity production, increase the resilience of the electricity sector and inform policy in relation to land use conflict (particularly for agricultural land). We use three Australia states as our case studies (South Australia, Victoria and Tasmania). These three states are an example of very different stationary energy resource, technology and policy contexts.

5.2 Methodology

5.2.1 The Model and the Global Context

The modelling outlined in the methodology, below, is part of a larger global ecological footprint model outlined in McBain et al. (2017). The mathematical model structure—a tensor framework—is outlined in Lenzen and McBain (2012). This structure represents an iterative tensor formulation representing finite-difference changes in variables resulting out of linearised non-linear cause-and-effect relationships. Variables are advanced in annual time steps, and the global system is broken up into 116 countries.

The model has an IPAT framework (Ehrlich and Ehrlich 1990) where environmental impact (I) is taken to be the product of population (P), affluence (A) and technology (T). We used three global Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) scenarios (A2, B1 and B2[1]) to provide exogenous data from 2010 to 2070 for a range of plausible futures at the sub-national, national and international scale (IPCC, n.d.). The trajectories of population, affluence and technology in these scenarios are interrelated. The components of the ecological footprint and biocapacity in the larger model are land use (cropping, forest, grazing, built land and plantations), drivers of agricultural productivity (land degradation, technological change and climate change) and climate change (emissions from the agriculture, stationary energy, transport, land clearing and forest sequestration). The fish footprint is not considered.

By aggregating the model results of nations, we investigate the global context and the global uncertainty that local decision-makers make policy decisions.

[1]The A2 storyline describes a very heterogeneous world. Population growth is high. Economic development is primarily regionally oriented and medium-low. Technological change is more fragmented and slower than in other storylines.

The B1 storyline describes a convergent world with a medium-high global population. It has rapid changes in economic structures and medium income growth. There is a globally coordinated emphasis which is on global solutions to economic, social and environmental sustainability.

The B2 storyline describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. Global population size is low and income growth is medium. Technology growth is less rapid.

5.2.2 The Regional Context

In countries such as Australia, the electricity sector is particularly carbon-intensive relative to the sector worldwide, most notably due to the cheap price of coal which is mined in the country (Garnaut 2011). Although a National Renewable Energy Target of 20% by 2020 has been set by the federal government, the relative contribution of electricity consumption to overall carbon emissions and the natural advantage of alternate energy technologies vary geographically (Garnaut 2011). For example, in the state of Victoria, the emission intensity is much higher than in other states because of the extensive use of brown coal, which produces much higher carbon emissions per unit of energy than black coal, more commonly used in the remainder of the country. In comparison, the use of hydroelectric generation in Tasmania means that the carbon intensity of electricity consumption in that state is lower. It is, therefore, important to consider state-specific policy recommendations for future stationary energy consumption in order to more effectively plan for future ecological footprint reductions.

The political and social acceptability of different approaches to ecological footprint mitigation are also likely to vary significantly between state jurisdictions. For instance, nuclear power may be regarded as a mitigation option that should be investigated for future energy supply in some jurisdictions, whilst in others it may be regarded as socially unacceptable by the community (and, thus, not considered as a viable future option).

5.2.3 Stationary Electricity Sector Model Variables

Below we outline the individual variables within our model relating specifically to the stationary energy electricity sector and justify our approach.

5.2.3.1 Estimating Electricity Demand

In order to estimate electricity demand, we needed to operationalise demand as a function of important driving forces. We used a modification of the STIRPAT identity (a variation of IPAT—Impact, Population, Affluence and Technology) originally developed by Dietz and Rosa (1997) to determine the relative importance of driving forces on electricity production. STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) accounts for stochastic, simultaneous influence of driving forces on environmental impact and can be used to determine the relative importance of each driving force. It can also be used to disaggregate the existing driving forces in the IPAT identity or include other factors within the model (York et al. 2003).

We follow the general approach outlined in York et al. (2003) by assessing the relationship between and importance of driving forces affecting greenhouse gas emissions from electricity production using multiple ordinary least squares (OLS) regression of cross national data in 1980–2000. Our model has a finite-difference form. Because we were ultimately interested in investigating the effect of alternative mitigation measures on *changes* in carbon dioxide (CO_2) emissions, we estimated our input parameters by regression of data available on changes in country-specific, annual electricity generated from 1980 to 2000 sourced from IEA (2012). This had the added benefit of reducing the effects of non-stationarity which is an important consideration for data that may not have a constant mean and especially important with the use of variables in time series with large numbers of time points which have an overly influential time trend (Jorgenson and Clarke 2010). See below, also, for additional measures taken to control for this.

We assessed the importance of nine potential driving forces of electricity demand within our model: GDP (gross domestic product), GDP per capita, manufacturing GDP, service GDP, population, number of households, urban population, urban area and urban density. Although there may be some correlation between population and number of households, it was important to enter them into the regression separately because they are likely to respond differently in the future, e.g. the number of households could increase at a greater rate than population as a whole because household size decreases with increasing income (Jennings et al. 1999). We found the following three variables to be both important for the development of policy and significant drivers: GDP, population and number of households.

Exploratory analysis revealed that the coefficients of the regression changed over time. This has also been previously found for other systems (Frees and Miller 2004; Hastie and Tibshirani 1993). Accordingly, we undertook regression analysis separately for each year and then applied a linear trend analysis to the coefficients for our three driving variables.

In order to test the validity of our regression coefficients, we randomly selected half the available national data to calibrate the model coefficients (above) and then tested our regression by applying our coefficients to the unused half of the dataset. Our model explained 0.86 of the variation in electricity demand. The remainder of variation is likely explained by factors such industrial demands which we did not consider here. In our ecological footprint model, we dynamically adjusted each regression coefficient according to the year of analysis assuming linear trends in coefficients over time.

We undertook a separate regression for Australian states and summed results for the nation as a whole. There was no evidence for changing coefficients over time for Australian states. The effect of the number of households was also found not to be significant. The coefficients for GDP and total population were 7.72×10^{-5} and 2.14×10^{-5}, respectively. The model explained 99% of historical variation in electricity demand for Australian states.

5.2.3.2 Historical Fuel Mix

The strongest driver of greenhouse gas emissions from the stationary energy sector is the local availability of energy sources or the fuel mix (Lenzen et al. 2013). Country-specific fuel mixes of electricity production were calculated using data for the percentage of electricity produced from different sources obtained from the World Development Indicators for oil, nuclear coal, natural gas and hydro. Country-specific geothermal, solar and wind sources we accessed. Total installed capacity data from 1980 to 2000 were obtained from the International Energy Agency (IEA 2012).

Australian, state-specific fuel mix was calculated as follows:

- State disaggregated electricity generation capacity by fuel type was sourced for 2006–2007 from the Australian Bureau of Agricultural and Resource Economics (ABARE 2009).
- Net electricity generation was calculated by dividing generation capacity by the fuel-specific capacity factors.
- Electricity imports and exports were added and subtracted, respectively, from net electricity generation, to obtain electricity consumption. The fuel mix of the energy imported was assumed to be in the same proportion as that of the state of origin.
- To obtain historical (1980–2000) state-level fuel mix data (%), the state fuel mix for 2006 was adjusted so that the proportion of electricity consumption from each particular fuel source varied in proportion to national changes.

5.2.3.3 Current and Future Emission Factors

The carbon intensity of the energy sector determines the magnitude of greenhouse gas emissions, indicated by emission factors. We calculated total emissions by multiplying appropriate emission factors by electricity demand from each fuel/technology source. Emission factors were derived from Lenzen and Schaeffer (2012) and include the full life-cycle of energy production including off-site emissions such as those associated with power plant construction and mining of fuel.

The 2100 emission factors from Lenzen and Schaeffer (2012) were assumed to represent a medium-level trajectory for technological adoption in the stationary energy sector. We applied the rate of technological change from Nakićenović and Swart (2000) (Table 5.1). For all types of stationary energy with a medium rate of technological change, we applied emission factors for 2100 directly from Lenzen and Schaeffer (2012). We adjusted low and moderate/high technological trajectories by multiplying 2100 values from Lenzen and Schaeffer (2012) by 0.6 and 1.2, respectively. The final scenario-specific emission factors for the different stationary energy types can be found in Table 5.1.

Note that the emission factors for biomass and nuclear go up between 2009 and 2100. This is because indirect emission intensities of single technologies depend on the emission intensity of the background economy, and as this gets decarbonised, the emission intensities of technologies go down. Also for nuclear, ore grades diminish; hence, the increase in emission factor, i.e. more uranium ore, must be processed to extract the same amount of uranium as uranium ore grades decrease. This results in an increase in greenhouse gas emissions associated with nuclear power (CSIRO 2011).

Emission intensity changes in each scenario. We calculate the rate of change between 2009 and 2100 and used this rate to adjust our emission factor each year dynamically. This reflects technological change relevant to emissions.

Table 5.1 Emission factors for stationary energy (MT/billion KWh). The assumptions for rate of technological change from Nakićenović and Swart (2000) are documented in brackets (l = low, m = medium, mh = moderate/high)

	Current	2100	B1	B2	A2
Coal	0.97	0.57	0.57 (m)	0.68 (l)	0.57 (m)
Natural gas	0.46	0.31	0.31 (m)	0.20 (mh)	0.37 (l)
Oil	0.70	0.44	0.44 (m)	0.42 (l)	0.53 (l)
Hydro	0.25	0.25	0.16 (mh)	0.25 (m)	0.30 (l)
Geothermal	0.17	0.03	0.02(mh)	0.03(m)	0.04 (l)
Nuclear	0.07	0.13	0.08 (mh)	0.13 (m)	0.16 (l)
Wind	0.05	0.01	0.006 (mh)	0.010 (m)	0.012 (l)
Solar	0.10	0.05	0.03 (mh)	0.05 (m)	0.06 (l)
Biomass	0.08	0.10	0.06 (mh)	0.10 (m)	0.12 (l)
CSP[a]	0.06	0.03	0.02 (mh)	0.03 (m)	0.04(l)
CCS coal[b]	0.73	0.52	0.52 (m)	0.62 (l)	0.52 (m)
CCS natural gas[c]	0.31	0.31	0.31 (m)	0.37 (l)	0.31 (m)

[a]Concentrated solar power
[b]Assumed post-combustion carbon capture and storage (CCS) with 85% capture efficiency of CO_2
[c]Assumed pre-combustion CCS with 85% capture efficiency of CO_2

We used the above emission factors for Australian states except for brown coal which is generally used in Victoria and has emissions 45% higher than black coal (Feron and Paterson 2011).

5.2.3.4 Land

For many technologies, the land requirement of power generation consists mainly of the area taken up by the power plant (i.e. an insignificant area relative to other land uses). However, a number of stationary energy production technologies occupy significant areas of land, e.g. hydro, solar and wind. We incorporated this into our model with the use of stationary energy technology-specific land use intensities.

Land use intensities for electricity production from different technologies for the beginning of the modelling period were sourced from Gagnon et al. (2002) and Trieb et al. (1997) (Table 5.2). In the absence of any available data, future SRES-specific land intensities were derived from present-day values. We assumed future values changed in the same proportion as the technology changes affecting emission factors in Table 5.1. The exception to this rule was biomass which was adjusted dynamically in accordance with changes in the productivity of cropping systems (McBain et al. 2017).

5.2.3.5 Fuel Mix for Other Nations in the World

The fuel mix was guided by IPCC which documents the assumed percentage of primary energy from coal and zero carbon technologies, respectively. Our explicit fuel mix was assumed uniform between countries (Table 5.3) but is also constrained

Table 5.2 Land intensity of stationary energy technology

	Land requirement ha/GWh	B1 2100	B2 2100	A2 2100
Coal	400,000	235,052	282,062	235,052
Natural gas	200,000	134,783	84,913	161,739
Oil	200,000	125,714	119,429	150,857
Hydro	15,200,000	9,576,000	15,200,000	18,240,000
Geothermal	100,000	11,118	17,647	21,176
Nuclear	50,000	58,500	92,857	111,429
Wind	7,200,000	907,200	1,440,000	1,728,000
Solar	4,500,000	1,417,500	2,250,000	2,700,000
Biomass	53,300,000	41,973,750	66,625,000	79,950,000
CSP	600,000	189,000	300,000	360,000

by natural geographical constraints to technological uptake within the modelling process (Sect. 1.4.6).

5.2.3.6 Assumptions and Constraints on Fuel Mix

The potential for alternate power supply in each jurisdiction is determined by factors such as resource characteristics (appropriate wind regimes, solar exposure), the availability of appropriate land (both of which can be quantitatively derived and together determine the geographical and technical potential) and technology, economic viability, social acceptance, the effectiveness of policy, etc. (the latter three are more difficult to quantify) (de Vries et al. 2007; McDonald et al. 2009).

Here we consider the geographical/technical potential of solar, biomass, wind and geothermal which are all, to some degree, limited by either available land area or resource availability within a country. The technical potential was calculated for each power source within each available land use in order to derive an upper limit to the adoption of each power source.

Wind

Wind faces grid integration problems above 20% penetration. Above 20% excess wind energy "spills" large amounts of electricity produced (Hoogwijk et al. 2007). Lenzen and Schaeffer (2012) in the GWEC (2008), for example, constrain wind energy to 17% penetration even in the advanced scenario. Wind energy is not distributed uniformly in space (Lu et al. 2009), and regional patterns mean that some nations will have a much lower capacity to produce wind energy than this technological limit of 20%. The maximum country-specific capacity for wind was estimated from Lu et al. (2009) for all countries with capacity factors >20% for both onshore and offshore. In the absence of state-specific information, the Australian potential for on- and offshore wind was split evenly across states.

Table 5.3 Assumed fuel mix of electricity consumption under SRES scenarios for other nations

SRES	Year	Coal	NG	Oil	Hydro	Geoth	Nuclear	Wind	Solar	Bioms.	CSP
A2	2050	0.51	0.187	0.03	0.044	0.044	0.0437	0.04	0.04	0.044	0.04
A2	2100	0.6	0.091	0	0.046	0.046	0.0456	0.05	0.05	0.046	0.05
B1	2050	0.32	0.15	0.08	0.064	0.064	0.0643	0.06	0.06	0.064	0.06
B1	2100	0.12	0.116	0.01	0.108	0.108	0.1077	0.11	0.11	0.108	0.11
B2	2050	0.19	0.222	0.04	0.079	0.079	0.0793	0.08	0.08	0.080	0.08
B2	2100	0.28	0.154	0.01	0.09	0.090	0.0896	0.09	0.09	0.090	0.09

NG natural gas, *Geoth* geothermal, *Bioms* biomass

Hydro

Significant expansion (more than twice current capacity) of hydropower is not expected because (1) many of the world's large rivers are already dammed and (2) small hydropower is still costly (IHA, IEA-HA, ICOLD, CHA 2000; Paish 2002). Country-specific upper limits to technically exploitable hydro power capability (gross theoretical capability currently technically possible) were sourced from the World Energy Council (2004).

For Australia, further potential for the development of large-scale hydroelectric projects (World Energy Council 2004) is limited. Most available sites are already developed, and many needed a compromise between wilderness preservation and other environmental factors. Further opportunities exist for the refurbishment of existing plant and equipment to increase efficiency of production (the average age of plants of over 45 years) and mini-hydro projects.

State-specific hydro power potential is likely to be limited in parts of Australia where rainfall/stream flow is inadequate or too seasonal. Also, the potential for hydro power in Australia will depend on the effects of climate change on both annual average rainfall and rainfall variability. For mitigation scenarios, we have made the assumption that the potential of hydro to 2050 increases conservatively to a maximum of 5% of total electricity supply.

Solar

Future growth of solar photovoltaic depends on the reduction of costs in generation, for which there is significant uncertainty (van der Zwaan and Rabl 2004). Not many projections include a global share of PV higher than 5% penetration by 2050 (Lenzen and Schaeffer 2012).

Country-specific solar capacity was calculated from GIS maps of global direct normal solar radiation (kilowatt-hours a square metre a day). This dataset was developed to assess the availability of solar resources for concentrating solar power that tracks the sun through the day (CSP). Areas suitable for CSP must have direct normal solar radiation of greater than 5 KWh/m^2 day (UNEP 2010). We assumed that land would not be cleared for the installation of solar energy infrastructure as the carbon release from cleared vegetation would be counterproductive to the spirit of transition to renewable energy. We also assumed that new renewable power infrastructure would not compete with existing agricultural land which was required to produce food for populations. Built land was considered inappropriate for the installation of CSP but was exclusively assumed suitable for decentralised conventional solar installations. Any land classified as protected at the national and international level was excluded as suitable area for solar power infrastructure. We subtracted the above excluded land using 2000 data from the following sources, built land, inland water, grazing land, cropping land, forested land (Klein Goldevijk 2001) and protected land (Millennium Ecosystem Assessment), to obtain a net land available for photovoltaic (PV) and CSP production. Capacity factors of 90% and 17% were assumed for CSP and PV solar, respectively, which are mid-way between values for 2009 and 2100 presented in Lenzen and Schaeffer (2012).

Geothermal

Limits to country-specific installed geothermal capacity were taken from Gawell et al. (1999). In Australia, geothermal resources are mainly centred along the southern Victorian coastline and in South Australia and Tasmania. Little geothermal energy is currently on line (Holm et al. 2010). Australia's future geothermal capability could approach 10% by 2030 (Australia's Centre for International Economics 2007; Louthean 2007). The state-scale potential for geothermal energy has not been estimated. Accordingly, the 20 TW of national geothermal potential was split across each state in Australia as follows: Queensland (Qld), Western Australia (WA), = 1 TW; South Australia (SA) = 6 TW; Victoria (VIC) = 12 TW (Holm et al. 2010).

5.2.4 Mitigation Policy Options

5.2.4.1 Fuel Mix of Australian States

We applied an assumed future share of energy contribution to each jurisdiction at a particular time to investigate the consequences of alternative future fuel mixes. This fuel-specific future "share" of the energy mix was determined on the advice of a range of state policy makers.

We used a list of mitigation options for the stationary energy sector from Pacala and Socolow (2004). Importantly, this list included only mitigation options for stationary power production which used scientific, industrial and technical know-how which exists currently, i.e. it does not rely on some future development or technology which is, as yet, unforeseen. This means that these options are currently feasible. The mitigation options included efficient base load coal plants, base load power plant, gas base load power replacing coal power and capture of CO_2, wind, biomass, solar photovoltaic, hydro, concentrated solar power, nuclear and geothermal replacing coal power.

As noted in Sect. 1.4.6, the potential for further development of hydro in Australian states is limited, and thus it remains a low priority for further expansion in most areas. Thus, any changes in the efficiency of existing hydro are factored into general technological improvements that are applied to all technologies within the model. The proportion of concentrated power is expected to expand at the expense of conventional solar as technology improves into the future (Lenzen et al. 2016). The priority given to geothermal power varies with geographical potential and varies significantly between states (see Sect. 1.4.6.4). The priority given to biomass was assumed medium for all states.

The relative priorities of all state partners on a scale of high (3), medium (2), low (1) or zero were adjusted so that they reflected the proportions of the entire fuel mix assumed for modelling (Table 5.4). Our case study jurisdictions each had existing policy that considered carbon capture and storage (CCS) a lower priority so we assumed <25% CCS by 2100.

We also investigated the impact of a more stringent fuel mix with a greater proportion of lower carbon energy options which preclude the use of coal (Table 5.4).

Table 5.4 State priorities translated into 2100 fuel mix for state mitigation scenarios

Fuel	QLD (%)	WA (%)	SA (%)	VIC (%)
Less stringent mitigation				
Coal	5	14	13	9
Gas	10	21	13	11
Oil	0	0	0	0
Hydro	3	0	0	3
Geothermal	0	0	13	19
Nuclear	0	0	13	16
Wind	20	14	13	6
PV	11	7	13	9
Biomass	20	14	8	13
Concentrated solar power	10	7	13	9
Carbon capture and storage	20	25	5	7
More stringent mitigation				
Coal	0	0	0	0
Gas	11	25	14	12
Oil	0	0	0	0
Hydro	3	0	0	3
Geothermal	0	0	14	21
Nuclear	0	0	14	18
Wind	20	17	14	7
PV	11	8	14	10
Biomass	22	17	10	14
Concentrated solar power	11	8	14	9
Carbon capture and storage	22	25	5	7

5.2.4.2 Uptake of New Technology of Australian States

Technology will lag behind the technological frontier. The technologies of most coal-fired power plants existing today, for example, lag behind the latest technological frontier because they were constructed over 30 years ago (Rosenfeld and Bassett 1999). Not many models consider this technological frontier (Clarke et al. 2008). We assumed that the age distribution of power generation plants followed a normal distribution where the age of the average power station was 30 years. Policy implementation which increases the rate of capital stock turnover will mean that this normal distribution becomes skewed to the left (i.e. there is an increase in the fraction of power stations which have newer infrastructure and technology). We investigated policy requiring the turnover of capital stock at 20 years instead of the current assumed (and optimistic) average of 30 years.

5.2.5 Timing of Mitigation

Building a resilient stationary energy sector means that it is not vulnerable to significant disruption in the future. One of the key disturbances likely to affect the resilience of the energy sector is peak coal, i.e. the time at which maximum global coal production is reached. After this point, the price of coal is likely to increase as resource availability decreases.

Mohr and Evans (2009) find that peak coal (as measured by tonnage produced) is likely to occur globally between 2010 and 2048. For Australia, they estimate peak coal to occur between 2050 and 2070. Similarly the Energy Watch Group (2007) estimates a global peak at around 2025 assuming a 30% increase above current production. The timing of global peak coal production is, however, highly uncertain and heavily contested.

We used a standard risk assessment that considers both vulnerability and consequence to inform the appropriate timing for implementing the mitigation options (Sect. 1.5) to maintain the resilience of the electricity sector.

5.3 Results and Discussion

5.3.1 Model Output Comparison with Literature

Our modelled outputs for emissions from global electricity production (6654 Mt CO_2-e or carbon dioxide equivalent) are consistent with those derived from Garnaut (2011) which indicate 2005 global emissions of just over 7000 MT CO_2-e due to electricity consumptions. Our modelling of Australia's emissions (i.e. the sum of state emissions) from electricity consumption of 135 Mt CO_2-e compare well with the estimate of 175 Mt CO_2-e for electricity generation by the Australian Greenhouse Office (2008).

5.3.2 Mitigation Timing

The uncertainty about the timing of peak coal means we need to consider three main risks. Each of these risks has varying consequences:

1. *Early peak coal* will likely result in an energy crisis because a transition to alternative power options will be required at very short notice (given the typical lifetime of most power plants). A rapid transition is likely to require large financial consequences (e.g. energy prices, new infrastructure), costs and health consequences. Intermediate climate change adaptation costs are likely.
2. *Later peak coal and little transition from carbon-intensive stationary energy production* is likely to entail large financial (e.g. energy prices) and non-financial (well-being, etc.) costs associated with climate change adaptation.

In addition, large costs are likely in the longer term from an energy crisis and subsequent transition to non-coal energy production once peak coal occurs.

3. *Late peak coal and early transition from carbon-intensive stationary energy production* is likely to entail significant cost associated with investment in alternative energy. However, these costs are spread across an extended period, and smaller investment is required each year resulting in a smaller per annum financial imposition. This transition is strategically planned over the long term. There is less likelihood that societal welfare will be indiscriminately and heavily compromised. Intermediate costs are expected for adaptation to climate change.

In summary, greater control over potential costs to society is possible if transition to low carbon energy production occurs early, given the uncertain timing of peak coal. The precautionary principle would dictate that transition away from carbon-intensive energy sources occurs irrespective of the actual timing of peak coal. This also allows Australia as a society to plan its investment in a strategic manner.

5.3.3 Modelling Output

Total future global electricity demand under the three SRES scenarios differed significantly. Electricity demand increases linearly for all scenarios until 2030 (Fig. 5.1a). Under an A2 scenario with little globally coordinated governance, and high rates of population growth, medium-low growth in affluence and low technological investment, electricity demand continues to increase linearly until 2070. Under the presumption of low population size, medium income growth and medium levels of technological investment (B2—also has little globally coordinated governance), demand starts to plateau around 2065. Under the globally coordinated world with medium levels of affluence, medium to high populations and medium-high investment in technology (B1), electricity demand peaks around 2045 and has already declined significantly to 2020 levels by the end of the modelling period in

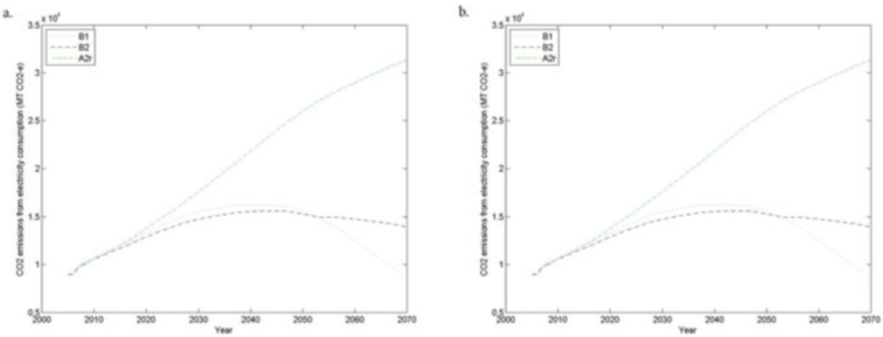

Fig. 5.1 Total global electricity demand (**a**) and CO_2 emissions (**b**) from the stationary energy sector under three baseline SRES scenarios

2070. State electricity consumption in the absence of specific demand management continues to increase to 2070 under all global futures, in line with global trends.

The resulting patterns of global CO_2 emissions from electricity consumption largely mirror those of electricity demand (Fig. 5.1b), but investment in technological advancement tends to influence a slowing in the rate of emissions after 2050 for A2 (despite continued population growth) and early declines in peak emissions for B2 and B1 (in 2045 and the late 2030s, respectively).

With no mitigation at the state scale, future CO_2 emissions mirror global trends with the highest growth in CO_2 emission occurring under an A2 scenario and much lower future emissions under a B1 and B2 scenario, respectively (Fig. 5.2a). The adoption of policy relating to changes in fuel mix significantly reduces CO_2 emissions in all states (Fig. 5.2b, c). The more stringent the fuel mix, the greater the reduction in CO_2 emissions. Relative to changing the future fuel mix, emission reductions resulting in an earlier adoption of technology (i.e. a younger capital stock of power stations) were minimal. The success of mitigation options at the state scale is greater should global trajectories follow the B1 or B2 path. In comparison, the success of mitigation options under an A2 scenario is still effective, but less so.

Unlike CO_2 emissions, alternate future fuel mixes increase the demand for land because energy technologies such as solar, wind, hydro and biomass all have high land requirements compared to fossil fuel technologies (Fig. 5.3).

5.4 Building Robust Stationary Energy Policy

Robust policy for the Australian electricity sector must not only consider the risks associated with key future disturbances such as peak coal (Sect. 1.6), but it must also consider the global uncertainty that jurisdictions find themselves making policy decisions within. Policy makers in Australia are, to some extent, at the whim of a global trajectory that is uncertain and beyond their direct control. Therefore, policy options must maximise the chance of maintaining the resilience of the national stationary energy sector despite this uncertainty.

The environmental outcomes of the three global SRES scenarios diverge significantly because of varied, but equally probable, future trajectories in population, affluence and technology. From the perspective of minimising the likelihood of dangerous climate change, it is preferable that Australia finds itself in a global context that follows the B1 trajectory. For this to happen, the scenario descriptors tell us that all nations will need to work together to lower population growth, decouple the growth in affluence from growth in emissions and accelerate the adoption of technologies that minimise emissions from the stationary energy sector. To play its part, Australia will require clear policies of leadership in global climate change mitigation.

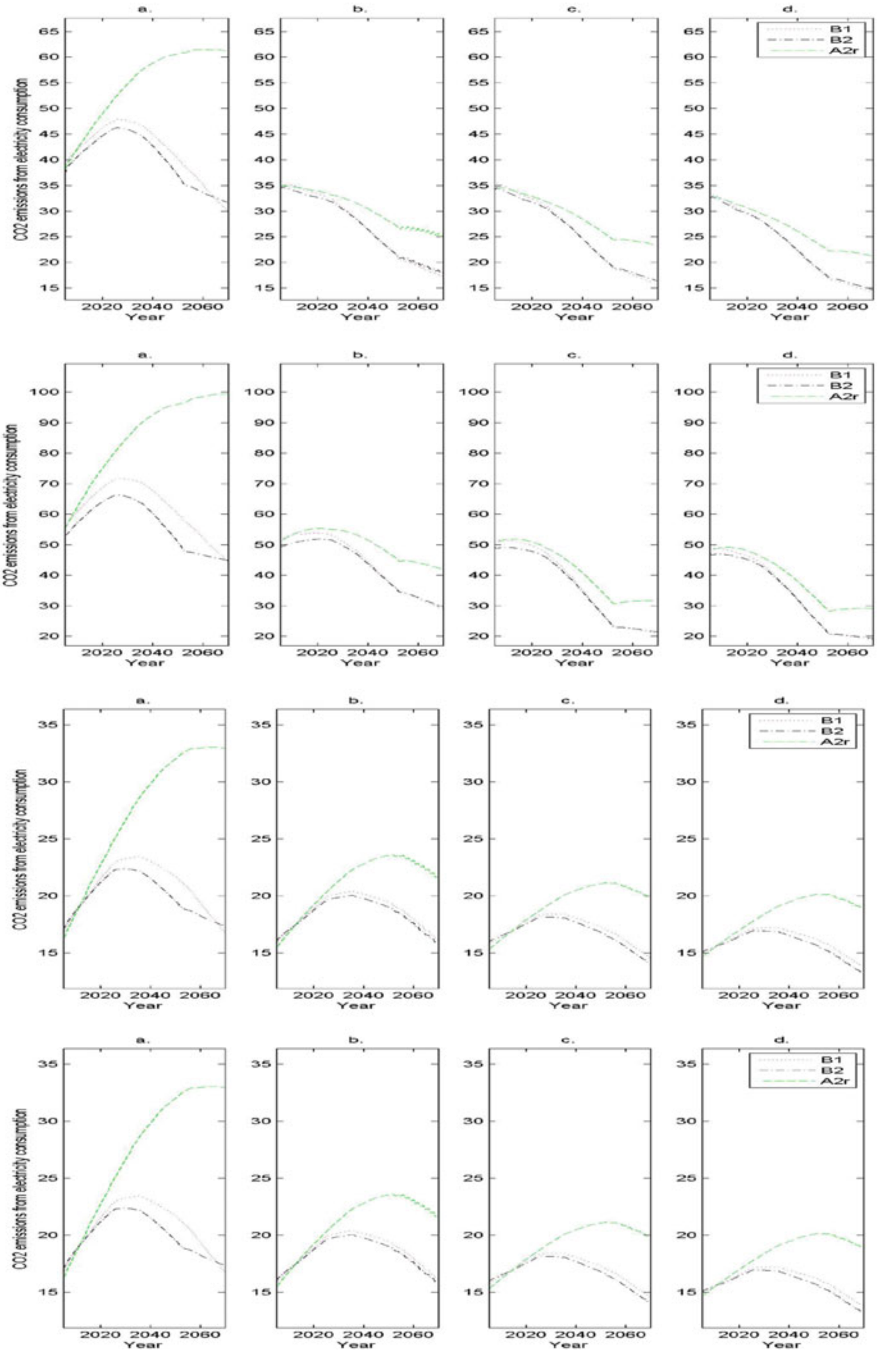

Fig. 5.2 CO_2 emissions (Mt CO_2-e) of the electricity sector in Australian states (Queensland, top; Victoria, second from top; South Australia, second from bottom; and Western Australia, bottom) under three scenarios from left to right: (**a**) no mitigation, (**b**) less stringent mitigation fuel mix, (**c**)

5.5 Legal and Policy Frameworks

It is important that Australian jurisdictions plan national and state stationary energy policy that is successful irrespective of which global future eventuates. Historically, however, Australian policy (Garnaut 2011) has not encouraged early, deep transition to low carbon energy production in the absence of a coordinated global transition because of the disadvantages faced by the globally connected Australian economy. We find that in the context of global future uncertainty and the risks of peak coal combined, such a policy approach is unwise for the resilience of the Australian economy, society and the environment.

If, for instance, the A2 trajectory predominates globally, peak coal is likely to occur sooner (due to high coal consumption), and Australia will need to transition to a low carbon energy sector sooner so that funding is available after energy transition for investment in climate change adaptation.

Early, planned investment will also mean that Australia can strategically build the specialist expertise required to design, build and install new technologies—building such workforce capacity takes time and has implications for education policies. In contrast, an unplanned, late, forced (and necessarily rapid) transition at the same time as the remainder of the world's nations will mean that Australia may have to compete for expertise in a massive global expertise shortage. This risk exacerbates the energy crisis and makes the transition to a low carbon electricity sector more expensive.

Transition early will require a strategic, adaptive planning framework so that investment can vary depending on the particular global trajectory that occurs. For example, funding for mitigation compared to adaptation is likely to be higher in a BI future compared to A2. The more stringent the fuel mix adopted, the more resilient the electricity sector to the introduction of a global carbon price or peak coal.

Different modelling outcomes between Australian states highlight the need for state-specific policy decisions to account for idiosyncrasies of natural resource availability, current dominant energy sources and policy settings. For example, mitigation options for states with a high reliance on gas (e.g. South Australia) tend to have less effective CO_2 emission mitigation under an A2 global future. These jurisdictions become more vulnerable should this global scenario eventuate together with a globally coordinated response to climate change (e.g. global carbon price). Future peak gas could further increase the vulnerability of the energy sector if too much reliance is placed on this fuel. For this reason, Diesendorf (2005) advises that natural gas is understood as a transitional fuel for long-term planning.

Differences between states require customised policy, but it can provide greater resilience at the national scale. The interconnected power grids in Eastern Australia, if designed well to strategically accommodate renewable technologies, can provide modularity—key feature of resilient systems that avoids too much centralisation that

Fig. 5.2 (continued) more stringent mitigation fuel mix and (**d**) more stringent fuel mix and increased capital stock turnover

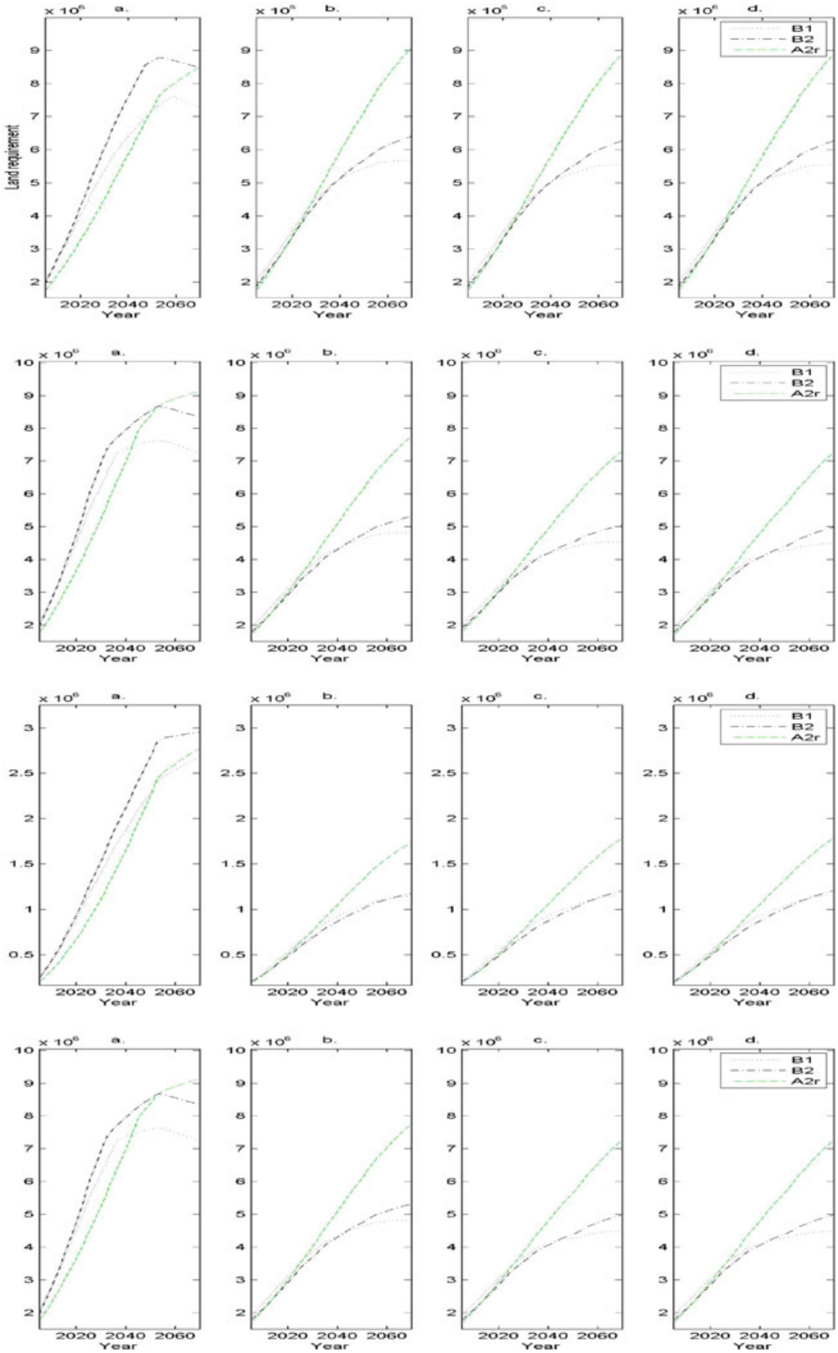

Fig. 5.3 Land area requirement (ha) of the electricity sector in Australian states (Queensland, top; Victoria, second from top; South Australia, second from bottom; and Western Australia, bottom) under three scenarios from left to right: (**a**) no mitigation, (**b**) less stringent mitigation fuel mix, (**c**)

is vulnerable to disruption (Norberg and Cummings 2008). A modular network of smaller-scale loosely connected systems gives greater energy security.

For optimal resilience with a mix of different technologies, it is important to build redundancy into the system. For instance, having greater total electricity production capacity at any one time than the likely total future electricity demand will be important (1) in case of disaster and (2) in case of weather-dependent limitations to any one technology (e.g. drought, low wind) (Lenzen et al. 2016). The collaboration between policy makers from multiple disciplines will be critical to the success of such policy development (Albrecht et al. 2001).

5.6 Conclusion

This research finds that resilient energy policies must consider emission reduction and land requirements together. Globally and nationally, the human demand for land (the remainder of the ecological footprint) is likely to increase significantly in the future due to continued land expansion (e.g. built land), demand for goods (e.g. food and timber) and reduction in land productivity (due to land degradation, plateaus in technological progress and climate change) (McBain et al. 2017). Many renewable energy technologies (e.g. solar, wind) require extensive areas of land. Complementary policy will need to consider opportunities for co-use of land (e.g. wind together with grazing, decentralised solar on existing built land), use of land whose provision of other goods and services would not be compromised (e.g. offshore wind, solar on less productive land), implementation of sustainable land management and heavy research investment in technological efficiency. Co-use of agricultural land for wind energy, for instance, has the potential to provide income diversity for the farming sector, but policy approaches for such a complex transition must be well planned, transparent and inclusive to succeed (Harding et al. 2009).

5.7 Future Roadmap

At the national scale, clear policies of leadership are required for global climate change mitigation to maintain the resilience of Australia's electricity sector. At the sub-national scale, policy must be resilient to whichever uncertain global future eventuates. This is because the effectiveness of sub-national policy (two different fuel mix scenarios and the rate of technological uptake) varies with global uncertainty. To be robust, local policy must be customised to local geographical context and must be highly adaptable and responsive to different futures. Holistic policy development considering both the carbon and the energy land footprint is required.

Fig. 5.3 (continued) more stringent mitigation fuel mix and (**d**) more stringent fuel mix and increased capital stock turnover

To limit land use expansion through vegetation clearing, the land required to expand the renewable energy sector will need to co-inhabit with existing compatible land uses or seek to use land in a way that does not compromise the productivity of other goods and services (including the non-monetary ecosystem serves).

In order to address the complexity of developing stationary energy policy, we need to consider multiple scales, future uncertainty and emissions and land requirements together. Modelling future the ecological footprints of the electricity sector allows us to significantly increase the resilience of the Australian electricity sector to future global uncertainty and global coordination addressing climate change (such as a carbon price). The approach to policy development presented here is applicable to other regions worldwide.

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Biomass as a Cornerstone of a Circular Economy: Resources, Energy, and Environment

6

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Abstract

The circular bioeconomy is one development strategy that has at their center the use and management of the biomass. Biomass could transform the bases of a global economy highly dependent on non-renewable raw materials and fossil origin, to a mostly bio-based economy that can simultaneously address the three main global challenges: provision of safe water, accessible energy for all, and climate change mitigation. In order to the circular bioeconomy not to be just a popular global goal, it is necessary to identify concrete measures that can make the concept operational, so that politicians, decision makers and stakeholders can see its practical implications. In this chapter, is reported an experience of an Integrated Waste Management Technology (IWMT) with microalgae in Argentina. The proposed IWMT includes microalgae as a complementary treatment of sewage effluents in waste stabilization pond systems, with the triple objective of wastewater purification, recovery of nutrients in biomass, and mitigation of greenhouse gases by using bioenergy from the biomass generated. Experiments were carried out with the *Scenedesmus quadricauda* microalgae, growing it in four concentrations of effluents (T25%, T50%, T75%, and T100%). Microalgae productivity parameters and energy and environmental qualities were studied. The species was able to grow successfully in T25% and T50% treatments, but not in T75% and T100%. This implies that it is still necessary to dilute the effluents to reduce their organic load, which at some times of the year (mainly the dry autumn-winter season) may exceed the limits allowed for their discharge. The crop has been able to grow without temperature control. The maximum CD in the treatments was around 70% higher than the control (only culture medium). The organic load reduction capacity was on average 83.4% ± 5% and 74.55% ± 4.2% (for T25% and T50%, respectively). The removal of phosphates and nitrates was 57.6% and 58.7% in T25%, and 54.6% and 76.9% in T50%. Total coliforms and fecal coliforms were reduced by 89.6% and 77.4% for T25%, and 86.6% and 68.7% by T50%. In all cases, it was possible to confirm the ability of the microalgae to remove nutrients and reduce the organic load and pathogens. The water treated with microalgae has reached permitted values for be discharged. The biomass generated has a high energy potential in comparison with other fuels, close to 4.41 ± 0.43 kWh/kg. The integration of algae in tertiary systems could improve the treatment of wastewater and water cleaning, with the possibility of achieving the reuse of water. The proposed system was simple, and can be easily replicated on larger scales, including some optimization factors if necessary. Under the pressure of climate change, the IWMT will be essential technologies particularly in regions with low water and energy availability, mitigating GHG emissions and strengthening local communities.

Keywords

Bioenergy · Circular bioeconomy · Ecological footprint · Microalgae · Wastewater remediation

Abbreviations

CD	Cell density (cell/mL)
CFP	Carbon footprint (t CO_2eq)
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand (mg/L)
DM	Detmer culture medium
DT	Doubling time (day)
EFP	Ecological footprint
GHG	Greenhouse gas
HCV	Higher calorific value (MJ/kg)
IWMT	Integrated waste management technology
LCV	Lower calorific value (MJ/kg)
ORP	Open raceway pond
PBR	Photobioreactor
RE	Removal efficiency (%)
TBH	Total biomass harvested (grams)
TN	Total nitrogen (mg/L)
TP	Total phosphorus (mg/L)
WFP	Water footprint (m^3 per unit of manufactured product or service consumed)
WSP	Wastewater stabilization ponds

6.1 Introduction

The "biomass" includes a very heterogeneous set of materials that have organic matter as the main component (Sherwood 2020), excluding those that have been incorporated in geological formations undergoing a mineralization process (i.e., fossil fuels). An observation to the elemental composition of the biomass resources allows to assume that about 50% of the dry weight of them is carbon (Grobbelaar et al. 1988). On this basis, it is stated that the energy obtained from any of these resources is carbon neutral: although there will be CO_2 emissions (main greenhouse gas, GHG), that carbon had already been fixed by the plant previously, through photosynthesis. So the use of biomass does not generate emissions or contribute to global warming (which may not apply in all cases, Agostini et al. 2014; Haberl et al. 2012; Wiloso et al. 2016; Khan et al. 2020a, b). It is a renewable resource, although it will depend on the intensity of use (Keegan et al. 2013). It is widely available (possibly, the sites with the lowest biomass presence are the deserts and arid areas of the world) and accessible as it does not require specific equipment and qualified personnel to be able to locate and access resources (such as fossil fuels) (Bilgili et al. 2017; Pleissner 2020).

The great diversity of materials that are included under this term (forest, agricultural, livestock, agro and forestry industries, sewage effluents, energy crops, microalgae, urban wastewater, urban solid waste, sedimentation sludge, etc.) makes it a versatile energy source, from which solid, liquid, or gaseous biofuels can be obtained, using more or less complex processes and for various applications (REN-21 2019; Hidalgo et al. 2019; Ubando et al. 2020). An energy system based on biomass is intimately linked to each territory: from the production or generation of biomass, the recollection, processing, transportation, energy conversion, and final application (Pfau et al. 2014; Manrique 2017; Meena and Lal 2018). In these biomass supply chains, each stage involves different organic resources or residues, actors and sectors of the territory (such as the forestry, energy, agricultural, economic, industrial, governmental sector and many others). (Carus and Dammer 2018; Manrique et al. 2020). A bioenergy project will, therefore, impact in multiple aspects of the territory (economy, social, politician, institutional, environmental) not only in the provision of renewable energy or mitigation of GHGs, which are the most recognized advantages worldwide (Kraxner et al. 2003; Keegan et al. 2013; Agostini et al. 2014; Rocca et al. 2015; Paletto et al. 2019; Linser and Lier 2020).

In rural or marginal urban areas, where modern energy services do not reach, biomass constitutes one of the most accessible fuel sources in its traditional form (REN-21 2019). In these sectors, the use of abundant residual resources can promote employment opportunities and niches for micro- or medium-sized companies (collection, treatment, commercialization and diverse equipment, among others), mobilizing regional development. As there is the possibility of introducing management practices and more efficient technologies, the energy obtained from biomass will result in greater benefits not only at the local level, but also at the national level (diversified primary matrix and less demand for imported fuels) (Demirbas et al. 2009; Heimann 2018; Pleissner 2020). Also, it can contribute to the fight against desertification, since it makes possible the productive use of marginal lands, on slopes or semi-arid lands and the implantation of energy crops in abandoned lands, which could prevent soil erosion and degradation (Kraxner et al. 2003; Manrique 2017; Jhariya et al. 2018a, 2018b). It can also be integrated with environmental recovery processes, mainly when they correspond to the use of by-products of productive processes or waste o sewage from human activities (Abdel-Raouf et al. 2012; Nagarajan et al. 2020).

For the characteristics mentioned, the biomass resources could transform the bases of a global economy highly dependent on non-renewable raw materials and fossil origin, to a mostly bio-based economy (Bilgili et al. 2017; Meena et al. 2018) and simultaneously address the three main global challenges: provision of safe water, accessible energy for all, and climate change mitigation (International Energy Agency (IEA) 2016; Mouratiadou et al. 2016; Del Borghi et al. 2020; Leivas et al. 2020). This chapter analyzes through a concrete case study how could be possible providing a comprehensive territorial strategy that is compatible with these current world goals towards sustainability (United Nations (UN) 2019a). Firstly, the role of biomass within this triple global challenge and the emergence of the new paradigm of the circular bioeconomy are discussed. Then, it is examined how the biomass can optimize communities' ecological footprint (EFP) and finally, a proposal for the use and management of biomass, and its potential in sanitation, recovery of nutrients, and energy generation, is evaluated.

6.2 Water, Energy, and Climate Change: The Top Three Global Challenges

6.2.1 What Role Does Biomass Play?

Climate change and access to water and energy represent three of the main challenges that will determine the sustainable development in the coming decades (Fig. 6.1) (Mouratiadou et al. 2016; Del Borghi et al. 2020; United Nations (UN) 2019a; Leivas et al. 2020). Since a few years ago, these aspects have been concurrently tackled from a nexus approach under the understanding that one aspect influences and is influenced by the other and all three are fundamental for the subsistence of human life (Food and Agriculture Organization of the United Nations (FAO) 2014; International Energy Agency (IEA) 2016).

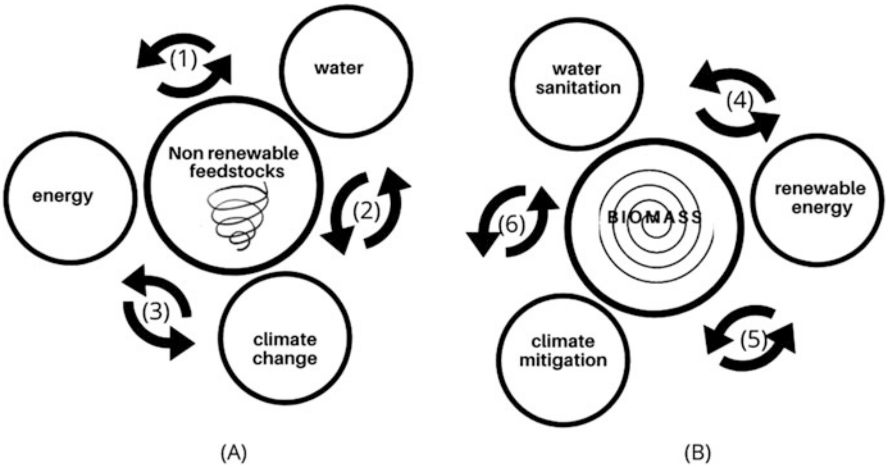

Fig. 6.1 Contrast between organizational models of the world economy: (**a**) fossil fuel dependent economy and (**b**) circular bioeconomy, and potential linkages between water, energy, and climate change (see in the text). Where: the downward spiral of (**a**) refers to the depletion of finite resources and (1–3) imply high dependence of one sector on the other, and high negative impact on each other. (1) Increased use of fossil energy will demand more water and (3) greater amount of GHG emissions. Greater change in the climate will imply less availability of water (2) and will require more energy to access water (3). The continuous spiral in (**b**) refers to renewability of the raw material and (4–6) propose ideal relationships between the elements, with optimization of their use, minimization of impacts, and multiple advantages of biomass utilization. Microalgae biomass could allow simultaneously water recovery, renewable energy generation, and climate change mitigation

In a fossil-dependent world economy such as the current one, energy and water are intricately connected (Bilgili et al. 2017; Leivas et al. 2020; Teotónio et al. 2020) (Fig. 6.1a). The energy sector requires 15% of global water withdrawals for energy production (including from resources extraction to their transformation into energy) (World Water Assessment Program (WWAP) 2017). By 2035, global energy consumption will increase 50%, implying an increase in water consumption of 85% (International Energy Agency (IEA) 2016). The water access demands energy for pumping water extraction, transportation, treatment, and desalination as well as for irrigation. The climate change will affect both the energy and water sectors (Mouratiadou et al. 2016; Meena et al. 2020a). Indeed, as the temperature rises as projected, there will be places with greater demand for water in the face of drought and reduced rainfall, so access to water will require greater energy expenditure (Leivas et al. 2020). For example, the surface water pumping requires 30% less energy than the underground water pumping, but because the water level could decrease in some territories, it is very probable that the groundwater demand increases (World Water Assessment Program (WWAP) 2017). The provision of cleaner water and energy services is also linked to the health, economic activities, and family life; therefore, climate change will mostly affect the most vulnerable sectors (Mouratiadou et al. 2016; Bilgili et al. 2017). Finally, the emissions derived from the use of fossil fuels for the provision of energy imply the greatest impact on the warming of the Earth's atmosphere (mainly from electricity generation and transport). In this way, the GHG emissions into the atmosphere are strongly dependent on the current ways of organizing the world economy: almost 80% of these emissions are related to the energy sector (FAO Food and Agriculture Organization of the United Nations (FAO) 2014; Intergovernmental Panel Climate Change (IPCC) 2006).

In a context of probable modification of the average conditions of the global atmosphere, which will affect the availability of water and access to energy sources (Siddiqi and Anadon 2011; Leivas et al. 2020) the *bioeconomy* represents an opportunity to rethink the development of the territories, as well as to face the commitments against the climate change (El-Chichakli et al. 2016; Del Borghi et al. 2020) (Fig. 6.1b). The base of the bioeconomy is the use and management of biomass in its multiple forms getting food and animal feeds, bio-products, and biofuels (Birner 2018; European Commission (EC) 2018; Sherwood 2020). It appears as a new model towards sustainability and seeks to highlight the biological origin of economic processes, and the problems humanity faces in relying on a limited amount of fossil resources, which are unevenly distributed and whose intensive use is affecting atmospheric GHG balances (Rodriguez et al. 2017; Birner 2018). It is not a new word, but its concept has been and is being redefined over the years, in the search for a conceptual and operational framework that leads the transformation of the global economy highly dependent on non-renewable raw materials to a sustainable "biological or biobased economy" (Bilgili et al. 2017; Sanders and Langeveld 2020; Pleissner 2020).

On the other hand, the so-called *circular economy*, driven by environmental problems and resources scarcity, has also gained strength since the late 1970s

(Wautelet 2018). It emerges from different schools of thought, and proposes a different look at the current resource management schemes in the various territorial production chains, where there are large amounts of waste and effluents, which in marginal economies are largely untreated. This new model of intervention on the resources of nature emphasizes a measured and rational use of the raw material of origin, and a follow-up from its collection, its transportation, its processing, and its conversion into some type of final product or service. It seeks the benefits maximization that each resource can provide, and the minimization of material and energy losses in the production circuit. In this sense, each portion of matter or energy removed from a stage pursues to be reinserted in a new cycle of use and, therefore, is described as an economy with closed material loops. It is thus presented as a model that overcomes the traditional economic scheme of linear use of resources (Ellen Macarthur Foundation (EMF) 2015; Kirchherr et al. 2017; Kalmykova et al. 2018; Del Borghi et al. 2020). The key to this model is that nothing is lost but that the different production cycles are intertwined with each other, and, therefore, the residues of one cycle constitute value resources for the following cycle (Ellen Macarthur Foundation (EMF) 2015). Sharing, maintaining, reusing, redistributing, remanufacturing, recovering, and recycling are some of the basic principles that underpin the new model (Carus and Dammer 2018).

The bio- and circular economies are currently considered as two complementary policy strategies that have biomass and its derivatives (organic waste, effluents, and wastewater) as the basis that supports their actions (De Schoenmakere et al. 2018). The term "*circular bioeconomy*" integrates the principles of bioeconomy into a broader set of policies that promote the circular economy (Carus and Dammer 2018; Sherwood 2020). Although this current of thought is in the initial stage of conceptualization and practice (Kirchherr et al. 2017; Linser and Lier 2020), some characteristics have reached consensus in the world community to define the circular bioeconomy, where the biomass is the cornerstone (Keegan et al. 2013; Nagarajan et al. 2020; Pleissner 2020). This new model includes a comprehensive, efficient, and prioritized use of resources ("cascade use," Keegan et al. 2013; Erajaa 2016; Pleissner 2020); substitution of materials and energy from fossil sources, with materials and energy derived from biomass (biomaterials and bioenergy) (Kalmykova et al. 2018); efficiency of processes and introduction of environmentally friendly technologies (bioprocesses, appropriate and clean technologies) (Vanhamäki et al. 2020); reintegration of waste into new productive cycles (circular economy), and less demand for fresh materials (BIORES 2015; Von Braun 2015; Carus and Dammer 2018; Sherwood 2020; Del Borghi et al. 2020) among the main concepts.

In the context of the global challenges posed, cascading chains with long-term carbon sequestration must be prioritized for the mitigation of climate change while promoting an efficient and minimized use of water resources (Vanhamäki et al. 2020). The energy use of biomass is the one that gives the least added value to the resource, so it must be included as the last option for use within the chain, so that the material has been previously used in all possible ways (Carus and Dammer 2018).

6.2.2 Ecological Footprint and Circular Bioeconomy

From a broader perspective, the circular bioeconomy can have a high impact on reducing the EFP. This concept was continuously matured by one group of scientists (Global Footprint Network, GFN) since the 90s. It is a measure of human demand on the Earth's ecosystems (including food, wood, fiber, carbon sequestration, and infrastructure housing) and the Earth's ability to meet these demands ("biocapacity") and shows this into one number (Borucke et al. 2013). The GFN also estimates the "Earth Overshoot Day," day when humanity will have used the year-round budget for nature's resources (Monfreda et al. 2004). The date has been advanced 2 months in the last 20 years (Wackernagel et al. 2019). On July 29 the last year (2019) the global human demand for resources and services was 75% greater than the supply (1.75 planets), implying a value that is 2.5 times higher than the estimated six decades ago (1961). This implies that we are depleting our natural capital and this can be seen through the overexploitation, deforestation, contamination, loss of biodiversity, climate change, among others (Jhariya et al. 2019a, 2019b). Avoiding ecological collapse and therefore humanity requires a rigorous immediate action plan.

In this context a global conversion of the economy is necessary: from fossil-fuel-driven cultures to biomass-driven cultures (Galli et al. 2012; Pleissner 2020). This phenomenon has already occurred previously in historical times but in the opposite direction: societies highly dependent on biomass resources reorganized their economies with a focus on new fossil energy resources in the eighteenth century (with the advent of coal) and in the 19th and 20th centuries (with the advent of oil). In this time, the technical and technological developments allow more efficient ways of using available and renewable biomass and even get benefits that go beyond energy (Matamoros et al. 2016; Tang et al. 2020), mainly in rural areas (Pleissner 2020).

The joint application of both concepts of "bioeconomy" and "circular economy" ("circular bioeconomy"), from a competitive approach that guides practical strategies on the regions, reduces the assimilation pressure of residues within ecosystems, but also the over-extraction of resources (De Schoenmakere et al. 2018). Since the circular bioeconomy avoids using fossil carbon, the carbon footprint (CFP) will be low as a direct consequence of its implementation (Carus and Dammer 2018) contributing to climate mitigation targets. Moreover, there are some key areas in which the circular bioeconomy promoting could have a significant impact for the EFP decreasing in the communities (Pfau et al. 2014):

- Resource use optimization: lower demand for natural resources due to a more comprehensive use of them, and reduction in the waste discharge and rubbish generation (Ellen Macarthur Foundation (EMF) 2015; Pleissner 2020; Del Borghi et al. 2020).
- Carbon reserves: in its natural forms, biomass fixes carbon in the tissues, keeping it there for long periods of time, with which by forming ecosystems, it not only constitutes an important reserve of carbon not emitted into the atmosphere, but

also the associated biodiversity is preserved as a source of future resources (Intergovernmental Panel Climate Change (IPCC) 2006; Manrique 2017; Carus and Dammer 2018; Giuntoli et al. 2020; Manrique et al. 2020).
– Energy: renewable energy can be obtained from biomass residues and/or use of biomass in those ways in which it does not compete for the use of land, water, or affect biodiversity (residual biomass). Although biomass combustion generates carbon emissions, it is assumed that this carbon was previously fixed by the biomass plant structures and, therefore, does not contribute to global overheating, making it possible to partially reduce the use of fossil fuels (Agostini et al. 2014; BIORES 2015; European Commission (EC) 2018). It is fundamental because currently, the carbon emissions from burning fossil fuels constitute 60% of humanity's EFP (Wackernagel et al. 2019). From another angle, every time a material is recovered, reused, or recycled, there is indirectly an energy saving by avoiding the energy demand for the production of a new product unit (Kirchherr et al. 2017; Carus and Dammer 2018; Vanhamäki et al. 2020).

There is still a fourth aspect in which biomass can contribute to reducing EFP (in a similar sense to that analyzed for energy) and is linked to water use (Qadir et al. 2020). On the one hand, the use of some forms of biomass can imply water savings: for example, taking advantage of existing residues for food, feed, energy, or substances purposes, instead of growing a new biomass unit with the same purpose, which will demand more water. On the other hand, wastewater and effluents can be recovered and cleaned, through phytoremediation, enabling this same water to be reused (Prajapati et al. 2013; Singh et al. 2016; European Commission (EC) 2018; Nagarajan et al. 2020).

For a growing world population, in a finite world, only a circular bioeconomy will be able to sustain the growing demand for subsistence (European Commission (EC) 2018; De Schoenmakere et al. 2018). Linser and Lier (2020) argue that the circular bioeconomy is the pathway to meet the Sustainable Development Goals (SDG) by 2030 (United Nations (UN) 2019a). The promotion of a circular bioeconomy does not imply assuming that biomass can potentially achieve the complete replacement of fossil fuels and non-renewable materials that are currently used (like as minerals and metals, for example, Carus and Dammer (2018). At least not with the current technological and production means (Sherwood 2020). However, the society in general agrees about the need to reduce the quantity and quality of waste generated in order to ensure the capacity of natural systems to remain productive in time (Qadir et al. 2020; Vanhamäki et al. 2020). Achieving greater efficiency in resources use, limiting the use of finite feedstock, and promoting renewable and less polluting systems than current ones are the fundamental principles of circular bioeconomy. However, attaining circularity requires concrete alternatives that give multiple solutions to the needs of the territories and their communities (Kalmykova et al. 2018; Sherwood 2020).

6.2.3 Territorial Comprehensive Management Waste

It is easy to understand that in primeval cultures the solid wastes were dumped or buried outside their settlements, while aqueous discharges were made directly into the ground or into local water courses, and gaseous emissions were simply released into the atmosphere (Meena et al. 2020b, c). However, as the communities increased in number and quantity of demands, the amount of waste generated also grew in volume, quality, and speed of generation, requiring increasingly organized forms of management to avoid sources of contamination (Seadon 2006; Rodríguez and Aramendis 2019). Indeed, global solid waste generation is expected to grow a 61% by 2050 (from 2.1 billion tons per year) (Kaza et al. 2018) and wastewater volumes are projected rise up to 573.8 billion cubic meters by 2050 (Qadir et al. 2020), involving twice the current generation. These huge quantities of waste and effluents generated from the productive activities contain materials, water, and energy that are annually wasted, and they generate environmental impacts and economic costs (Tarallo et al. 2015; World Water Assessment Program (WWAP) 2017; Nagarajan et al. 2020; Rajesh Banu et al. 2020).

From the outlined outlook, it is worth asking: What are the practical tools that the circular bioeconomy paradigm can provide in this context? Which concrete strategies can contribute to face the three global challenges water–energy–climate change while taking care of converting waste into resources? Perhaps one of the first proposals that have a place within this new paradigm is those related to the proper management of waste. The "integrated waste management" was first mentioned in the 1990s, as a new starting point for waste treatment with efficient material and energy management and reduction of environmental impacts (UNEP 1996; Morselli et al. 2008). Integrated Waste Management Technologies (IWMTs) include comprehensive and hierarchical management proposals (cascade use) to treat most of the discarded residual fractions (Seadon 2006; Gouveia et al. 2016; Morselli et al. 2008; Hidalgo et al. 2019; Rajesh Banu et al. 2020) and where the ideal is the total and absolute reduction of waste (Tarallo et al. 2015; Sanders and Langeveld 2020).

In a context of future scarcity, all residual flows have become part of a new category of interest, where water, energy, and materials are abundant resources (Abdel-Raouf et al. 2012; Acien Fernández et al. 2017; Barkia et al. 2019). Its use not only implies a thoughtful and committed involvement in safeguarding the natural terrestrial and aquatic environment, but a potential source of income and engine of initiatives with local impact (Drira et al. 2016; Gouveia et al. 2016; Hidalgo et al. 2019). The IWMT might be one of the most successful strategies for efficient resource management. Although IWMTs are not standardized technologies, they basically include all the concepts of the circular economy and there are still successful examples in the circular bioeconomy, such as those in which microalgae are included as one of the most versatile biomass resources. In these new management schemes, microalgae could become the star of this circular bioeconomy (Xiao et al. 2011; Gouveia et al. 2016; Acien Fernández et al. 2017; Nagarajan et al. 2020; Rajesh Banu et al. 2020). Microalgae can easily adapt to different conditions and are practically ubiquitous in all kinds of environments. They have high efficiency in the sunlight use, a fast growth, and higher productivity than other agricultural crops (Sydney et al. 2011; Han et al. 2015). Their potential role as suppliers of different types of fuels (biomethane, biodiesel, bioethanol, biohydrogen, among others) makes them a multiple alternative for the global energy supply (Anand and Arumugam 2015; Zuliani et al. 2016). Although the cultivation of algae like any other crop requires the addition of nutrients (Slade and Bauen 2013), it is possible to grow algae in nutrient-rich effluents with the dual purpose of cleaning the water and capturing those nutrients as inputs for the multiplication of algal biomass (Kothari et al. 2012; Nagarajan et al. 2020). This water purification capacity is known as "phytoremediation" and it makes microalgae an excellent environmental resource, since once the generated biomass is harvested, it can be used for industrial, food, medicinal, cosmetic, or energy purposes (Prajapati et al. 2013; Singh et al. 2016; Rajesh Banu et al. 2020). Successful global experiences encourage in this regard (Andrade et al. 2009; Abdel-Raouf et al. 2012; Wong et al. 2015; Zuliani et al. 2016; Barkia et al. 2019; Tang et al. 2020).

6.2.4 Circular Bioeconomy: Alternative or Need?

Currently, more than 80% of the world's wastewater does not receive any type of treatment, a figure that reaches 95% in some less developed countries. The wastewater sanitation services that cover rural and urban sectors can only be considered as safe (no contact with human excreta) in 26% and 35%, respectively (World Water Assessment Program (WWAP) 2017). In addition, the presence of emerging pollutants, many of which have toxic effects is increasingly frequent and in higher quantities because hardly the traditional wastewater treatment plants have the technical capacity to remove these new substances (Matamoros et al. 2016). Likewise, wastewaters contain many nutrients which can produce eutrophication in the bodies of water (Andrade et al. 2009; Singh et al. 2016). Although there are physical or chemical processes that could be applied for the purification of the effluents, this implies a high investment of money and energy, and not in all cases they are efficient systems (Drira et al. 2016). Systems such as the wastewater stabilization ponds (WSP), which are the most common and widely used due to their simplicity, absence of mechanical elements and the low cost of investment, operation and maintenance; commonly do not remove in a 100% the load of incoming waste and many organisms still remain in treated effluents. Even when discharges are made in compliance with the standards that regulate the discharge limits, they often pollute the receiving waters due to the variation in the flow of water and the cumulative effects on the environment (World Water Assessment Program (WWAP) 2017).

The integration of algae in tertiary systems could improve the treatment of wastewater and water cleaning, with the possibility of achieving even the reuse of water if the conditions for its use were reached (Gouveia et al. 2016). Moreover, the culture medium implies a high cost in microalgae cultivation (Kothari et al. 2012), so the nutrient-rich wastewaters are an opportunity and not a problem for the microalgae production (Menger-Krug et al. 2012; Nagarajan et al. 2020).

Given that the circular bioeconomy pursues the utopia of maximizing efficiency in the use of resources and zeroing waste (Clark et al. 2016) by returning them to use (Von Braun 2015; Vanhamäki et al. 2020), it is necessary to identify concrete measures that can make the concept operational and that politicians, decision makers, and stakeholders can observe its practical implications, in order to include them in a specific regional implementation strategy (Vanhamäki et al. 2020). However, there are still not enough experiences or guidelines, which can lead this popular global and current goal into practice (Sherwood 2020; Pleissner 2020). The IWMT with microalgae may be one of the oldest and best known of the strategies that must be studied, adapted, and promoted in the territories (Oswald et al. 1953).

This work contributes in this direction, focusing on one IWMT with microalgae in Argentina, where there are few experiences yet, but with promising results (Méndez et al. 2011; Codina et al. 2012). IWMT from microalgae can become an efficient technical, environmental, and productive practical strategy, of immediate application, with impact on the water security, health ecosystems, conserving energy and mitigating the GHG emissions. However, given that many factors define the growth and composition of microalgae biomass and their purification capacities, the performance must be evaluated in local conditions (Park et al. 2011). An IWMT system is described in the next section, where its qualities, potentials, and needs for further research and development can be appreciated, for a broader promotion and impact.

6.3 Biomass Production from Wastewater: A Win–Win Strategy?

Biomass energy recovery is an efficient alternative to the urgent need to reorient the production model towards a circular model based on the bioeconomy. Not only does it mean obtaining a renewable fuel, neutral in terms of CO_2 emissions and competitive in price with fossil fuels, but it also has a fundamental part in the ecosystem management and opportunity of development of world rural areas. This chapter reports the results of a study of productivity, energy, and environmental qualities of microalgae growing in urban sewage effluents, highlighting some aspects of performance optimization, which was developed as part of the National Microalgae Network (https://www.magyp.gob.ar/site/areas/microalgas/). This Network was created in 2015 in Argentina, through an initiative promoted by the Ministry of Agriculture, Livestock and Fisheries and the Ministry of Science, Technology and Productive Innovation, and works to join public and private efforts for integrated development of technology and its application to specific problems in the country. The context of opportunity for the application of the proposed IWMT system is reviewed below.

6.3.1 National Context for the Promotion of Integrated Waste Management Technologies

At the present, around 50 governments of the world (developed countries and many in development), have defined formal strategies for the development of their Bioeconomy and are making progress in the design of specific programs and policies for their consolidation (German Bioeconomy Council (GBC) 2018; Linser and Lier 2020). Argentina has joined this trend, with the creation of its Bioeconomy Promotion Program under the Secretariat of Aggregate Value of the Ministry of Agribusiness, given the abundance of biomass resources in the country, industrial capacities, services, and of the quaternary sector (of information and knowledge) existing (Trigo et al. 2017). As in other countries of the region, the strategies developed around the water, energy, and climate change will enable the strengthening of regional economies and territorial sustainability.

The greater challenge in the country is the water quality and not the quantity, since the national coverage of sewage services is 40% of the population, compared to 82% covered by the public water network (Instituto Nacional de Estadísticas y Censos (INDEC) 2010), with differences between urban and rural sectors. For the year 2015, about 40 million inhabitants of the country are registered in urban areas, sector where there is still a lack of 13% in the access to the public network water and 42% to sewers (Bereciartua 2017). Some sources estimate that the level of wastewater treatment is between 15 and 20% of the collected water. The situation in rural areas is more disadvantageous, although it is currently not possible to have reliable statistics. National statistics allow identifying and dimensioning some key areas where the country should concentrate efforts (InterAmerican Network of Academies of Sciences (IANAS) 2019), to achieve 100% safe water coverage.

From the energy point of view, the total renewable power capacity was doubled from 2007 to 2017, and without considering the hydropower, the capacity of renewables was multiplied by six (REN-21 2019). However, excluding the hydroelectric power, the share of renewable sources is still low (barely 2%) although Law 27,191 provides that in 2025, 20% of all Argentina's energy generation will be renewable. The energy diversification together with the promotion of energy efficiency measures is key to achieving international environment commitments but above all, to ensure one environmental quality that allow sustain the country economy and their people (KPMG 2019).

Finally, in terms of climate change, between 1961 and 2018, the temperature increased on average 1 degree Celsius in the country. Rainfall also increased significantly and the trend, in the medium term, will be even worse (Secretaría de Ambiente y Desarrollo Sustentable de la Nación (SAyDS) 2015). In particular, extreme temperatures and water scarcity are expected in the northwest region. Argentina presented emission reduction commitments as National Determined Contributions (NDCs), which differ in that they contain goals that depend on external financing (conditional) and others that do not (unconditional). The country has proposed to unconditionally—that is, without receiving financing and technological support—reduce 18% of GHG emissions by 2030. The country could reduce an additional 19%, which would be conditional on some type of international support, be it financial, technological or capacity development. In total, the reduction would be 37% until 2030. 93% of the Argentine reductions involve the transport sectors (through changes in the forms of mobility), energy (boosting energy efficiency and renewable energies), and forests (through its conservation and recovery). There is great potential in the implementation of bioeconomy strategies to achieve the proposed objectives. This study reflects some of these possibilities.

6.3.2 Microalgae Growth in Sewage Effluents

The strain used for this study was from the Microalgae Laboratory of the Faculty of Natural Sciences of the Trelew, belong to the National University of Patagonia San Juan Bosco. For the selection of the species to be used, a sampling was carried out in the receiving freshwater body of the treatment plant, characterizing the phyco-flora that was present in the sample concentrated by phytoplankton net of mesh size of 30 μm, by means of a qualitative analysis. The determination was made in the Laboratory of Water Quality of the Faculty of Natural Sciences of the National University of Salta.

Scenedesmus quadricauda was selected since it was recognized as having optimal qualities for use in wastewater treatment for its ability to withstand high concentrations of nutrients, have high metabolic activity, and ability to resist environmental variations (Xiao et al. 2011; Anand and Arumugam 2015). *Scenedesmus quadricauda* (Turp.) De Breb., Var. Longispina is described in Guerrero (1941) as microscopic, tetracellular colonies or with fewer cells; the distal with two powerful straight stingers, longer than them. The habitat where it found is freshwater puddles. According to the Biodiversity Information System (Biodiversity Information System (BIS) 2019), the species has been found in eight provinces of the country, including the Province of Salta.

The microalgae were kept in modified Detmer culture medium—DM—(Accorinti 1960) in a chamber under lighting conditions with 12:12 photoperiod (3000 lux), daily agitation. A system of continuous tests was designed to allow the progressive acclimatization of the microalgae by growing it in sewage effluents. Dilutions of the effluent were made at 25, 50, and 75% with the DM until 100% effluent was reached (Table 6.1). The tests were done with sewage effluent pre-treated with coarse filtration using cotton and gauze as a filter medium, with an initial Scenedesmus cell density (CD) of 250,000 cells/mL. Triplicate tests were performed, with a volume of 3000 mL in each case, and in parallel, control cultures

Table 6.1 Treatment characteristics

Treatment	Characteristics
T25%	25% sewage effluent and 75% DM
T50%	50% sewage effluent and 50% DM
T75%	75% sewage effluent and 25% DM
T100%	100% sewage effluent

Table 6.2 Composition of typical wastewater of the study area

Variable	Unit	Value
COD	mg/L	280.78 ± 390
TN	mg/L	15.39 ± 5.76
TP	mg/L	0.841 ± 0.44
Sulfides	mg/L	3.67 ± 5.75
Phenols	mg/L	0.088 ± 0.05
Settable solids 2 h	mg/L	0.11 ± 0.13
Temperature	°C	23.12 ± 6.56
Conductivity	μS/cm	531.1 ± 95
pH		7.54 ± 0.23

COD chemical oxygen demand, *TN* total nitrogen, *TP* total phosphorus

were started only containing the DM medium with the microalgae without effluent (T0%). The first set-up tests were made by growing the strain in DM medium (control) with and without temperature control. After these first experiments, a better response of the crop was observed growing at room temperature, so the rest of the treatments were performed at room temperature.

The sewage effluents for the tests were obtained from samples taken at the exit of the third pond of the sewage effluent plant called the North Purification Plant, which is located in the north of the municipality of Salta capital (left bank of the Mojotoro River). Sampling campaigns were carried out in the different seasons, observing great variability in the samples (Table 6.2). The trials began with samples from the fall and winter campaign and were repeated twice. 50 litters of sample were collected each time in plastic drums from the outlet duct of the tertiary ponds. Samples were stored at 5 °C in a refrigerator for testing. Subsamples were taken for physical–chemical analysis in an external Laboratory, with certification.

Microalgae productivity parameters and energy and environmental qualities were studied. CD was estimated with a 0.1 mm deep Neubauer chamber until the start of the stationary phase. Specific growth rate (day-1) was estimated as: μ = (ln Nf- ln Ni/(tf-ti)); Ni = cells density at the start of the exponential phase (ti), and Nf = CD at the end of the exponential phase (tf). Nmax (cell/mL) was considered by convention the highest μ observed for each treatment. The doubling time (DT), time needed for the population to double, was calculated as DT (day) = (lnNt-lnN0/0.639)/(t-t0), where 0.639 = Ln2. Sampling was done every day. Before entering the stationary phase, the agitation was stopped to induce the sedimentation of the biomass for 3 days. Finally it was calculated the total biomass (TBH) harvested by means of a centrifuge (5000 rpm) and dried at 70 °C ± 0.5, until it reached a constant weight.

Given the enormous amount of biochemical components that microalgae possess, it is possible to obtain practically any liquid, gaseous, or solid fuel (Ubando et al. 2020). However, the most basic form of energy generation from algal biomass is the direct combustion of the same generating heat and electricity (Kadam 2002). Therefore, the calorific value of algal biomass in its solid fuel form (dry biomass) was explored. Higher calorific value (HCV) was determined by Parr 1108 Oxygen Combustion Bomb. Specific experimental procedures and calculation formulae are detailed by the European Standard EN 14918: 2009. Following Grobbelaar et al. (1988), a 7.45% participation of elemental hydrogen in microalgal biomass was assumed for the Lower Calorific Value (LCV). On the other hand, in general terms, it was considered that the purification capacity of the algae was efficient, if the effluents were able to meet the discharge limits required by current legislation. In addition, RE between the initial situation and the final situation was evaluated to know the magnitude of the change (both in COD and in nitrates and phosphates). The Removal Efficiency (RE) was estimated considering: RE = (Cf-Ci)/Ci * 100%, where Cf is the final concentration at time tf and Ci is the initial concentration at the time ti. Laboratory determinations were made following the standard SM (Standard Methods for the Examination of Water and Wastewater) as follows: COD (mg/L) according to SM 5220 D Ed22, nitrates and phosphates (mg/L) according to SM 4110 B Ed22, and total and fecal coliforms according to SM 9221 B/C Ed 22. All values are summarized as mean ± SD. The student t-test was used for statistical analysis (significance: $\alpha = 0.05$).

6.3.3 Results and Discussion on the Experience

It was interesting to observe the response of the tests, with the lower investment of energy resources and the lower costs, in view of the possibility of their easy replication in different locations. The first trial with the control culture in DM medium was carried out to compare its response to ambient temperature conditions (13.3 ± 3.1 °C) and controlled (18 ± 0.1 °C), considered as half of the safe thermal limit (Zargar et al. 2006). It was interesting to know how microalgae cultivation could respond to climatic variations in the region, with low temperatures. Figure 6.2 shows a better crop yield of *S. quadricauda* when it was subject to the temperature dynamics of the autumn-winter season. This could imply that the crop responds better when it is subjected to thermal stress, with an incidence of temperatures higher and lower than the control temperature (Sonmez et al. 2016). In both cases, the point of maximum growth was obtained on day 13.

On the other hand, the temperature records inside the laboratory where the tests were performed using thermocouples stored in data logger for later analysis. These data were compared with temperature records outside the building (exterior) (Table 6.3). The amplitude of the temperature range recorded outside was greater than that achieved in the laboratory, and extremes of about 1 °C and up to 30 °C can be observed, achieving possibly more favorable conditions for the growth of the crop inside the laboratory. The next tests were, therefore, carried out at room temperature. This is an advantage by replicating the trials in open ponds, enabling perhaps this IWMT in regions of the world where there are high temperature fluctuations (diurnal and seasonal). Likewise, avoiding temperature control implies a decrease in operational costs. Sonmez et al. (2016) effectively observed that *Scenedesmus sp* can adapt successfully to daily temperature fluctuations in a range of 10–50 °C, even

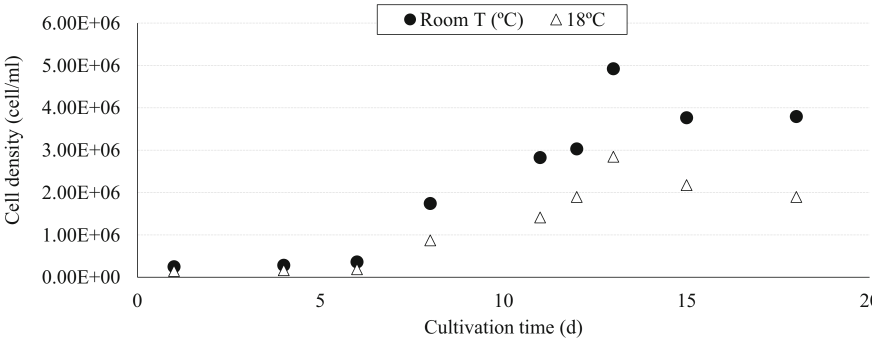

Fig. 6.2 Growth (cell/ml) of *S. quadricauda* in Detmer medium at room temperature (circle) and controlled temperature (triangle)

Table 6.3 Average temperatures recorded during the test period inside and outside the laboratory. Different letters in the same row, indicates significant difference ($\alpha = 0.05$)

Temperature	Room T (°C)	T (°C) (exterior)
Mean	13.6[a]	11.1[b]
Standard deviation	3.1	5.1
Minimum	7.6	1.2
Maximum	23.4	29.4

increasing lipid production when the species is subjected to the variable temperature regime (between 16 °C and 30 °C).

Figure 6.3 shows the cell growth parameters for the four treatments performed. For 25% of effluent, the culture was reproduced until doubling the initial concentration between day 2 and 3 (DT = 2.87 d), with a DT less than the control (DT = 3.38 d), associated with the greater availability of nutrients. On day 7, the greatest difference in CD was recorded with respect to the control, reaching a 95% higher value (value = 2.75×10^6 cell/mL). In later days, this difference was decreasing. On day 12, the aftershocks reached a stabilized value of 4.51×10^6 with the lowest coefficient of variation (CV = 0.5%), which was still higher than the control (65% higher). The maximum CD (5.77x 10^6 cell/mL $\pm 0.42 \times 10^6$) implied a 69% higher value in the treatments. A TBH of 0.526 g was achieved, implying a production efficiency of 0.173 g/L, achieving 1.7 times the amount of the control.

For the T50% treatment, the cultures had behavior similar to the first treatment. The cell DT was also faster than in the control (2.78 d vs 2.92 d) and in turn, it was also shorter than for T25%, possibly because the algae achieved an acclimatization process during the first treatment. In this case, the greatest difference in the cellular density of the treatment with respect to the control was reached at day 5 (113% higher). On day 12 the repetitions reached a stabilized value similar to the first

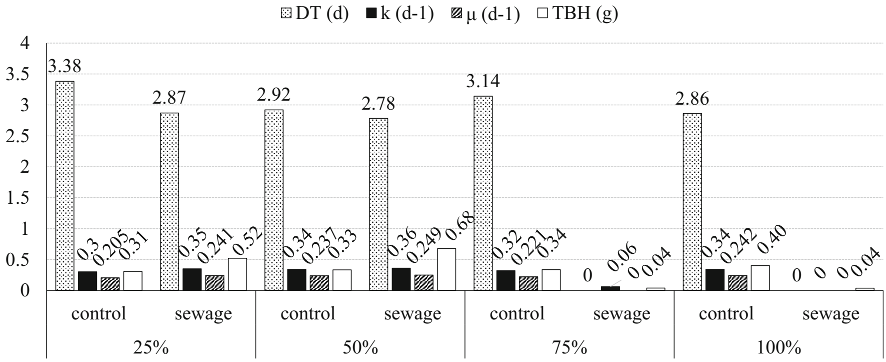

Fig. 6.3 Cell growth parameters for the four treatments in relation to the control. Where: DT, cell time doubling (days); k, number of generations (day-1); μ, growth rate (day-1); and TBH, total biomass harvested (grams)

treatment (with a value of 4.97 × 10^6 cell/mL and a CV = 1.46%). The maximum CD achieved was higher than in T25% (7.52 × 10^6 cell/mL ± 0.37 × 10^6). The TBH achieved was 0.687 g, implying a production efficiency of 0.226 g/L, achieving twice the control culture, and a total of 0.16 g more than in T25%.

The treatments T75% and T100% practically remained stationary and the microalgae could not reproduce. After a week they began to disappear, possibly due to the presence of other microorganisms of greater tolerance and aggressiveness such as the group of rotifers, which were detected in the trials, since the effluent was not sterilized. Although there are various treatments to combat them (Park et al. 2011), the objective was to know the response of the IWMT system with the lowest level of manipulation, energy investment, and resources. The T75% treatment reached day 7 a maximum CD of 4.15 × 10^5 cell/mL ± 1.42 × 10^5 cell/mL, after which it began to decrease dramatically. In the case of the T100%, the maximum value reached was 3.95 × 10^5 ± 1.73 × 10^5 cell/mL after which it also began to decrease its existence. The TBH was only 11% and 9% of the total value achieved in the control, whose average was 0.34 g ± 0.04 g.

The RE is shown in Fig. 6.4. The purification capacity of *S. quadricauda* could only be evaluated in the first two treatments that effectively fulfilled the growth cycle until the start of the stationary phase, while the species could not thrive in treatments T75% and T100%. The COD reduction capacity was on average 83.4% ± 5% for T25%, and 74.55% ± 4.2% for T50%. The removal of phosphates and nitrates was 57.6% and 58.7% in T25%, and 54.6% and 76.9% in T50%. Total and fecal coliforms were reduced by 89.6% and 77.4% for T25% and 86.6% and 68.7% by T50%. This implies that the microalgae have contributed to the sanitation of the effluents that, at some times of the year, exceed the organic load as well as the concentration of pathogens, allowed for discharges into watercourses. In this case,

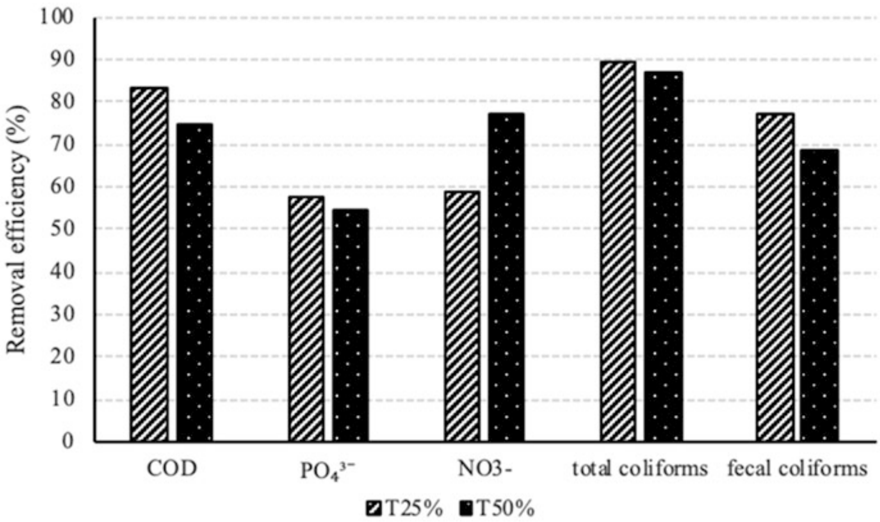

Fig. 6.4 Efficiency of removal of nutrients, organic matter, and pathogens present in the sewage effluents, by means of microalgae (in percentage)

the waters treated with microalgae have reached permitted values for be discharged. The study of nutrient removal by microalgae is the basis for the design of hydraulic retention time prediction models, necessary to adapt effluents to the discharge standards (Han et al. 2015).

The RE found is within the range of one of the few studies in the country on this species, carried out by Méndez et al. (2011), who indicate a COD removal capacity of 73.7%. Other authors report a COD removal of 55.7% (Chacón et al. 2006), 35.59% (Andrade et al. 2009) in fish farm effluents and 91.4% in WSP treatments plants (León and Chaves 2010). Regarding nutrients, nitrogen and phosphorus are the main chemical constituents of the dry weight of the microalgae biomass (Grobbelaar et al. 1988). Nitrogen is incorporated as nitrate ($NO^{3\ -}$) or as ammonium ($NH^{4\ +}$) (Abdel-Raouf et al. 2012). It is a critical factor in regulating the lipid content of microalgae, since nitrogen limitation stimulates lipid accumulation in algae cells, but decreases algal biomass production, so they are mutually exclusive mechanisms (Park et al. 2011; Anand and Arumugam 2015). Although the phosphorus content of microalgae is around 1%, it is essential in nucleic acid formation and energy transfer and it is one of the greatest growth limitations (Slade and Bauen 2013). In both cases its assimilation by algal biomass, therefore, is a fundamental nutrient recycling. Méndez et al. (2011) indicate removal of 40% nitrates, 93.8% phosphates, and total and fecal coliforms of 84.8% and 85.9%. Andrade et al. (2009) report removal efficiencies of 94.44% for ammoniacal nitrogen and 77.54% for phosphates. Xiao et al. (2011) point out that the removal of the total phosphorus and nitrogen in the digested wastewater after 8 days cultivation was more than 94%. Hammouda et al.

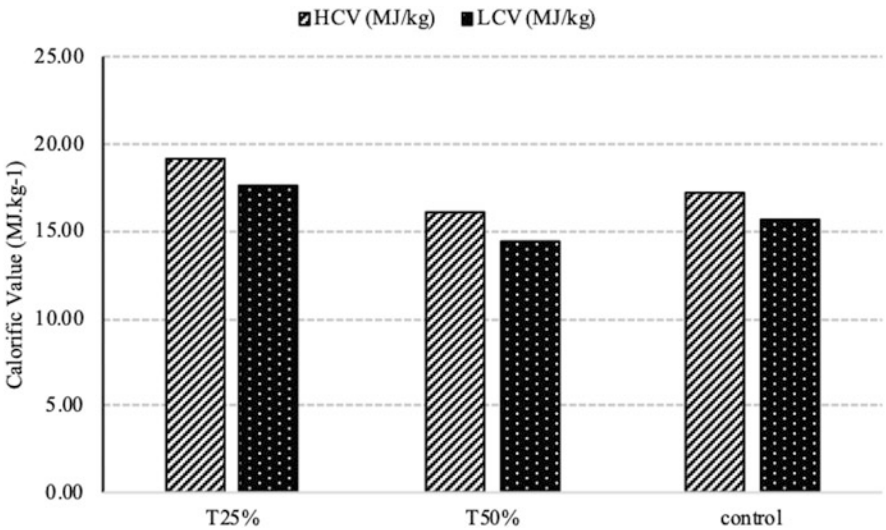

Fig. 6.5 Energy content of the microalgae biomass generated

(1995), in laboratory cultures using *Chlorella sp.* and *Scenedesmus sp.,* obtained 100% removal of nitrate, ammonium, and phosphorus after 36, 42, and 48 days. Furthermore, the microalgae reduce the pathogens present, probably by raising the temperature, the pH, and the dissolved oxygen concentration (Schumacher et al. 2003). It has been estimated that for every kg of microalgae biomass generated from sewage effluents, between 1.5 and 2 kg of O_2 may be released (Grobbelaar et al. 1988; Muñoz et al. 2004). In all cases it was possible to confirm the capacity of the microalgae to remove nutrients and reduce the organic load and pathogens. Further research is necessary to delve specifically into the recovery of other toxic ions or ions of economic interest, the feasibility of which has already been observed since the 1990s for this same species (Harris and Ramellow 1990). Abdel-Raouf et al. (2012) points to numerous trials with dangerous ions where the algae have been successful.

In recognition that each effluent that can be used as a culture medium will have a different physical and chemical composition (Anand and Arumugam 2015; Matamoros et al. 2016), it is necessary to evaluate the particular energy qualities of biomass in each of these effluents. The calorific value of the generated biomass is shown in Fig. 6.5. The results obtained are highly promising, and located within the range from 14 MJ / kg to 24 MJ /kg already mentioned by other authors (Chen et al. 2014). As in the previous case, given that the last two treatments could not be completed, the biomass harvest and subsequent processing by a combustion bomb were only performed to treatments T25% and T50%, as well, to the control culture.

The biomass obtained from the T25% tests has an energy content that was 11.19% and 12.33% higher than the control value (for HCV and LCV, respectively); while for E50% the biomass shows values 6.96% and 7.67% lower than the control (for HCV and LCV, respectively). Comparing between treatments, the energy

Table 6.4 Lower calorific value (LCV) for different resources reported in the webpage of the Forest Research of UK (https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels/)

Fuel	LCV (MJ/kg)	Bulk density (kWh/kg)
Wood (solid-oven dry)	19	5.3
Wood pellets (10% MC)	17	4.8
Miscanthus (bale—25% MC)	13	3.6
House coal	27–31	7.5–8.6
Anthracite	33	9.2
Heating oil	42.5	11.8
Natural gas	38.1	10.6
LPG	46.3	12.9

Where: 10%MC and 25%MC = 10% and 25% moisture content; LPG = liquefied petroleum gas

content was higher for T25%, which was even more advantageous than the HCV obtained for the control.

In any case, the biomass generated has a high energy potential (from 16.04 to 19.17 MJ/kg), in relation to other solid, liquid, and gaseous fuels (Table 6.4) being located at the same level as wood pellets with 10% humidity. The available energy is equivalent to an average of 4.41 ± 0.43 kWh/kg. Coimbra et al. (2019), who worked with *Chlorella sorokiniana*, found higher values but in algal biomass growing in synthetic wastewater ($HCV_{0\%}$ = 22.9 MJ/kg), suggesting that this biomass could be mixed without problems in carbon combustion systems, without notable effects in their energy performance (co-combustion processes). Chen et al. (2014) obtained a similar HCV to that obtained for T50% in this study (HCV = 16.1 MJ/kg) from the same *Scenedesmus* genus.

6.3.4 System Optimization Aspects

The proposed IWMT system could be optimized with the management of some fundamental variables of the process of cultivation, harvesting, drying, and use of biomass. In general terms, the cultivation of photoautotrophic microalgae can be carried out through two basic designs (Slade and Bauen 2013; Sonmez et al. 2016; Martins et al. 2018): open raceway pond (ORP), which are open ponds and with little or no control of the microalgae growth processes; and closed photobioreactors (PBRs) where it is possible to control the process conditions. PBRs are the only ones feasible for large-scale biomass production although currently commercial production is limited to a few hundred tonne and it is carried out in large ORP or lagoons. The ORP is simpler, cheaper, and longer lasting systems than the PBR (Garofalo 2009; Rodolfi et al. 2009), and they are the main system used to produce human nutritional products (Barkia et al. 2019). The difficulty of controlling crop parameters makes this system less efficient, but more accessible in different local communities. In addition, the ORP is the only systems that can meet the double objective of sanitation and production of useful biomass (Abdel-Raouf et al. 2012;

Kothari et al. 2012; Gouveia et al. 2016). However, in the proposed IWMT from microalgae, the economic exploitation of biomass for products with high added value (biodiesel for example) is unfeasible given the high investment costs that this would entail by the variable quality of the substrate and the handling of large volumes of water (Rocca et al. 2015).

Even so, there are certain crop management parameters that could be optimized with relative ease for greater system productivity, adaptation to a change of scale, or its re-adaptation in other communities. Among these parameters are temperature, light, nutrients, pH, and agitation (Zargar et al. 2006; Han et al. 2015; Zuliani et al. 2016). Some authors mention that the optimum range the temperature is between 16 and 27 °C (Suh and Lee 2003): lower temperatures decreases the efficiency of microalgae-based treatments and higher temperatures can lead to energy losses. The selection of the species is fundamental. In this study, *S. quadricauda* managed to survive the autumn-winter conditions of the region, grown in a laboratory at room temperatures. Bakuei et al. (2015) study the performance of *Scenedesmus sp* in the face of different types of lights, water sources, and pH, under controlled temperature and light intensities. The higher biomass concentration was obtained by applying tungsten lamps (versus led and fluorescent lamp) with more red light emissions and lower blue light led to; distilled water or diluted seawater versus tap water (the presence of chloride ions might be inhibitors for microorganism growth); and alkaline medium (8.2–8.7). Gas exchange must ensure the contribution of CO_2 and the removal of photosynthetic O_2. The exchange across the surface of the crop is insufficient so that it is necessary to provide aeration and/or to have an adequate system of agitation and mixing (Suh and Lee 2003). Because the reduction of nitrate or the assimilation of CO_2 supposes an elevation of the pH of the culture medium, this should be corrected by means of buffered media, adding acid in a controlled way or injecting in the air stream an adequate proportion of CO_2 (Park et al. 2011). Logically, this will necessarily imply an energy expense and higher costs. Abu-Ghosh et al. (2015) suggest an energy expenditure of around 27 kJ to pump CO_2 into the system for every 1 kg of dry algal biomass.

Furthermore, microalgae crops are susceptible to grazing by some zooplanktonic groups, such as cladoceros, rotifers, or nematodes, especially in open systems (Rocca et al. 2015). However, there are practical and economical methods of controlling these microorganisms like as adjust pH to a value of 11 (Park et al. 2011). Several investigations have shown that in addition to the availability of nutrients, the relationship in which they are found influences the correct growth of microalgae, such as N: P rate: P below the optimum, will be limited to nitrogen; while in greater than optimal relationships, the limit will be phosphorus (Rocca et al. 2015). *S. quadricauda* has shown a clear response to inhibitory processes caused by nitrogen deficit, increasing 2.27 times the production of lipids in dry weight, but decreasing 27 times the production of biomass (Anand and Arumugam 2015). Finally, the availability of light is one of the determining aspects for the optimal microalgae growth, which should be considered as another nutrient since it will become biomass. The optimum range the light intensity is between 200 and 400 μE/m^2.s, when the photosynthetic apparatus becomes saturated (Pancha et al. 2015).

The harvest and drying stages can also be optimized. There are many chemical, biological, and physical or combinations harvested techniques that have been studied (filtration and flotation; coagulation or flocculation; gravity sedimentation or centrifugation). The final decision of the method that will be used, many times will be made based on costs, recovery efficiency, and availability of technology (Kothari et al. 2012; Rocca et al. 2015; Barros et al. 2015; Drira et al. 2016; Koutra et al. 2018). Bagchi et al. (2015) highlight that the drying process is also a highly expensive stage (up to 30% of the total cost) and demands a lot of energy. They designed a drying oven that saves 50% (0.017 kWh) of the energy generally used in this process. If the algae are harvested with energy fines, part of the calorific value of the algae biomass could be used for drying the algae to acceptable solids content (Azari et al. 2019).

Nevertheless, there is still no agreement on which methods of harvesting and dewatering might be more advantageous and less energy-demanding for microalgae production (Slade and Bauen 2013; Tedesco et al. 2014; Rocca et al. 2015; Azari et al. 2019). In the proposed IWMT, the drying and harvesting process must still be optimized, reducing energy expenditure. Solar dryers are being developed as complementary to the system under experimentation, and could imply significant energy savings. On the other hand, there are numerous examples of energy use of effluents through anaerobic biodigestion processes, whereby the energy demand for drying would be greatly reduced (Prajapati et al. 2013; Zuliani et al. 2016; Koutra et al. 2018; Olsson 2018). Although this energy application would allow bypassing the biomass drying stage, it is undoubtedly a use with fewer added values, which would only allow a marginal energy benefit. In addition, it would imply having some conditions of the system, for which only some plants have currently achieved internal energy self-sufficiency (Tarallo et al. 2015).

The next challenge is to continue expanding the scale of work, and gain experience in the ORP, which will involve a critical evaluation with its corresponding environmental impact, in recognition of the need for space (land use), handling of large volumes of water, and danger of contamination of operators (Azari et al. 2019). Negotiations with the responsible Company of the treatment plant have already begun. Since the maximum biomass production capacity with microalgae (photosynthetic) is determined—among other factors—by the availability of solar radiation (Suh and Lee 2003; Pancha et al. 2015; Acien Fernández et al. 2017) which is a function of geographical location, the north of the country has great advantages (WB 2020). Due to the high levels of solar radiation registered in this area, so it provides the optimal conditions for algal growth, although this advantage has not yet been sufficiently exploited. The simultaneous effort at the National Network will make it possible to expand the successful results to numerous communities and promote concrete technologies for the strengthening of the circular bioeconomy.

6.3.5 Towards Mitigating Carbon Footprint through the Algal Biomass

The previous results allow visualizing the practical application of the circular bioeconomy through an IWMT incorporating microalgae. In particular, applying the IWMT reduces the CFP (Wiedmann and Minx 2007), that becomes especially important as it is the fraction of the global EF that has the greatest impact on climate change (more than 60% currently) (Wackernagel et al. 2019). Globally, there are two main strategic approaches to achieve the reduction of CO_2 present in the atmosphere (which has been recognized as the main GHG, Intergovernmental Panel Climate Change (IPCC) 2018): a) capture del gas that has already been released, through the use of "negative emission technology," NETs (IPCC 2018); or b) avoid the release of various emissions, or offset them by achieving carbon neutrality.

In the first group (item a), the capture or removal of atmospheric CO_2, three main strategies are distinguished (Molazadeh et al. 2019): (1) the use of chemical methods (Kraxner et al. 2003) (2) capture and retain CO_2 and insert it into the ocean or geological structures or CCS technologies (Ajayi et al. 2019), and (3) biogenic carbon sequestration through photosynthesis (Wiloso et al. 2016). The absorption (through physical or chemical solvents) is the most widely used chemical method to clean the combustion gases (Kraxner et al. 2003). Other options are the use of gas separation membranes or methods of adsorption and cryogenics, although greater effort must be made to achieve the least environmental impacts of this type of application, beyond the demand for space and investment to apply those (Molazadeh et al. 2019).

The CCS technologies are still highly expensive and there is much to know regarding leaks over the years (IPCC 2018; Ajayi et al. 2019; Molazadeh et al. 2019). Last, biological CO_2 fixation is an inexpensive, safe, and non-polluting method of capturing CO_2 (Kumar et al. 2010), and occurs naturally through photosynthetic land and aquatic plants. In this sense, it is assumed that 50% of the biomass generated is carbon (Intergovernmental Panel Climate Change (IPCC) 2006), although the elemental composition of the microalgae biomass can vary in a range from 37% C to 54% C (Coimbra et al. 2019). In IWMT autotrophic systems (where essential metabolites are photosynthesized from inorganic substances), microalgae take easily existing CO_2 from the atmosphere. Although the CO_2 capture capacity of these microorganisms is faster than land plants (up to 50 times), even this capture capacity is limited (Xiao et al. 2011; Bilanovic et al. 2009). However, in the case of the proposed IWMT, and as already mentioned among the optimization aspects, it is possible to inject inorganic carbon to achieve a more efficient system. CO_2 can be bubbled as well as a higher dose of nutrients if these are scarce. At this point, not only will greater efficiency be achieved, but also power plants' emissions as a source of CO_2 can be used (or cement plants, fermentation industries, among others, Azari et al. 2019; Molazadeh et al. 2019), with an extra benefit.

In the second group (item b), considering that the global energy sector is the main generator of CO_2 emissions (Intergovernmental Panel Climate Change (IPCC) 2018), bioenergy is the main strategy to achieve carbon neutrality. The use of energy from biomass releases an equivalent fraction of fossil energy that will not be used, and, therefore, will imply a reduction in emissions linked to the carbon emission factor of the substituted fuel (Intergovernmental Panel Climate Change (IPCC) 2006). In this work, algal biomass has energy content per unit of matter that means between one third and one half of fossil fuel energy (Table 6.4). On the other hand, each biomass feedstock for bioenergy has a different impact of the CFP reduction (Haberl et al. 2012). The proposed IWMT system has the advantage of using a "type" of biomass resource that does not imply competition for the use of land or water, nor will it lead to new deforestation indirectly, nor will it affect the prices of local food or feed (Menger-Krug et al. 2012; Martins et al. 2018). This is of fundamental importance since numerous authors have questioned the neutrality of bioenergy for these causes (Haberl et al. 2012; Wiloso et al. 2016; Agostini et al. 2014; Paletto et al. 2019), pointing out that said neutrality is only fulfilled under certain conditions. Haberl et al. (2012) mention that biomass only compensates for emissions from fossil fuels while it is growing and storing carbon (in vegetation or soil). However, if that biomass is harvested intentionally for energy purposes, there is a new amount of emissions generated, and, therefore, there is more fossil carbon that will not be lost but instead biogenic carbon will be emitted. Agostini et al. (2014) point out that if the biomass source is stemwood from dedicated plantation for bioenergy, this would cause, in the short term, an increase in GHG emissions compared to a scenario with the use of fossil fuels, and only it could be beneficial in the long term. Therefore, according to these authors, biomass has a positive effect when it is growing but not when it is used as source of bioenergy. Now, if the biomass source for bioenergy is residual feedstocks not used for any other purpose and which would also release CO_2 when decomposing, then there would be a true GHG mitigation impact (Haberl et al. 2012).

Another important aspect to consider in the CFP is the type of conversion energy technology that will be used in the IWMT (Paletto et al. 2019; Coimbra et al. 2019). Thermochemical conversion routes are the most effective and promising options, including pyrolysis, gasification, and combustion (Coimbra et al. 2019). Processes that improve the energy value of biomass, like as the torrefaction could be an alternative option (Chen et al. 2014). Although they involve a higher level of complexity, other biochemical conversion routes (in addition to the anaerobic digestion already mentioned) that can achieve high-value biofuels (alcoholic fermentation and transesterification) could also be explored (Singh et al. 2016; Barkia et al. 2019) given the forecast high demand for liquid fuels (biodiesel and bioethanol) in the future (Global Bioeconomy Summit (GBS) 2018; Azari et al. 2019; Intergovernmental Panel Climate Change (IPCC) 2018). The bioenergy that could be generated from this microalgae biomass is not only renewable, but would also imply a reduction effect of GHG emissions into the atmosphere since 1 kg dry mass was generated from 1.83 kg of CO_2 sequestered from the atmosphere (Slade and Bauen 2013; Bakuei et al. 2015; Azari et al. 2019). By last a new trend known as climate positive solution proposes an alternative that overcomes the previous ones: Bioenergy & CCS (BECCS): this implies the utilization of biomass as a fuel for industrial or power generation processes and the capture and storage of the CO_2

released in the process (Kraxner et al. 2003; Realmonte et al. 2019) into geological formations (or their removal using some of the chemical methods already described). Even these processes are still being studied currently (Intergovernmental Panel Climate Change (IPCC) 2018; Realmonte et al. 2019). The CO_2 biofixation and bioenergy are the two main strategies promoted by the circular bioeconomy (Pfau et al. 2014).

6.3.6 Application of Algal Biomass for Reducing Water Footprint

An analysis of the implication of the proposed system on water demand (known as the "water footprint" WFP, Hoekstra et al. 2011) can contribute to a better understanding of the importance of promoting this type of alternative IWMT. The WFP is an indicator equivalent to EFP: while it calculates the demand for productive land of a given population to supply itself with products and services, the WFP calculates the demand for water to cover those same needs. Likewise, this indicator can also be useful to the product or service analysis in a particular way. It includes three categories of water use: (1) Green WFP: amount of rainwater accumulated in the soil within reach of crops; (2) Blue WFP: amount of water used from natural or artificial sources; and (3) Gray WFP: dirty water generated during the production cycle (assessed as the quantity of necessary water to adjust the effluent to allowable tipping limits) (Hoekstra et al. 2011).

In the case of the IWMT analyzed, although it is not the main objective, biomass is grown from microalgae. Like all crops, the production of algae for energy generation will involve the stages of cultivation, harvesting, drying, and energy conversion (Azari et al. 2019). The demand for water, therefore, will be associated with each of these stages, which in turn will involve energy expenditure. For each tonne of generated biomass, it is necessary to remove an amount of water that is up to 250 times higher in weight, which implies the management of large volumes of wastewater and a great associated cost (Barros et al. 2015). Here the importance of a right choice of algae harvesting techniques that allows an efficient use of an abundant volume of water and its recycling (Rocca et al. 2015). However, the volume of water involved depends upon the type of cultivation system and its geometric characteristics (ORP or PBR system) (World Water Assessment Program (WWAP) 2017; Azari et al. 2019). The main difference in water demand between ORP systems (operating from fresh water and effluents) and PBR lies in the loss of water from the ORP system through evaporation and leaks (Azari et al. 2019), which will depend fundamentally of the geographical location. In a context of water scarcity and high temperature sites, this loss may be unacceptable, so PBR systems may be convenient (Martins et al. 2018). However, the costs will also be different: US$ 494/t algae generated for open ponds have been estimated, and a range from US $ 639 to US$ 1737/t algae in PBR of different characteristics. In other words, the ORP system implies an investment that is 30% less than the more economical PBR system (Clippinger and Davis 2019). The demand for water in the cultivation stage in ORP systems reaches up to 13,000 m3 /ha/year (Chinnasamy et al. 2010) or up to

200 m3/GJ of energy from microalgae biodiesel obtained (Gerbens-Leenes et al. 2014). Therefore, the use of municipal and agricultural wastewater can minimize the amount of fresh water necessary for the cultivation, constituting a great environmental advantage and contributing to sustainability objectives (Martins et al. 2018). In effect, Azari et al. (2019) found that the WFP is 96.80% lower (just a water consumption of 117.8 kg per 1 kg of biodiesel) when the ORP system uses effluents than when the same system uses fresh water to obtain biodiesel from algae.

Although the demand for water from the cultivation stage is excluded from the WFP analysis-because wastewater is used instead of clean water (either fresh or salt water)-, other demands for water through the process must be considered (Azari et al. 2019). It is worth mentioning, for example, the washing and cleaning of the facilities, biomass processing, or the need for dilution when the effluent is highly concentrated. Indeed, the results of the IWMT analyzed in this work show that the successful growth of algae was only possible when the effluent concentration was up to 50% in the culture medium; although perhaps the algae support a lower concentration of effluents when the mixtures are made from fresh water and not with culture medium. The recommendations of the analyzed system are to dilute the effluent mainly in the dry seasons of the year, where it arrives more concentrated. Other indirect water demands are generated as a consequence of the production of electricity necessary for the process (Martins et al. 2018). Therefore, the reduction of WFP is in turn associated with lower energy demand and lower CFP. For example, the CFP in the ORP system with wastewater (67 g CO_2 eq. per MJ of produced energy) is 55% lower than other ORP from clean water and these emissions are basically associated with the electricity demanded in the different steps of the process (about 85% of this demand) (Azari et al. 2019), which can include the operation of mixers (to keep microalgae suspended and facilitate their contact with light and atmospheric CO_2), thermal regulation processes or harvest, drying and energy conversion (Martins et al. 2018).

Finally, the optimization of the proposed system from the point of view of the WFP would imply the reuse of the water treated by the microalgae, for different purposes (World Water Assessment Program (WWAP) 2017). Global perspectives of the possibilities of these strategies can be seen in countries such as Israel, a leading country in water recycling (more than 80%) which implies a great effort to achieve highly treated effluents and not cause damage to crops and soils (Tal 2016). The influence of IWMT systems could be global, if a systematic action plan was promoted in all regions. For this, awareness and evaluation is necessary, which allows its promotion from a conscious strategy and on the basis of adequate investments and political framework. Early regional planning and corresponding regulations and control schemes will allow to take advantage "upstream," that is, from the points of demand for clean water and effluent generation, to endorse efficient use and decrease the volumes of effluents to be treated, with the implication of savings in water, energy, and costs, reducing environmental impacts (mainly in the most vulnerable communities).

Within this effort, it is important to agree on an appropriate definition that can be coined identically worldwide, since there are discrepancies and inaccuracies in the concepts of "reuse" and "recycling" (in some cases synonymous and in other cases with a different scope), within which there are no precise limits for what is considered fully, partially, or untreated/treated water (World Water Assessment Program (WWAP) 2017). This effort is essential to observe the level of achievement of the stated goal and record progress in the same way among countries. Likewise, it is necessary to enable adequate registry systems for this goal, since the lack of primary data registries and the lack of updating of information are common problems in third world countries, not only associated with the subject of water and effluents (Manrique et al. 2020).

6.3.7 Conclusions about the Experience

In the study reported, microalgae growing in different concentrations of sewage effluents, with minimized controls during the cultivation process, had good growth, achieving removal efficiencies of organic matter, nutrients, and pathogens greater than 50% and reaching the maximum CD in a maximum time of 17 days. The maximum biomass yields were achieved at effluent concentrations not exceeding 50%. A higher concentration of effluent was limiting for growth, so, in the beginning, treatment for bioremediation should include a stage of mixing of the effluent (with river water, for example) at the discharge point of the purification pond, so that the microalgae can thrive. The proposed system was simple, and can be easily replicated on larger scales, including some optimization factors, such as pH control, lighting, agitation, among others, if necessary. IWMT will be essential technologies particularly in regions with low water and energy availability (since the proposed system involves a reduction in the WFP with respect to its non-implementation), mitigating GHG emissions (CFP reduction) and strengthening local communities in the face of climate change.

6.4 Future Perspectives in the Biomass Sector

6.4.1 Current and Future Challenges for Achieving Sustainability from the Circular Bioeconomy

From the year 2000 onwards, two perspectives of bioeconomy can be recognized. The first, the fossil to biomass substitution perspective, which recognizes that new technological developments for biomass utilization will allow access to large feedstock supplies of biomass for new bioprocesses or biofuels, it was the one that has prevailed during the first decade of this century. Probably, this trend was promoted by the predictions of depletion of fossil fuels and their high price, and later, by the commitments made in the fight against climate change that found a milestone in the Paris Agreement.

The second perspective places its emphasis on a knowledge-based bioeconomy and biotechnology. It promotes the new technologies and processes developed from the latest advances in chemistry, mechanics, systems engineering, life sciences, and information technologies, with numerous applications (such as precision farming, healthier biochemical products, new recyclable materials, synthetic biology, digitization, and advanced manufacturing) (Birner 2018; Global Bioeconomy Summit (GBS) 2018; Linser and Lier 2020). This perspective is the one that has begun to predominate in recent years (Birner 2018). Biorefineries are one of the maximum exponents of what the circular bioeconomy promotes (Keegan et al. 2013; Rajesh Banu et al. 2020; Ubando et al. 2020).

Currently, both approaches appear mixed and with different variants in the national strategies proposed, from the concept to the scope, depth and type of activities, and areas that formed the bioeconomy (Global Bioeconomy Summit (GBS) 2018; Birner 2018). This is not only a technical option, but the result of different country characteristics, political preconditions, circumstances, priorities, settings, technological development, resource base, and public demands (Linser and Lier 2020). Even so, since approximately 2015, there is a clear reference that these strategies will contribute to meeting the sustainability objectives and those related to climate agreements (European Commission (EC) 2018; Global Bioeconomy Summit (GBS) 2018; United Nations (UN) 2018). However, these proclamations lack empirical evidence given the short existence of these national strategies, and most of them do not have goals or quantitative indicators that allow this evaluation to be carried out over time (German Bioeconomy Council (GBC) 2018). So, can it be simply assumed that compliance with the bioeconomy strategy will necessarily imply the achievement of sustainability goals? From the academic scientific field there is no consensus in this regard, and conflicting visions can be identified.

Some proponents of this circular bioeconomy paradigm assume innate sustainability and base their argument only on the analysis of some specific contributions of it (renewable resources and energy or some physical and ecological benefits of biomass use: Jenkins 2008; Navia and Mohanty 2012; Barkia et al. 2019). Intermediate positions recognize that the bioeconomy could bring benefits under certain conditions (Garofalo 2009; Demirbas et al. 2009; Bilgili et al. 2017; Scheiterle et al. 2018). Others more skeptical, distrust the new umbrella of the bioeconomy as a new green make-up, and point to problems associated with its promotion as the land use antagonism: food vs feed biomass production (Rosegrant et al. 2013); but also the threat to biodiversity or ecosystems that the production of biomass feedstocks may imply; or the negative balance of GHG emissions in the processing of biomass for energy (Agostini et al. 2014; Raj et al. 2020; Banerjee et al. 2020). At the other extreme, detractors point out that the implementation of the bioeconomy paradigm is disconnected from regional realities (Marsden 2013); it lacks sufficient regulatory frameworks to verify the fulfillment of goals and progress towards sustainability (Sheppard et al. 2011) and is basically promoted from a neoliberal capitalist ideology that moves everything under the rules of the market (Birch 2006; Birch et al. 2010; Gottwald 2016).

This current controversy should draw attention to the need to specifically consider sustainability as a central objective of the bioeconomy itself (Chisti 2010; Marsden 2013; Pfau et al. 2014; Scheiterle et al. 2018; Heimann 2018). If sustainability objectives are not clearly defined in each territory, the bioeconomy will not necessarily contribute to the achievement of the SDGs, since it will be guided by economic benefit and market interests (Birch et al. 2010). The 2030 Agenda still calls for more vigorous and urgent action (UN 2019b) particularly with regard to the goals of climate change (SDG 13), safe water (SDG 6), and access to energy (SDG 7), always considering an adequate management of resources. Indeed, there are still major challenges in terms of: (1) climate change: despite international agreements, carbon markets, and other incentives, the temperature has risen 1 °C from the reference scenario (United Nations (UN) 2019b); (2) water: a quarter of the world population faces extremely high water stress (WRI 2019); around 10% world population still did not have basic drinking water services (United Nations (UN) 2019b) while 380 billion m^3 were eliminated as effluents across the world (Qadir et al. 2020); and (3) energy: about 39% of the world population lack clean fuels and technologies. Within a delicate framework of support for terrestrial and aquatic environments (risk of extinction of species and ocean acidification) (United Nations (UN) 2019b), further discussion is necessary for both goals of the bioeconomy and sustainable development, converge favorably and be verified. The last requires a specific action plan with quantitative aims (Global Bioeconomy Summit (GBS) 2018) based on concrete strategies custom-made for the territories and a regulatory framework that considers the different areas of action of the bioeconomy (Pfau et al. 2014; Rodríguez and Aramendis 2019).

6.4.2 Policies, Legal Framework, and Financing for the Circular Bioeconomy

Although the circular bioeconomy is under construction and redefinition of its bases and foundations (Carus and Dammer 2018), this new paradigm of production and consumption must be strengthened from a new institutional political framework that allows its development. Existing rules and regulations correspond to a fossil-dependent world economy based on the industrial revolution and need to be reviewed, modified, or adapted to the new bio-circular context (Bilgili et al. 2017; Rodríguez et al. 2017; Rodríguez and Aramendis 2019).

One of the challenges of the bioeconomy lies in the possibility of structuring the different value chains (which includes all the economic activities carried out in a territory, being the harvest of available raw materials the first link in the chain) in interconnected processes that simultaneously meet the dual objective of efficient management of feedstock: recirculation of energy and the cascade use of resources (BIORES 2015; Sherwood 2020). This challenge will be overcome with an appropriate territorial planning policy, based on stakeholder's consultation and consensus (from public and private sectors), and regulations that promote responsible behavior in the productive processes, with a view to reducing environmental and social impacts (Chisti 2010; Rodríguez et al. 2017; Paletto et al. 2019; Vanhamäki et al. 2020).

The cascade use of a resource (taking advantage of the raw material for the elaboration of products, by-products, extraction of substances, and finally energy, Carus and Dammer 2018; Del Borghi et al. 2020), can be a difficult path to follow in small domestic economies (Demirbas et al. 2009; Pleissner 2020). While some world economies have resources, infrastructure, technology, and capital to reach the simplest level of plant cells to take advantage of each of their functional chemical groups (Ubando et al. 2020), in other regions (and even within the countries there are these differences), there are still unsatisfied basic demands that are those that should mobilize all attention, resources, and efforts towards more sustainable communities and territories (Food and Agriculture Organization of the United Nations (FAO) 2014; World Water Assessment Program (WWAP) 2017, Linser and Lier 2020; Pleissner 2020). In this sense, it is necessary, on the one hand, to generate more discussion on how the bioeconomy can reduce these inequalities within and among countries (disparities also observed between urban and rural areas) (Linser and Lier 2020) and, on the other, to promote differential bioeconomy strategies that allow optimal levels of circular bioeconomy to be reached within territories (involving both public and private sectors) (Vanhamäki et al. 2020).

Assumed that rural development is one of the aims of the bioeconomy (Pfau et al. 2014), a set of policy instruments focused on different regions must be developed. Public policies are those that will allow to model the character of circular bioeconomy in the territories, articulating the different ministries in a new space the interaction (production, health, environment, agribusiness, science, and technology, etc.) and the jurisdictional hierarchies (nation, province, municipality). These policies should start from the recognition of the characteristics and local individual needs (small family farming, small-scale enterprises, regulation of links and intermediaries in value chains), promoting infrastructure investments, and ensuring the participation of all levels in decision-making processes (Von Braun 2015; Rodríguez and Aramendis 2019; Manrique et al. 2020).

In other words, the bioeconomy of each country must start from the recognition of the bioeconomy of its regions, its different capacities, and its territorial vocation (particularly local feedstock offer). Each region should recognize their comparative advantages, and specialize and focus on them to create added value to their local productions (Global Bioeconomy Summit (GBS) 2018). Marketing within defined spaces will not only grant identity and empowerment to small local economies by promoting jobs and generation of incomes, but will also demand less fuel consumption for transportation and therefore a reduction in GHG emissions (Seadon 2006; Heimann 2018). It is also possible to boost the cascade use of biomass in developing economies, which will depend on clear organizational and political aspects, territorial planning and synergistic work in the territories (Rodríguez et al. 2017). The regulations should contemplate, for example, the addition of value through product origin seals, quality standards, and certifications of local manufactures or fair trade. Likewise, incentives for investment and innovation that support the creation of new small-businesses or new value added small-companies in the different productive chains of the territories. The advancement of communication and information technologies is contributing to being able to implement circular and cascade processes, opening the space to the introduction of multiple companies that provide new creative services (Carus and Dammer 2018; Global Bioeconomy Summit (GBS) 2018; Rodríguez and Aramendis 2019). There is great potential ahead, which must be deployed within ethical agreements and sustainability limits clearly defined in each site.

6.4.3 Research and Development for Integrated Waste Management Technologies Implementation

To the extent that the circular bioeconomy has motivating principles on which society agrees (basically generation and efficient use of biomass resources and diminish rubbish and refuse) (Heimann 2018; Hidalgo et al. 2019; Sherwood 2020), concrete strategies are required to guide efforts to implement these principles in practice. These will also become evaluation and monitoring points for the quantification of results (Linser and Lier 2020).

The definition and achievement of these strategies must be supported by a strong component of R&D at the local level (Scheiterle et al. 2018; Dietz et al. 2018; Kalmykova et al. 2018), generating integrative information across value chains (Sanders and Langeveld 2020). It must be considered that the bioeconomy can be approached from multiple fields of the science, whose knowledge of different nature will imply a high complexity at the time of its integration for decision-making in the regions. Therefore, interdisciplinary approaches, in ad hoc teams for solving specific problems in the territory, with the integration of contributions from the people involved in the biomass value chains, will allow the knowledge generated to be effectively applied, bridging the gap between science and society (Chisti 2010; Rodríguez et al. 2017; European Commission (EC) 2018).

For example, the solutions that focus on trinomial water–energy–climate change are what will consolidate the social and environmental networks, by mobilizing small domestic economies with practical solutions of the IWMT type (Nagarajan et al. 2020; Rajesh Banu et al. 2020). This will be of great impact in emerging economies, developing countries, or marginal sectors, in which the treatment systems are inefficient but in turn there is a high need for basic resources (water, energy, nutrients) (World Water Assessment Program (WWAP) 2017; Qadir et al. 2020). Qadir et al. (2020) estimated that globally, a total of 25.9 Tg of three essential nutrients (N, P, K) are lost annually in sewage effluents and Tarallo et al. (2015) recognize that the potential energy in the wastewater is around 500% the energy used for treatment processes. However, current technologies do not allow 100% recovery of the nutrient load and few systems recover nutrients and energy (Abdel-Raouf et al. 2012; Barkia et al. 2019; Qadir et al. 2020). The inclusion of microalgae as natural accumulators of nutrients, achieving greater system efficiency, should be promoted and tested in pilot plants and even replicated in real conditions at the local level, which makes it possible to define the limitations and real opportunities for co-benefits (benefits secondary) beyond the effluent sanitation and ecological benefits in receiving water bodies (Park et al. 2011; Prajapati et al. 2013; Matamoros et al. 2016; Rajesh Banu et al. 2020; Nagarajan et al. 2020). Likewise, is currently possible to achieve a neutral energy balance in the wastewater treatment cycle through the onsite renewable bioenergy generation (Tarallo et al. 2015). Numerous and more or less efficient bioenergy technologies are available on the market, and those have potential for local manufacturing in small economies (Slade and Bauen 2013; Prajapati et al. 2013; REN-21 2019; Manrique et al. 2020; Vanhamäki et al. 2020).

IWMT could be one of the fundamental tools of the circular economy, taking advantage of a greater portion of the resources and giving value to the wastes (Hidalgo et al. 2019). Although the IWMT do not fully incorporate the concept of cascade use, do bring the return of matter and energy to the system and provide solutions to specific local demands. In this line, there is still much to explore, defining solutions adapted to the territories according to existing biomass resources, but above all identifying sources of residual biomass that could be reused in circular processes (Jenkins 2008; León and Chaves 2010; Kaza et al. 2018; Pleissner 2020).

Scientific and technological networks will be of fundamental value in the territories and will make it possible to generate information on the new relevant variables (biomass, potential, distribution, functionalities); promote discussion tables; facilitate the dissemination of strategies and awareness of the population about the new products and services; socialize successful experiences and the failure analysis as an engine of innovation; constitute points of connection between multiple stakeholders: producers, consumers, government, academia, industry (Von Braun 2015; Clark et al. 2016; Rodríguez et al. 2017; Kalmykova et al. 2018; Vanhamäki et al. 2020). Undoubtedly, there is still a long way to go in developing IWMT strategies, but the benefits are more than promising.

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Land Footprint Management and Policies

7

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Abstract

There would be significant rise in production of animal products as well as food products due to higher demand across the globe. This would lead to generation of competition for the cultivable land which would be regulated by array of factors along with population explosion, alternation in consumption pattern of food as well as production of biofuel. Therefore, it is necessary to explore the inter-relationship between the agricultural land use and the pattern of consumption by the human. Various methodologies and modeling approach are available for calculation of land footprint. As per requirement, land footprint may be extended by considering environmental impacts on spatio-temporal scale to evaluate the embedded land under land footprint. Weightage on land area, land quality was given for estimation of land footprint for various types of land uses in the form of cropland, deforestation, and grassland ecosystem. Reducing land footprint requires awareness regarding the issue and control over the growth of economy across the globe which alters the consumption pattern as well as the pressure on natural land resources. Further research and extensive studies are required to generate suitable database for effective screening of suitable land use systems for reducing the land footprint.

Keywords

Footprint · Extended land footprint · Challenges · Mitigation strategies

Abbreviations

EU	European Union
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GHGs	Greenhouse gas
Mha	Million hectare
US	United States
USA	United States of America

7.1 Introduction

Land with a significant production potential in terms of agriculture and forestry is a scarce resource across the globe. Land footprint is a concept that integrates human consumption pattern, land use and their inter-relationship. It reflects the level of available productive land both under national and international level. It is very much dependent upon the fact that how much human beings consume for a certain period of time. In this connection the major production of human consumable materials comes from the forestry and agricultural sector. It was observed that ever-increasing human population is depleting the natural resource at a faster rate and is going beyond the carrying capacity of the Earth (Lambin and Geist 2006; Meena and Lal 2018). Land footprint provides us with an estimate to have appropriate space to work for the humanity. According to Rockström et al. (2009) it is the essential requirement to achieve or screen the sustainable land use systems (Fischer et al. 2016).

Land footprint can be used as an effective tool to monitor the spatial heterogeneity of the earth surface based on human consumption patterns. It was observed that cropland footprint of Germany is greater than the global average value which principally comes from livestock part on per capita basis. The available land area needs to be mostly attributed towards cropland followed by livestock production. It is interesting to note that the global average of non-food cropland footprint is much lower in comparison to individual country or specific places (Fischer et al. 2016; Meena et al. 2018). Considering the general facts about land footprint it cannot explain properly regarding the land quality and its environmental impact along with the productive potential of particular land use. Therefore, the concept of land footprint needs to be extended.

7.2 Concept of Land Footprint

The concept of land footprint is a methodology that reflects the land requirement for producing goods and environmental services (Bruckner et al. 2012). Land footprint simply refers to the foreign land which is dependent upon the different land uses. Within the concept of land footprint, the variation in the biological productivity is generally not taken into consideration. During the calculation of land footprint accounting is done in terms of its land use pattern and not in terms of area such as acres or hectares of land. This clearly reflects the actual land use across various regions of the globe. In terms of crop production if a nation produces ten times more produce than the other country then it implies that ten times more land investment for that country to which the agricultural produce belongs. Therefore, it has been reported that Australia has five times more land demand than USA (United States of America) due to extensive grading activity in the Australian pastures as well as its low production potential. It was observed that similar area with land use type reflects different environmental impacts on different areas. The ecological conditions prevailing over an area determines the fate of environmental impact in specific areas. This is clearly reflected in Brazil where the impact is severe due to the formation of pastureland at the cost of rainforest ecosystem. On the other hand, the impact is less severe in the USA in comparison to Brazil due to the formation of pastureland at the cost of prairie grassland ecosystem (Ferng 2011; Meena et al. 2020a).

While calculating land footprint the land quantity engaged in particular land use followed by consumption trends and pattern needs to be quantified properly. Further it is necessary to assess the sustainability of particular land use practice. It is therefore, urgent need to design specific indicators reflecting the impact of particular land use based on human consumption pattern (Fischer et al. 2016).

7.2.1 Extended Land Footprint

While considering the extended land footprints one needs to give stress upon the quality, effectivity of particular land use along with associated social and environmental impacts. The output can be measured in terms of productivity of different ecosystems in terms of agricultural unit or from different forestry units (Jhariya et al. 2019a, b). Further, identify the potential environmental impact associated with the particular landuse along with human consumption pattern having positive or negative impacts. Thus this type of approach helps to determine the pressure on ecological services offered by ecosystem imposed by particular land use (Meena et al. 2020b, c).

Land footprint is used to characterize a particular land use on the basis of human consumption pattern. Further, evaluation of footprints through area-based approach usually measures the amount of land area invested for particular land use (Fischer et al. 2016). Further, the concept can be extended by incorporating the quality and environmental impact related to land use pattern, consumption pattern and their proper management.

7.2.2 Land Footprint as an Integrated Concept

It is a very integrated concept initiating from prevailing land use to primary production, land involvement in production of goods and services, supply chain across the globe to the end users through consumption. Information related to the environmental impact needs to be collected in relation to crop production and animal husbandry management. For instance, it can be evaluated the level of deforestation per hectare versus per ton produce harvested.

According to Arto et al. (2012) land footprints can be defined as the area of land used to produce the agricultural produce and the amount of production satisfies the domestic demand of a country irrespective of the location of the area. This approach thus helps in to evaluate the dependency of a particular country on other places (Giljum et al. 2013b). It is therefore can be considered as *virtual* land flows (Meier et al. 2014; Qiang et al. 2013).

Von Witzke and Noleppa (2010) defined the term virtual land as the amount of land that is required to produce one unit of agriculture produce. According to Wackernagel and Rees (1996) it is the measure of land use at actual level. Therefore, land footprint can be effectively utilized to prepare a comparison of land use at global level and ultimately which clearly reflects the unequal distribution of different land use at different regions. Imbalance in the production area and consumption area may act as pressure indicator of environmental impacts. As the area of production has increased it ultimately leads to various forms of environmental degradation (Raj et al. 2020; Banerjee et al. 2020). Therefore, land footprint is a useful tool or estimate of the pressure in the production and consumption sector leading to abnormal changes in the environment of a country (Bringezu et al. 2009).

7.3 Land Footprints at Global Scale

In the upcoming decades or days proper availability of land would be a challenging task for the global people. With gradual growth of science and technology every individual is going for more production in order to feed the ever-increasing human population. As a consequence, the competition for productive land would increase day by day. Subsequently there would be a change in the consumption pattern followed by a rise in bio-energy production (Haberl 2015). It is a clear fact that the world food production rate needs to be doubled to feed the global population and therefore meet the demand (Tilman et al. 2011). Now, to solve the problem of land availability for food production one needs to go for agricultural expansion. According to FAO (Food and Agriculture Organization) report up to 1400 Mha (million hectare) land are available for agricultural expansion till 2050 (Alexandratos and Bruinsma 2012). While calculating such land areas in terms of agricultural expansion does not provide us the actual estimate of land availability and therefore there is low availability of land in actual figure as it is associated with various socio-economic and environmental consequences. These are the hidden factors which influences the land use as well as land quality of a particular area (Lambin et al. 2013).

It is a common fact that earth has one part of land area of which two third portions has already been occupied by human beings. There is extensive and intensive form of land use globally. From world perspective grazing occupies 365 of land area, 27% is under forest land, agriculture harbors 12% of land area followed by a meager contribution by the urban space. Rest of the land is not productive for land use as half of it is wastelands or is in unusable form and rest of the part is pristine forest which is devoid of human use (Erb et al. 2009). It was observed that distribution of land across various nations of the globe varies from area to area. As per the estimate 32% of the people across the globe require more land that the average value of land footprint till 2001. These people have been reported to use more than two third lands for production of crops (Wilting and Vringer 2010).

Globalization is an important aspect of the present world through which the commodity is undergoing export and import across the various nations. As a consequence of that the trade gain at international level has attained significant importance rather has become a significant factor in evaluating the land footprint for a particular region or country. The land footprint study by Kissinger and Rees (2010) has revealed that besides fulfilling own needs country like United States (US) is still dependent upon the external measure although they have sufficient level of productive land.

Fader et al. (2011) reported that the mechanism of current trade is leading to savings towards global landholdings. By the term land savings they mean to the self-sufficient process at the light of present consumption and production trends. According to their process they have calculated the land requirement up to the level to produce the products within own territories. Further they suggested that the present trade has the land savings up to 41 million hectares per annum basis. From this it can be concluded that the present pattern of trade at the international level would reduce the land requirement provided the trade must include the ecological opportunity cost and move from developing to developed world. As the trade at the international level is technology oriented therefore, international trade would lead to optimization of the use of global natural resources (Steen-Olsen et al. 2012).

In European subcontinent import activities takes place from wide varieties. Major imports come from Asia which includes the undivided Russian region along with other countries which happens to be the major exporter of feed. Africa and Latin America happens to be the largest land suppliers and from Asian subcontinent China stands to be the largest land supplier. European Union (EU) stands to be the largest continents in terms of land use for infrastructure, settlement, and agricultural activities. About 38% embodied land area of EU imports the products. From the land use perspective grain crops and oilseeds require largest area for crop cultivation followed by grazing land and forest. Beverage crops tend to have high land footprint value in the embodied form. Staple food crops have moderate level of land footprint value. As per Van der Sleen (2009) the increase in demand for oil seed crops has contributed towards significant increase in land footprint within a span of 15 years (1990–2005). It was observed that EU countries harbor lands from various countries in order to fulfill the demand of food of their countries. From cropland perspective Brazil shares 13 Mha, Africa shares 10 Mha of cropland, China shares 10 Mha of cropland, Argentina shares 7 Mha of cropland, South-East Asia shares 6 Mha of cropland, US shares 5 Mha of cropland. Further, EU reflects 27% foreign land displacement globally (Yu et al. 2013).

Land use data in hectare/person of different regions of the world are depicted in Table 7.1. The region of N. America represents maximum (1.69) land consumption in hectare/person followed by Russia (1.26), Asia and Oceania (1.10), Latin America (1.05), Africa (0.98), some European region (0.83) whereas India contributed only 0.18 hectare/person as compared to world average land use (0.63), respectively (Bruckner et al. 2015; CBS, PBL, RIVM, WUR 2018).

Around 22 million hectares areas are shared under cropland footprints of the Germany which is categorized into food consumptive and non-food consumptive uses. Crop and livestock's-based diet comes under food consumptive uses whereas animal wools, horn, hides, biodiesel from plants, cloth from cottons, vehicle tires from plant exudates natural rubbers, etc. comes under non-food-based commodities of industrial uses. Almost half (48.0%) of the total cropland footprints are shared by livestock's-based food uses for diets followed by crop-based food uses and non-food commodities for industrial uses in equal contributions as 25%, whereas least (2.0%) value shared by seed and other on-farm wastes in agricultural land. In compared to

Table 7.1 Land use data in hectare/person of different regions of the world (Bruckner et al. 2015; CBS, PBL, RIVM, WUR 2018)

Region	Hectare/person
N. America	1.690
Russia	1.260
OECD Asia and Oceania	1.100
Latin America	1.050
African region	0.980
European region	0.830
Rest of Asia	0.400
China	0.310
Indonesia	0.230
India	0.180
Global average land use	0.630

Germany, the shares from crop-based food uses diets are maximum as 49.0% followed by 31.0, 12.0, and 8.0% from livestock's-based food uses, non-food commodities for industrial uses, and seed and other on-farm wastes, respectively, under the global cropland footprints which is around 1515.0 million hectares around the world (Fig. 7.1). Similarly, cereals crops shared 48.0% of global cropland areas followed by oil seeds (17.0%), fodder crops (12.0%), root crops and pulses (8.0%), vegetables, spices and fruit crops (8.0%), respectively (Fischer et al. 2017a).

Recently, Nijdam et al. (2012) have analyzed 52 LCA (life cycle assessment) studies for both vegetal and animal source of protein and explore average land requirement for production of certain food items/products. In this context, Table 7.2 showing average land required for protein enriches items per kg of products. In this table, beef and cow-based products required higher land uses followed by mutton (26.5), poultry (6.5), and eggs (5.5) where least average area required by only milk item as 1.5 m^2 year kg^{-1}, respectively.

Land footprint value varies significantly among various parts of Europe. It was observed that in most of the countries the value of land footprint is higher than the average value of land footprint of EU. However, the nations of Eastern Europe reflect lower values than the average value of EU. Among the Scandinavian countries Sweden and Finland the per capita land footprint value ranges up to 4.1 ha. The land footprint value of Norway stands to be 3.6 ha on per capita basis (Lugschitz et al. 2011).

It was observed that demand of land changes depending upon the economic status of the country. In economically developed countries land requirement other than food production takes a considerable share in comparison to the poorer countries whose economic is still growing (Yu et al. 2013). Further, income levels tend to determine the nature of human consumption pattern followed by differences in land footprints. For instance, for developed nations with developed economy reflects lesser land investment for primary production. As per the records up to 46% of the land areas are displaced for agricultural production and up to 10% of land area is dispersed for forest produce. In comparison the developing economy such as Indian

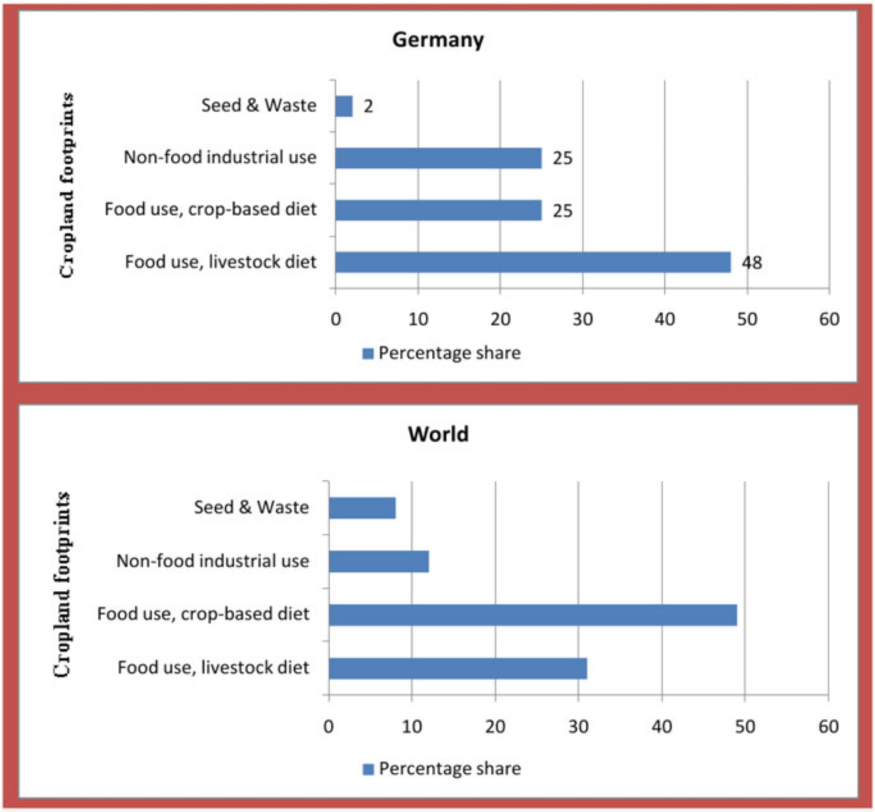

Fig. 7.1 Cropland footprints in Germany Vs World (Fischer et al. 2017a)

Table 7.2 Average land required for protein enrich items per kg of products (Nijdam et al. 2012)

Items/products	Average land required in m^2 year kg^{-1}
Beef for industrial uses	213.5
Beef based wide spreading pastoral systems	95.5
Cows based products	353
Pork based items	11.5
Poultry based products	6.5
Eggs items	5.5
Mutton	26.5
Milk item	1.5
Cheese products	11.5
Aquaculture based seafood items	4.0
Milk and egg based protein	2.0
Hundred percent vegetarian (vegetable) products	2.5
Dry pulses (highly rich protein)	5.5

and China share their land up to 92% for agriculture and forestry production. This stands for them as primary consumption. Further, in the African countries more than 90% of land area has been attributed towards primary production in agriculture and forestry. Therefore, with gradual increase in the economic condition and earning the consumption pattern changes which put pressure on the land resources, thus increasing the land footprint. However, the role of non-agricultural products used for human consumption also plays significant role in causing variation in land footprint (Yu et al. 2013).

In the present times there is a gradual rise in the sector of biofuels production for social well-being in terms of using renewable energy. As the demand for biofuels increases the pressure on agricultural land for feedstock preparation has increased tremendously. This has resulted into more land investment in biofuels production leading to alteration of land use from consumption purpose to non-food consumption purpose (Searchinger 2013). Therefore, biofuels production has caused a significant change in land use over the globe. It was also associated to release emission of CO_2 associated with biofuels production (Hertel 2010).

The mechanism of biofuels production and land investment would alter the land use for other purposes in comparison to agricultural production. This would have to fold effects, firstly reduction in yield from agriculture and secondly higher emission of GHGs (greenhouse gas). However, biofuels serve the purpose of reduction of C emission in comparison to fossil fuels at the market level (Laborde 2011).

The biofuels production would be dependent upon the production of crops such as the oil crops which have combined effect on the food markets at the global level, thus increasing the agricultural intensification and expansion (Yu et al. 2013).

7.4 Livestock, Human Consumption Pattern, and Land Footprint

Human consumption of animal products is a type of unsustainable behavior and change in attitude or behavior in this direction would definitely help to reduce the natural resource depletion event followed by reducing land requirement in the form of land footprint (Herrero et al. 2016). Thus, livestock and its management has become an integral part for sustainability of the agroecosystems (Garnett 2009). According to Steinfeld et al. (2006) livestock systems covers one-third ice-free surface of the globe resulting into one-fifth portion of global GHG emission. Researches revealed that diet comprising of meat and allied products leads to more energy and land footprint in agroecosystem (Nijdam et al. 2012). Further researches have revealed that alteration in the dietary pattern would put pressure on agriculture land at global scale supported by the ever-increasing strength of human population. Further, with changing pattern of human consumption the dependency on meat and other livestock materials would increase in nations under developed economy. Changes in the consumption pattern are obvious due to growth in economy, improved lifestyle, standard of living followed by more protein, calorific value, and other nutritional requirements by the same amount of meat and dairy products.

In order to fulfill the demand for livestock products one needs to have more pasturelands for sustaining the livestock population. As a consequence, massive deforestation takes place (Nijdam et al. 2012). Research estimate reflects that 30% of crop calories produced are used to feed the livestock of which 12% gets returned back as food to humans (Cassidy et al. 2013).

Proper management of livestock population is also an important aspect for mitigating climate change (Bajzelj et al. 2014). This would also help to reduce the demand for land and water and their associated footprint. Reduction of meat as dietary constituents has also gain significant importance in terms of environment and health benefits. As per the research reports, changes in consumption pattern towards vegetative material may tend to reduce the mortality up to 10% (Friel et al. 2009; Springmann et al. 2016; de Ruiter et al. 2016).

7.5 Alterations in Land Footprint and Land Use

Various factors contribute significantly towards changing land use pattern as well as the land footprint. For example, severe deforestation takes place after initiation of urbanization in an area. The first and foremost factor is the changing consumption pattern. It was observed that diet with high nutritional supplements have demand and as a consequence tends to show the ever-increasing pattern (Kastner et al. 2012). About 1 kg of beef production requires 420 sq. m area, whereas the same amount of vegetable protein requires only meager 2–3 sq. m area per annum basis. Therefore, human consumption in this place would govern the fate of land footprint in terms of land used for beef production and vegetable cultivation. This therefore clearly indicates that change in consumption pattern significantly contributes towards the increase in land footprint value. Such aspects are also driven through economic condition of the country. As per Weinzettel et al. (2013) the land footprint value increases one third with gradual increase in income. With gradual rise in economy human beings tend to change their consumption pattern as evident from Brazil and China (Alexandratos and Bruinsma 2012). In the upcoming times the growth in economy would promote the higher intensity of meat consumption. As per the research data, it was observed that within a span of 47 years (1961–2008) world human population has increases 2.2 times and in comparison, the meat consumption has increased up to four times (71–280 million tons) (FoE 2010). As per the prediction of Kharas and Gertz (2010) the rise in human population takes place from 525 million to 3.2 billion within a span of 21 years (2009–2030) in Asia. The trend is similar for other developing part of the world. In the developed world the condition is worser as dietary change towards animal protein is causing significant health impacts. As per the research report it was observed almost half of men and women is suffering the issue of obesity in EU (HDHL 2012).

As per the reports of FAO (2012a) it is interesting to note that up to 33% calories is obtained from animal protein in developed countries whereas it is only up to 10% in developing world. In terms of production if we compare between the developed and developing nation it clearly reflects the majority of vegetable source of protein of the diet of poor countries whereas it is just reverse for economically rich countries. Another important trend is that diets change across the regions as well as with variable income level. Even within the same region the dietary preferences varies. For example, the northern member states are more prone towards animal diet, whereas the southern member states are prone towards the vegetable diet. Also, as per the reports of FAO (2012b) the food intake increases up to 500 calories on individual basis within a span of 46 years (1961–2007). Further FAO suggests the similar pattern of dietary preferences in parts of Africa, Asia, and Latin America would have similar dietary preferences as per the developed nations in 1990. However, sub-Saharan Africa and South Asian countries will tend to show low calorie intake on per capita basis.

It was observed that the level of meat consumption varies significantly on country wise starting from 14 kg in Africa to as high as 121 kg per person in North America. As per reports there would be a steady rise in demand for animal products up to half on per individual basis till 2030 in Asia and African subcontinent. As a consequence of this crop cultivation and livestock management would rise at a significant rate (PBL 2011). Therefore, the land footprint across the globe would show a steady increase across the various nations.

Lands are important natural resources that hold many organisms and support other resources such as agriculture, forests, pasture/grassland, and wasteland and also utilized for industry, infrastructure, and other purposes. Human interferences into the land conversions reflect footprints that are depicted in Fig. 7.2 where A, B, C, D, E, F, G, and H indicate a conversion flow among different land uses and their footprints. Of the all, A represents the conversion of degraded/wasteland into the forest areas, B represents the forest land conversions into agricultural/cropland and technically called “deforestation” which is possible due to human interferences/anthropogenic factors. Burgeoning populations necessitates food requirements that leads to deforestations and conversions into cultivable lands. Similarly, C and D represent the conversion of pastureland into agricultural and wasteland into pastureland. The E, F, G, and H are conversions of all-important land use systems into industrial development, infrastructure, and other purposes which is serious concern and biggest hurdle raised by humans that affects overall environmental sustainability and ecological stability (Fischer et al. 2017b).

In terms of land use the land requirement for beef production varies between 7 and 420 m^2 year/kg. It shows the similar amount of land use like grazing. On the other hand, the land requirement for meat production under pastoral system is lesser than the grazing counterpart. Similarly, land use for cheese production is higher than land use for milk production. If we compare it with the vegetable protein the land use amount appears to be very meager (1–3 m^2 land area per annum).

Population growth is another biggest factor that would regulate the fate of land footprint in the upcoming years. Population growth would act as driving force for changing pattern of land use (Chertow 2001). As per the reports of United Nations the global population would rise up to 9.6 billion till 2050 (United Nations 2013). Growth is expected to take place in southern part of Asia and sub-Saharan Africa

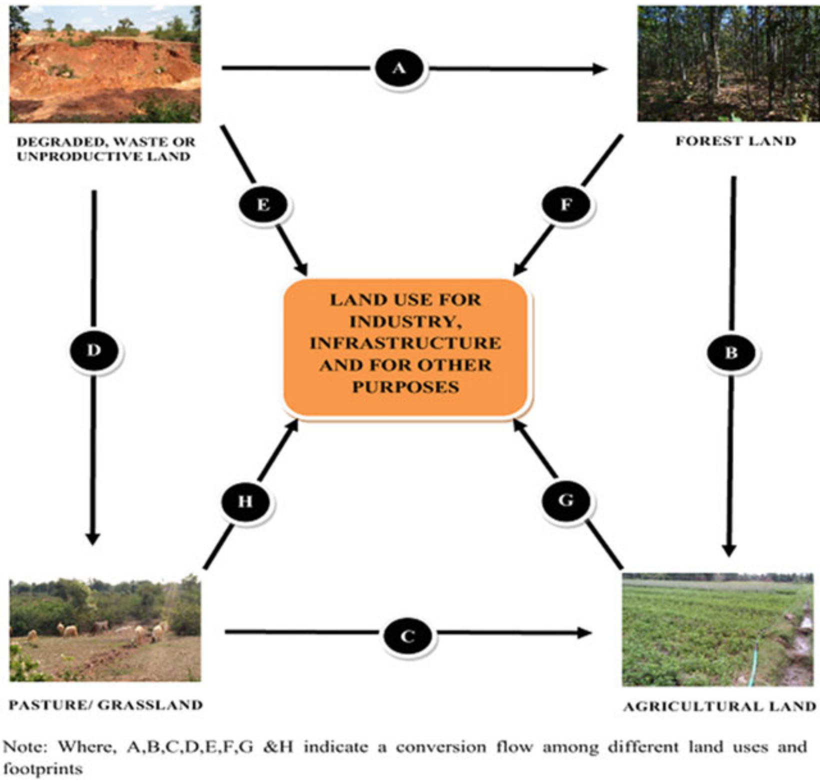

Fig. 7.2 Land use types, footprints, and conversion flows (Fischer et al. 2017b)

where the calories requirement and animal production is less than the developed countries. The dietary change and more inclination towards animal product would lead to intense agricultural expansion along with livestock management (Weinzettel et al. 2013). With the gradual growth of technology and science in the agriculture sector more improved variety came, technology of synthetic fertilizer came in the forefront but still the unprecedented growth of human population superseded all the technological progress. Further the issue has aggravated by the problem of environmental pollution and degradation. Across the globe in various continents there is gradual decline in availability of land for cultivation activities following agricultural intensification (Brouwer 2006). However, in some area (Africa and South America) decrease in availability of total land per capita basis was found to be more in comparison to only agricultural land use due to agricultural expansion of non-agricultural land.

Urbanization is an important factor in redirecting the land use change and changing the human consumptive behavior. Although it has a meager share (1%) on global perspective but it still plays a significant role in land use change and challenging environmental sustainability (Erb et al. 2009). Urbanization tends to increase per capita GDP (gross domestic product) of a country, promotes the use of natural resources and as well as it creates the opportunity for infrastructure development at the cost of environmental degradation. As per the reports the urban population has accompanied half of the population of the globe with major portion comprises of the developed economy followed by developing economy. A steady rise of 3.53 billion urban populations across the globe is predicted to take place in 2009. Further some parts of Europe have mentioned about shrinking urban population which may help to make the urban area to give a constant value (United Nations 2013). Prediction of two third portion rise of urbanization is happen to take place till 2050 due to new possibilities of economic activities as well as technological and agriculture growth. The possibility of maximum increase of urbanization may happen in those nations having higher rural population. As a consequence of urbanization, the associated land use change would tend to increase the land footprint considerably through altered pattern of land use (Hawkes 2006). Gradual urbanization would definitely change the human lifestyle pattern through more dependency on animal product and accordingly the land footprint of the agroecosystem would be modified. More area would be involved in livestock management for meat production or dairy products in comparison to general crop cultivation.

In the modern world bio-energy is the significant and emerging source of renewable energy accounting for one tenth of energy supply across the globe till 2009. This source of energy is mostly used for domestic consumption (IEA 2012). The major use of bio-energy is taking place through biofuel production which is increasing further pressure on land area through altered land use. As a consequence, it was observed that land for biofuel production undergoes competition for land area for crop cultivation (JRC 2013). Potential benefit of biomass-based renewable source of energy has driven the economy towards bio-products based economy system resulting into increase in land demand in the developed nations. However, this situation and its impact over developing economy are yet to be explored properly (Carus 2012).

7.6 Measurement of Land Footprint for Specific Land Uses

During land footprint estimation measurement of embodied land is very important along with consumption pattern and primary production. Different approaches were undertaken for estimation of land footprint includes scenarios of lesser consumption of animal products, expansion of biofuel production, etc.

7.6.1 Estimation of Footprint of Cropland Through Cropland Productivity

Rise in population followed by economic growth has emphasized 60% increase in agricultural production till 2050 (Alexandratos and Bruinsma 2012). Crop intensification through sustainable approaches would hold the key for efficient resource utilization in order to develop sustainable system of land use. It is one of the key strategies for the European subcontinent towards sustainable crop intensification (CEC 2011). Regarding extension of land footprint, one needs to go for efficient production followed by reduction in yield gap.

As per FAO the calculation for extension of land footprint can be done through evaluating the present rate of productivity and compare it with the actual level of production associated with the off-farm inputs and local environmental conditions (FAO 2011). In order to measure the efficiency of crop land utilization the indicator in the form of bioproductivity can be used effectively. This is due to the fact that the productivity of the agroecosystem is very much dependent upon the biophysical setup followed by technological knowhow the farmer and the agricultural research and extension activities through proper land management under prevailing socio-economic conditions (Banerjee et al. 2018; Jhariya et al. 2018a, b).

Calculation of land footprint is usually done by considering the land area produce agricultural product for domestic consumption along with land area used to produce imported product in the form of export. Calculation of crop land footprint gains relative weightage through productivity of the land in comparison to the average rate of productivity. Further, the process is affected by the bioproductivity of resources available to the concerned area followed by mechanism to achieve efficient production. In order to assess it properly one needs to have idea about the crop land productivity at spatial scale. This includes estimating the bioproductivity of a cropland from a country perspective or at global scale. Methodology for estimating land production potential needs to be done in order to find out the crop that is the best performer and therefore its production potential. On the basis of this value the potential productivity for the particular crop at global scale in a year can be calculated. Usually the land footprint value would be higher in comparison to the cropland footprint value under the conditions of efficient production and small gap between the yields.

Further, footprint calculation on the basis of area considered the productive potential of the land. This helps for a meaningful comparison of a footprint value across various countries of the globe, differencing capacity of production along with bio-productive capacity of the biomass-based croplands. At last the environmental consequences are evaluated and included in the modeling process. The major problem in assessing the environmental consequences is the temporal scale and the availability of the proper data. From this discussion it appears that suitable indicators for land footprint calculation should be screened out in order to recommend land use for sustainable purposes. For example, energy use pattern and agrobiodiversity in relation to land use intensity, deforestation, loss of wetland to assess land use change may prove beneficial for calculation of extended land footprint.

Nations consuming more commodities under the situation where the production is well below the sustainable yield, the crop land productivity would increase the footprint value in comparison to other nations. For example, nations of the African subcontinent tend to produce lesser amount with limited agricultural resources but the crop land footprint value based on consumption reflects higher value in comparison to other unweighted land footprints. Areas with high bioproductivity greater than the average value the crop land footprint would tend to increase in relation to unweighted footprint value. This situation may change if import comes from the regions with low bioproductivity.

7.6.2 Estimation of Footprint of Cropland Through Land Quality

Crop land in the form of agroecosystem is the most productive and variable zone depending upon the resources, environmental conditions, and the level of management applied. For estimation of the footprint values, land quality weightage is an important method in order to achieve appropriate value. For land quality estimation two variable conditions in the form of human made irrigation and natural irrigation were considered separately. According to the data set given by FAO STAT (n.d.), 1500 Mha crop land globally is under proper irrigation till 2010. Further, under arid and semi-arid condition cultivation of crops requires adequate irrigation. Specific crops are exclusively based on irrigation facilities. For example, countries like China and India harbor more than 60 Mha geographical boundary coverage of land under irrigated conditions. Irrigation plays a significant role in crop production throughout the world with more dependence on water resources. Rising problem of water scarcity has made the irrigation-based crop production problematic and unsustainable across the globe.

Higher weightage to land quality of crop land reflects greater exploitation of natural resources. However, lesser weightage of land quality may have some impact over the biodiversity (Raj et al. 2018). Land quality can be calculated through available soil area for net primary production under human made and naturally irrigated conditions (FAO and JRC 2012). Land quality can be explained in the form of biophysical conditions prevailing in the area under specific agro-climatic condition. It may also include topographical feature, soil conditions, and availability of infrastructure for irrigation. Using this methodology China tends to attain 20 tons dry matter biomass per hectare basis as average productivity on global scale.

Footprint calculation based on relative weightage on land quality tends to raise the land footprint components share which is associated with other land resources. For example, consumption of non-food products in comparison to the food product may reflects significant variation in the footprint value. The higher production capacity along with the commodity consumption pattern also influences the quality weighted footprint values. Commodity used in trades and measured through land quality-based footprint calculation reflects low production potential.

7.6.3 Footprint of Grassland Through Biomass Productivity

Grassland reflects significant variation in terms of productivity across various regions. For example, grassland of southern part of America tends to be highly productive as in case of semi-arid area of Asia. Grazing activity is very common for the livestock population and therefore it stands to be a dominant land use. Therefore, extending land footprints for grassland need to be done going beyond the area-based approach. For land footprint calculation of grassland weightage should be given to the biomass of the grassland vegetation in different locations. Further, the average yield of the grassland needs to be evaluated and used as reference yield. Using this reference level the actual average of grassland productivity along with its footprint can be calculated.

7.6.4 Footprint Estimation for Deforestation

Deforestation is a potential land use in the form of economy and productivity through producing various commodities. It involves a hybrid mechanism starting from production to supply and ultimately final consumption at the global level (Fischer et al. 2016).

Deforestation is associated with other forms of land use such as agricultural expansion for production of crops. From economic point of view, it also enters into the trade process in the form of timber products. As per the reports within a span of 50 years approximately 23.2 Mha land has undergone deforestation for agricultural productivity. Further, use of forest as pasture land has contributed 3.3 Mha land area for deforestation. Overall, a huge amount of land comes under the threat of deforestation due to changing land use pattern. It was observed that for oil crops and its associated products deforestation has been embedded in the traded commodity. For instance, 7 Mha of land area or greater in amount has been attributed towards deforestation due to oil crop production. In this Brazil holds half of the land investment. In terms of oil crops production EU contributes significantly to embed deforestation under trade process.

Land footprint calculation on the basis of area needs to be extended to include land quality as well as the effectivity of the embedded land along with important environmental impacts due to changes in land use. Extended land footprint calculation includes the quality of land as well as environmental attributes associated with land use, primary production at global scale and traces them from supply chain to consumption.

Deforestation happens to take place more on tropical regions associated with huge amount of biodiversity loss. As a consequence, it has become a potential threat as GHGs emission. Results reveal that most of deforestation footprint in the EU takes place due to agriculture expansion for crop production. The residual part has been contributed by the livestock populations. Such approaches are required in order to maintain livestock population which is connected with animal-based consumption pattern of the humans. Further, in this study identification of specific consumption pattern plays a significant role in footprint calculations. This would be helpful for the livestock population and calculating footprint value for cropland ecosystem where major share of land footprint comes from the livestock sector (Germany) followed by additional footprints of grasslands. It was revealed that livestock product consumption is associated with deforestation footprint.

7.7 Strategies for Reducing Land Footprint

It was observed that most of the cultivable land has been developed through forest degradation (Gibbs et al. 2010). This is a big issue as forest provides us with diverse ecosystem services in the form of carbon storage area and biodiversity reservoir (Machovina et al. 2015; Khan et al. 2020a, b). Depletion of forest cover would lead to massive deforestation and the ecosystem services would be hampered. Therefore, to meet up the demand for food for ever-increasing global population is the most challenging task for the upcoming century. As a consequence of this the land footprint would continue to increase and subsequently after certain time interval the existence of human civilization would be under question. Therefore, reducing the land footprint is the need of the hour. In order to preserve environment without compromising the food demand it is the urgent requirement that policies or strategies should be formulated to arrest the agricultural expansion at the cost of forest degradation. The agricultural yield needs to be increased within the existing setup as well as make a change in consumption pattern in order to reduce dependency on land or land deployment for more production (Tilman and Clark 2014; Erb et al. 2016). It was predicted that the earth without the deforestation activities demands the shifting of the food habit appears to be the best alternative to maintain the productivity without altering land use (Erb et al. 2016). Further at global scale the change in food habit from animal product consumption to non-animal production is a huge challenging task.

A good strategy must be needed for minimizing the land footprints in the world. Many authors have been worked on this by adopting some strategic plan to minimize the higher land footprints into a certain limit. For example, FAO (2012b) and PBL (2011), reported studies on the status of global land footprints of EU animal products of both cultivable/arable land and pasture/grassland including their 50% reduction status (Table 7.3). Cultivable/arable land shared maximum (69.30 million ha) land requirements as compared to 18.85 million ha in pasture/grassland for production of animal-based products whereas these values decreased into 50% due to decreasing

Table 7.3 Global land footprints of EU animal products of both cultivable/arable land and pasture/grassland (FAO 2012b; PBL 2011)

Animal items/ products	Land footprints status			
	In the year 2007–2009		50.0% reduced status	
	Cultivable/arable land	Pasture/ grassland	Cultivable/arable land	Pasture/ grassland
Pig meat	16.4	5.90	8.20	2.95
Bovine meat	21.5	0.00	10.8	0.00
Poultry meat	7.80	0.00	3.90	0.00
Other meat	2.10	3.10	1.06	1.54
Eggs item	3.33	0.00	1.70	0.00
Milk product	18.1	9.85	9.06	4.92
Total	69.30	18.85	34.64	9.34

consumption of animal products. Thus, land footprints decrease up to 50% that helps in less intensity on land and minimize the emission of greenhouse gases into the atmosphere due to deleterious and extensive animal productions.

7.8 Challenges of Land Footprints

Primary production is a key aspect as it is associated with land quality as well as the environmental factors. There is a strong nexus between the consumption patterns, land requirement along with environmental impact associated with primary production**.** However, incorporation of environmental impacts should be associated with primary production during evaluation of land footprints. In this connection, it is necessary to incorporate the site details and amount of damage that has taken place during land degradation (Bai et al. 2010).

Beside the applicability the calculation of land footprint seems to suffer some difficulties. For instance, it did not have the sound data basis to predict environmental impacts considering all different forms of land uses. It lacks the inclusion of concept such as productivity of land as well as primary productivity. The context of the nexus between land footprint and its impact on ecology and biodiversity of an area is yet to be explored properly.

Land footprint in isolation is less efficient for conveying information than combining with other forms of footprint. When combined with other forms of footprints it provides valuable information regarding the resource use from the nature. It was observed that palm oil plantation is associated with low land footprint but has high carbon footprint due to higher carbon emission through deforestation or wetland drainage activity.

During incorporation of environmental impacts for extension of land footprint there are some deficiency in the data base on particular issues such as land degradation, biodiversity loss, and impairment of water quality or loss of wetland. Further, there are some basic challenges in the evaluation process to account for specific impacts. Extended land footprint concepts are often limited due to lack of availability of proper data base and time period limitation. For example, data on deforestation is available for an interval of 5–10 years. As a consequence, proper linkage between environmental impact and primary production does not take place in a proper way to address sustainable land use. Consumption pattern were used to analyze the area based approaches for a particular region or country (Fischer et al. 2016).

It was observed that the use of system indicators reveals proper land quality evaluation for calculation of land footprint. This is very much applicable for grassland ecosystem due to their variation in terms of grassland qualities and productive capacity across the globe. However, proper definition of specific land uses such as grazing activity, grassland varies on area to area and on regional basis. For calculation of grassland ecosystem footprint environmental impacts and ecosystem services may not be included. The calculation for grassland footprint can be improved by incorporating the livestock feed balance calculation along with the land quality and livestock population.

7.9 Policies and Management Perspective of Land Footprint and Its Evaluation

In order to reduce land footprint various policies have been framed from European context. The policies should be such that it focuses on organic form of agriculture from both crop production and animal husbandry management in order to maintain the resource quality. Further, changing consumption pattern and environmental responsible behavior needs to be set as strict guidelines in order to achieve maximum benefits through footprint reduction. Scheme of eco-labeling could be helpful in this aspect to identify eco-friendly products needing lesser land requirement for production and therefore reduces the land footprint. As per the reports organic farming approach has the capability to feed about 9.6 billion people till 2050 with adequate protein and mineral supplement followed by its equal distribution (Erb et al. 2009). However, the organic farming would reduce the crop productivity in comparison to modern synthetic intensive farming practices. This would lead to increase in land demand and subsequently the land footprint in order to maintain the production status. Therefore, more emphasis should be given towards intensification practices in an eco-functional mode which would increase the quality as well as the yield along with reducing the negative aspects. Further, such approaches would also help to conserve the natural resource and maintain the ecosystem services for sustainable yield and production (FoE 2010).

From policy perspective changes in consumption pattern would help in reducing land footprint in developing and industrialized countries as their diet mostly comprises of animal protein. In this connection public awareness would do world good in order to change the consumption pattern and quantity. If the individual becomes adapted to lesser meat consumption it would reduce the livestock management activity and its subsequent land requirement. Further, lesser junk food consumption followed by increased consumption of foods and vegetables would also serve the purpose. From the farmer level recognition of traditional knowledge should be given top priority in order to produce eco-friendly product that would maintain the environmental sustainability and social well-being of human kind (FoE 2009; Wibbelmann et al. 2013).

In the energy sector there is steady shift towards renewable sources of energy in the form of bio-energy. In the developed world it was observed that switching over to renewable energy resources increase the land demand and thus increase the land footprint. However, when one considered about the benefits of using renewable sources in term of climate change mitigation it over rules the negative aspect of increasing the land footprint.

In recent times the event of globalization has mediated considerable level of export and import activities across the world. In this connection it is worthy to mention that northern hemisphere is the major exporter of cereal crops and its southern counterpart is the leader in export of vegetables, fruits, oils, and dry fruits. Increase production of vegetable product leads to an increase in land imports (Steen-Olsen et al. 2012).

Policies and strategies should be framed for the policy makers in order for continuous assessment and evaluation of land use and its changes across the globe. In this respect a monitoring task force at the international level should be developed to analyze the methodologies used for land footprint calculation and the associated critical issues. Guidelines should be framed for proper calculation of land footprints and statistical institutions at the national level should be involved in the task. Further integration of the accounting of land footprint is required to be done with the official accounting system in terms of socio-economic and environmental accounting.

Another important and key policy issues include targeting land use practices at the global level. Indicators for assessing the consumption pattern are safe or unsafe for particular land-use is very much essential in order to move towards a resource efficient sustainable world.

7.10 Conclusions

It was observed that population explosion, growing economy, unsustainable form of resource consumption are putting pressure on land, water, and other forms of natural resources. On the other hand, in the era of globalization the trade and business across the nations at the international level has put off a challenge in front of the consumers regarding their decisions about consumption pattern which may cause a severe deleterious impact in terms of resource depletion and associated rise in land footprint. This would be totally unsustainable from environment point of view. Proper policy formulation and management at the production sector and as well as in the consumer level would certainly help to reduce the land footprint from environmental sustainability perspective. The quest for environmental sustainability thus can be achieved through proper land use management and change which would encompass various spheres of environment and promote conservation and protection of natural resources. Therefore, proper evaluation of land footprint would promote sustainable land use for resource consumption followed by consumption-oriented land requirement.

7.11 Research and Development in Land Footprint and Future Perspectives

Land footprint is a critical issue from environmental sustainability point of view. In order to maintain the homeostasis of various ecosystems including the agroecosystem proper accounting of land footprint is very much essential. Various methodologies and techniques are available in land footprint estimation which needs to be reviewed properly in order to screen the best method to be used on various conditions for land footprint estimation. Further, the methodologies followed should be realistic in nature and can be followed on site as well as off site.

Variation is usually observed in different methodologies in land footprint calculation. During production of a particular product the local environmental condition as well as the socio-economic setup determines the pricing of the product. As a consequence, some products become costlier and some less costly. Land footprint estimation on these aspects varies significantly depending upon the methodology used for its estimation. Kastner et al. (2014) reported the variation of land footprints in China due to different approaches used in land footprint calculations. In one approach China reflects positive import based upon the flow of economy. This has variable influence in terms of addressing the foreign land requirement and food security issue. Therefore, proper exploration in terms of research and development is required to evaluate each individual method for land footprint calculation under various conditions. The concept of bio-productive land and actual land available for production needs to be distinguished properly. This would help in evaluation of land footprints appropriately.

Another big issue of land footprint includes its recent origin under the threat of environmental degradation, loss of productivity of agroecosystem, and prevalence of mega events such as the climate change. The concept of land footprint is very much recent and therefore needs to be properly explored to develop suitable techniques and methodology for its proper estimation (Weinzettel et al. 2014; Giljum et al. 2013a).

Future strategies need to be formulated for the clarity of technical terms within the concept of land footprint. For example, land footprint should be properly defined in terms of bio-productive land and the actual land available for production. In this aspect modeling of land use would be very useful to develop the coherence of concept related to land footprint with other sciences dealing with land quality. Further, when we are discussing about land footprint it should not only consider environmental impact of a particular land use but various uses of land to get a comprehensive value. All the different uses should be cumulatively assessed for land footprint calculation. Further, the intensity of land use in terms of crop production, maintenance of livestock population of dairy and meet product should be properly emphasized. Separate accounting for individual land uses needs to be done in order to evaluate the land footprint for particular land use. For predicting future trends and issues product wise valuation is required in order to assess the benefits of recycling in the production process. For example, use of crop residue for maintaining soil moisture level would help in the production process of crops and therefore land footprint value would reduce. Above all an integrated approach needs to be designed considering all the diverse methodologies and techniques that are available for land footprint estimations to avoid the challenges or problems that lead to variation in the results and also help to screen the best methods of the application.

Through the time span across the globe it was observed that the scientific studies done in various regions have got diverse dimensions in terms of scope, methodology, objectives, etc. Some studies were done calculating land footprint targeting particular product (Giljum et al. 2013a, b). Some studies focused on land footprint calculation of consumption pattern in the form of diet for specific nations in order to identify the environmental pressures in the production, consumption sectors (Meier et al. 2014; Fader et al. 2013; Kastner et al. 2014). Some studies were done to find out the rise and fall of particular product across various countries (Qiang et al. 2013; Bruckner et al. 2014). One of the most fascinating aspects is that all the estimations were done on different land conditions and to some extent some land uses such as land used as pastureland or forest is yet to be calculated properly in terms of land footprint.

Further studies based on indicators and relative weightage should be aimed towards agroecosystem, grassland, and other allied ecosystems by using land quality, energy use, and irrigation facility along with pasture land expansion. The relative contribution of non-food commodity towards cropland footprint was found to increase 5% within a span of 50 years. This value increases tremendously when considered in comparison to foreign land. Studying land footprint and associated environmental impacts requires more data bases and statistical information's through modeling approaches.

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Grey Water Footprint Accounting, Challenges, and Problem-Solving

8

Shervin Jamshidi

Contents

Abstract

Grey water footprint (GWF) is typically introduced as the environmental fraction of water footprint (WF). This indicator estimates the equivalent volume of freshwater required for assimilating the pollutants discharged by the production process to meet specific water quality standards. The conventional definition of GWF and its methodology for calculation is initially introduced in this chapter. This indicator is then compared according to the global

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and national data of crops. Based on these evaluations, it is reported that the average GWF hardly exceeds 15% of the total WF of crops globally. Nonetheless, GWF and its ratio to the WFs of products is highly variable in different nations or regions, among different crops and products, and even between the same products with different production processes such as the rain-fed and irrigated crops. Therefore, this chapter later focuses on the challenges of GWF assessment. Here, the shortcomings are highlighted in the definition of GWF which may introduce some misunderstandings, particularly for water allocation. For example, it is pointed out that the ratio of GWF to crop WF is mostly influenced by a set of agriculture-related factors instead of environmental issues. This point in addition to the low ratio of GWF to WF implies that this indicator might be neglected in comparison with the blue and green WFs of crops. Another shortcoming is GWF uncertainties. This chapter also discusses the four pillars of uncertainty, with their related challenges and possible impacts on GWF assessment. For example, the different methods of water quality regulation may result in different GWF for a product. According to all these gap analyses, this chapter reintroduces the developed methodology for considering environmental concerns in GWF accounting and reinforcing its ecological role. A hypothesized study is chosen with some environmental issues to show how GWF problems can be solved by the altered methodology. Afterwards, the results are compared by which a conceptual model is developed for illustrating the impacts of a new accounting approach on intensifying the multiple-pollutant GWF of products. Finally, some research roadmaps emphasizing GWF and possible future trends are notified and recommended.

Keywords

Environmental impact · Grey water footprint · Multiple pollutants · Uncertainty

Abbreviations

AC	Assimilative capacity
AWQS	Ambient water quality standards
BOD	Biochemical oxidation demand
C_d	Concentration of pollutant
C_{max}	Maximum allowable concentration of the pollutant
C_{min}	Minimum allowable concentration of DO in surface waters
C_{nat}	Natural concentration of the pollutant
COD	Chemical oxidation demand
C_{sat}	Saturated concentration of DO in surface waters
DO	Dissolved oxygen
DO_{act}	Actual minimum level of DO
DO_{std}	Minimum required DO
EC	Electro-conductivity
EC_{act}	Current EC of water

EC_{req}	Required level of EC in water resources
GW	Grey water volume
GWF	Grey water footprint
i	Pollutant
L	Pollution load
LCA	Life cycle assessment
MP	Micropollutants
MP_{act}	Current concentration of MP
MP_{req}	Risk free limit of MP in water resources
N	Nitrogen
NA	Not accountable
P	Phosphorus
Q	Annual discharge flow rate
Q_{act}	Current minimum flow of river
Q_{env}	Required minimum environmental flow
SWAT	Soil and water assessment tool
TDS	Total dissolved solids
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
WLA	Waste load allocation
WWTP	Wastewater treatment plant
Y	Production yield
ω	Correcting factor

8.1 Introduction

Water footprint (WF) of a product is known as the embodied freshwater volume consumed directly and indirectly in production processes (Hoekstra et al. 2011). It includes blue, green, and grey components in the calculation and can be variable due to the national or regional water demand, consumption patterns, or water use efficiency (Hoekstra and Chapagain 2006). The primary goal of this indicator is to enlighten the consciousness of consumers and producers about the value of hidden water in products. This indicator is now used widely for economic valuation and efficiency analysis of water systems (Bae and Dallerba 2018; Zhang et al. 2019). For example, farmer or manufacturers can account this indicator for optimizing their cultivation and production patterns (Mojtabavi et al. 2018; Mubako 2018). WF can comparatively indicate which types of crop patterns or regions are more efficient with the purpose of reducing water consumption. Regarding the review of Lovarelli et al. (2016), it can be concluded that out of 96 literatures, the whole studies about crop production have accounted the blue and green WFs. However, only 46% of these reviewed literatures have considered grey water footprint (GWF) assessment in addition to the blue and green WFs. It means that the GWF of products is sometimes assessed in literatures and reports. Moreover, they concluded that cereals have the highest subdivision analysis among agricultural productions in WF assessment (Lovarelli et al. 2016; Meena et al. 2018). Regarding this review, it can be also realized that GWF may have more challenges or research opportunities in comparison with the blue and green WF of productions.

GWF is one of the main three elements for WF accounting. This indicator is known as the equivalent volume of freshwater required for assimilating pollutants to meet specific water quality standards (Hoekstra et al. 2011). In other words, GWF is an indicator of the amount of freshwater pollution originated from an industrial, agricultural, or service activity and ultimately includes the concept of water quality in the WF assessment of products (Franke et al. 2013). The definition of GWF is basically developed for reflecting the water quality issues in WF accounting because contaminations have this potential to intensify the water scarcity problems and may limit its allocations (Pellicer-Martinez and Martinez-Paz 2016). For example, Kariman et al. (2017) have shown that pollutions discharged by fish farms alongside the streamline can impose adverse effects on the production yields of aquacultures downstream.

Typically, GWF includes the lowest share of WF for crops. This indicator is calculated by the methodology and supporting guideline introduced by Hoekstra et al. (2011). Equation (8.1) summarizes the main conventional method of GWF assessment (m^3/ton).

$$\mathrm{GWF} = \frac{1}{Y}\mathrm{GW} \tag{8.1}$$

where Y is the annual production yield of crop or product (ton/ha), and GW is the annual grey water volume (m^3/ha) accounted by Eq. (8.2) which converts the pollution loads by the assimilative capacity (AC) into the equivalent freshwater volume.

$$\mathrm{GW} = \max\left[\frac{L}{C_{\max} - C_{\mathrm{nat}}}\right]_i \tag{8.2}$$

Here, GW is the grey water volume (m^3/ha), L is the export pollution load (ton/ha) of pollutant i discharged to the receiving water body calculated by Eq. (8.3), $C_{\max}$ is the maximum allowable concentration of the pollutant, and C_{nat} is the natural concentrations of pollutants in the receiving environment on the condition that the anthropogenic emissions are removed. Here, the AC is set as the difference between $C_{\max}$ and C_{nat} which reflects the water quality issues in GWF.

$$L = Q \times C_d \tag{8.3}$$

In this equation, Q is the annual discharge flow rate (m^3), C_d is the concentration of pollutant i in the effluent of emission sources (g/m^3).

8.2 Conventional Grey Water Footprint Accounting

8.2.1 Global Scale

The conventional definition of GWF mentioned above is approximately used for a decade for accounting the WFs of crops and products. By referring to the reports published in the last decade, as Mekonnen and Hoekstra (2011), it can be realized that the GWF may be regionally variable where it can also be unique for any crop, product, or activity. As shown in Fig. 8.1, the average *GWs* of cereal crops are different between the five main continents of the world. America and Asia with, respectively, 7.4 and 7.2 m^3/km^2 grey water volume discharge the highest accumulated pollution loads to the receiving water bodies, while Africa and Oceania have the lowest values. In addition, the yields of cereal crops show that America and Europe have relatively the highest yields of 4.3 and 4 ton/ha, respectively, that can be due to their climate, soil properties, available technologies, etc. Therefore, the GWFs of cereal crops are accounted as 228, 174, 119, 116, and 101 (m^3/ton), respectively, for Asia, America, Europe, Oceania, and Africa (Mekonnen and Hoekstra 2011).

The average ratio of GWF to the WF of cereal crops in different continents is less than 15%. America and Asia are attributed as the two continents with the highest GWF ratio about 13%, while Africa and Oceania have the lowest share of GWF (less than 6%) (Mekonnen and Hoekstra 2011). It should be noted that this ratio is not dependent on the production yield (Y) and land area because these parameters are equal for both GWF and WF. Conversely, this ratio is dependent on the amounts of blue and green WF of crops. Therefore, it can be concluded that Asia and America relatively require more freshwater for pollution assimilation respecting their requirements on blue and green water. However, the point is that the variation of this ratio is not significant (from 6% to 13%) and consequently it may lead into neglecting detailed GWF accounting in the future particularly in large scales or for cereal crops. This possibility can weaken the applicability of GWF as an environmental fraction of WF assessment.

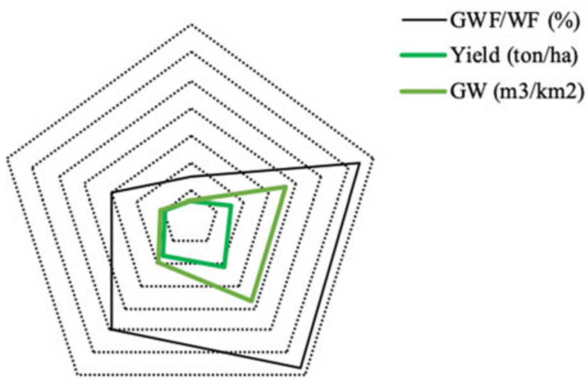

Fig. 8.1 Grey water of cereals in different continents (from Mekonnen and Hoekstra 2011)

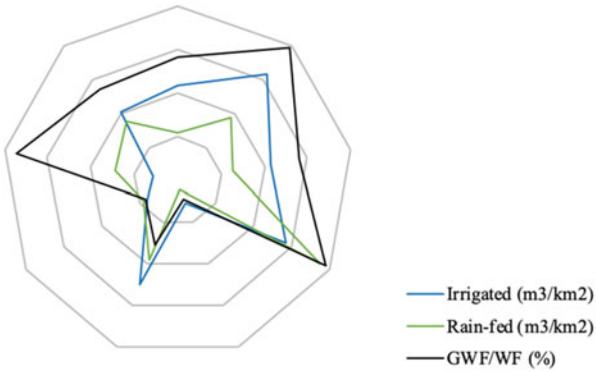

Fig. 8.2 Grey water of crops (from Mekonnen and Hoekstra 2011)

Figure 8.2 compares the globally average GWs of nine primary crops as wheat (*Triticum aestivum*), maize (*Zea mays*), rice (*Oryza sativa*), apples (*Malus* spp.), soybean (*Glycine max*), sugarcane (*Saccharum officinarum*), coffee (*Coffea* spp.), rapeseed (*Brassica napus*), and cotton (*Gossypium* spp.). This figure initially compares the GWs of irrigated and rain-fed crops. Normally, irrigated crops have higher GW (m^3/km^2) in comparison with the rain-fed crops due to the possibility of higher leaching of pollution from the irrigation process. However, there are exceptions, as always, such as apples or rapeseed. This figure also shows that some crops, such as coffee or soybean, may significantly discharge lower pollution loads in comparison with their blue and green WFs. The ratio of GWF to WF of these two crops is below 4% while for others hardly exceeds 15% (Mekonnen and Hoekstra 2011).

The global average ratio of GWF to WF of 50 crops (Table 8.1) is also less than 15% considering the reports published by Mekonnen and Hoekstra (2011). However, it may be varied in different nations. For example, this ratio for China, Iran, Spain, and the USA is, respectively, 30, 14, 11, and 19% (Water Footprint Network 2020).

8.2.2 National Scale

GWF is also accounted in addition to the blue and green WFs of crops on the national scale. In Iran, few studies have accounted the WFs of crops. By referring to the data that has been recently used by Ababaei and Etedali (2017), it can be concluded that the ratio of GWF to the WF (%) of wheat in Iranian provinces differs between the two types of irrigated and rain-fed crops. Here, the whole provinces have a higher ratio of the GWF to WF of the irrigated than rain-fed wheat. It is interesting because the WF of irrigated crops is normally the aggregate of blue, green, and grey constituents, while the WF of rain-fed crops typically includes green and grey fractions only. So, the irrigation increases blue WF and should reduce the ratio of GWF to WF. On the contrary, the ratio (%) is growing for the irrigated wheat

Table 8.1 The ratio of grey water footprint to water footprint (%) of crops (from Mekonnen and Hoekstra 2011)

Crop/product	GWF/WF (%)	Crop/product	GWF/WF (%)
Wheat	11.3	Eggplants	26.2
Rice, paddy	11.2	Onions	18.8
Barley	9.2	Garlic	28.9
Maize (corn)	15.9	Peas, green	25.2
Sorghum	2.9	Carrots	31.3
Potatoes	22.0	Bananas	4.2
Sugarcane	6.2	Oranges	8.8
Beans	19.5	Lemons	9.0
Peas	24.9	Apples	15.5
Pistachios	5.9	Pears	19.8
Soya beans	1.7	Cherries	7.0
Coconuts	0.6	Peaches	15.3
Olives	1.5	Strawberries	10.7
Sunflower seeds	6.0	Grapes	14.3
Cabbages	26.1	Watermelons	26.8
Asparagus	23.6	Mangoes	6.9
Lettuce	32.5	Pineapples	12.2
Spinach	54.8	Dates	4.3
Tomatoes	20.1	Coffee	3.3
Cucumbers	29.7	Tea	8.2
Peppermint	6.6	Millet	2.6
Tobacco	23.9	Cassava	2.3
Cocoa beans	0.9	Walnuts	16.6
Chocolate	1.1	Pumpkins	25.0
Artichokes	12.0	Kiwi fruit	7.4

than rain-fed in Iran. In addition, the ratio of GWF to WF (%) is much more than the global average. For example, in provinces like Fars, Khuzestan, and Ardebil, the ratio reaches to 35%, while the minimum ratio of irrigated wheat is 17%. This ratio seems more identical to the global mean for rain-fed wheat in which it ranges between 4 and 20%. This is due to the fact that using water for irrigation with misapplication of fertilizers can lead to more pollution exports through leaching and consequently higher GWFs. As a result, using less water for irrigation may not only reduce the blue but also the grey fraction of the WFs of crops, particularly in developing countries like Iran (Fig. 8.3).

Regarding the data of using nitrogen fertilizers shown for irrigated wheat (Fig. 8.4) and maize (Fig. 8.5), it can be realized that the application of fertilizer (kgN/ha) is relatively compatible with the GWF (m^3/ton) of crops in provinces. Conversely, it seems not correlated with the climate conditions of provinces. Kermanshah, Ardebil, West Azerbaijan, and Hamadan are rather cold and mountainous, while Fars and Khuzestan have Mediterranean climate located in the plains

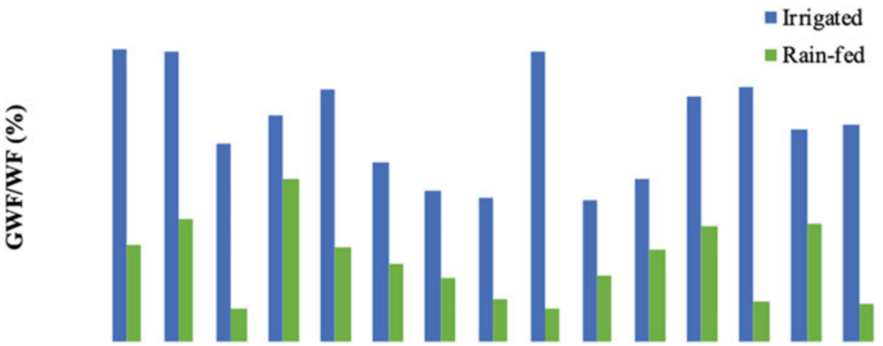

Fig. 8.3 The ratio of grey water footprint to water footprint (%) of wheat in some provinces of Iran (from Ababaei and Etedali 2017)

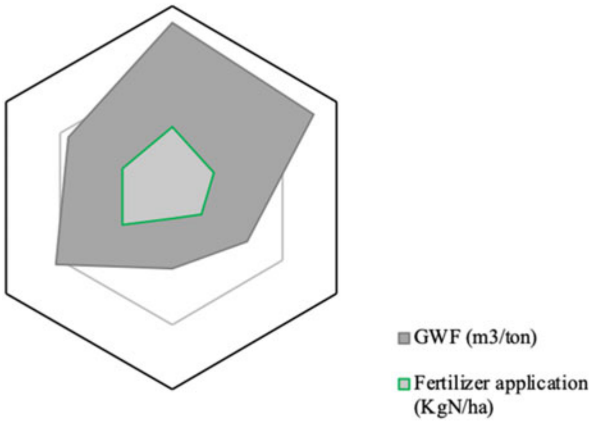

Fig. 8.4 Fertilizer applications (kgN/ha) and grey water footprint (m^3/ton) of wheat in some provinces of Iran (from Ababaei and Etedali 2017)

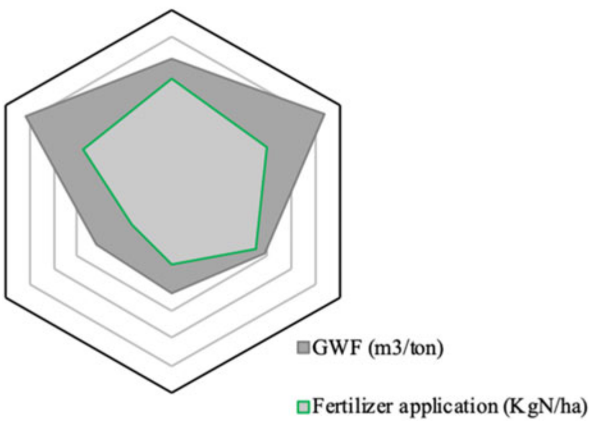

Fig. 8.5 Fertilizer applications (kgN/ha) and grey water footprint (m^3/ton) of maize in some provinces of Iran (from Ababaei and Etedali 2017)

of Zagros Mountains. Therefore, the conventional definition of GWFs of crops can only highlight the application of fertilizers, while it ignores other environmental issues.

8.3 Challenges of Grey Water Footprint Accounting

The conventional method of GWF accounting has some shortcomings and may increase some misunderstandings that limit the application of GWF. These shortcomings are mainly originated from the quality-based concept of GWF, various effective parameters, and the AC of receiving water bodies. The water quality itself is reliant on the type of pollution sources and emission loads, quality standards and monitoring limitations, and more importantly, the pollutants and their specifications for reaction or accumulation in water bodies. All of these factors increase the uncertainties of GWF accounting and may mislead any water or environmental policy-making.

As shown in Fig. 8.6, the GWF of the same product or crop with the same production process and production yield (Y) can be different among two manufacturers or farmers. For example, the manufacturer/farmer in region B may use some treatment systems that control pollution discharges. The wastewater treatment system can reduce the pollution loads (L) and consequently the GWF and WF of product. However, this difference does not always mean that region B has used treatment systems or region A has not used it (Gomez-Lianos et al. 2019). For adopting this misunderstanding, it is better to look closely at the definition of GWF.

As shown in Eq. (8.2), the GWF is reliant on both the pollution loads (L) and the AC of the receiving water body. It means that the AC of the receiving water in region B can be comparatively higher than region A and consequently the GWF is lower. This sentence means that the self-purification of the surface water in region B should be higher than region A or it may be concluded that region B contains cleaner water. However, these conclusions from Eq. (8.1) and the definition of GWF are also

Fig. 8.6 Water footprint (WF) of a same product with same production process in two regions

misleading. This is due to the fact that the AC of the receiving water is supposed to be defined as the differences between C_{max} and C_{nat}.

The two terms of C_{max} and C_{nat} determine the value of the AC in GWF accounting. However, these two parameters are usually calculated with respect to the regional standards, the conventional guidelines of GWF accounting, or the documented data series. For example, C_{max} can be defined by two methods of global standards or ambient water quality standards (AWQS). The global standards cannot represent the local environmental conditions or self-purification potential of receiving water bodies but they can generally be used to increase the unity in GWF accounting. On the contrary, AWQS can be set locally oriented by an integrated modeling that simulates the quality and quantity of receiving water bodies in different scenarios and conditions (Chukalla et al. 2018). Therefore, AWQS is not constant and varies from one basin to another due to the variations of land-uses and the ecosystem features (Monfared et al. 2017; van Vliet et al. 2017; Wu et al. 2016). It can also be modifiable during the time due to the variations of pollution mitigation policies (Feizi Ashtiani et al. 2015; Incera et al. 2017) and regarding the monitoring tools and methods (Zhao et al. 2018). In a nutshell, C_{max} is one pillar of uncertainty in GWF accounting in different regions and for different products/crops (De Girolamo et al. 2019). Another pillar is C_{nat}. This parameter should be supposed to be equal to the water quality condition when the anthropogenic effects are removed from the basin. In other words, C_{nat} should be calculated by the simulation techniques, or with respect to the long-term data series of water quality. In addition, the third method is to assume C_{nat} by the conventional guidelines. All these methods are based on a set of preferences that can increase the uncertainty of GWF accounting.

The third complicating point of the AC in GWF accounting is that in areas with strict standards, C_{max} is assumed closer to C_{nat}, and consequently the GWF increases. It means a paradox: "choosing strict standards can adversely increase the GWF of products." This may mislead decision-makers in trading products based on WF assessment and their overall virtual water. In other words, policy-makers in water divisions may choose to reduce the strictness of their own standards to reduce the share of GWF of products and consequently to justify exporting their virtual water to areas with higher WFs. Therefore, the standardization of water quality has also influences on the AC in GWF accounting.

Regarding the aforementioned problems of GWF, it can be concluded that the conventional approach of GWF accounting cannot result in identical methodologies or outcomes for products/crops. Yet, there are two other issues in GWF, as an indicator, that may have impacts on the methodology of accounting and decision-making. One issue is that C_{max} and C_{nat} are usually referred to the pollution concentrations in surface waters. The leaching to the aquifers and runoff fractions of pollution discharges can be variable in different regions. Franke et al. (2013) believed that GWF can provide a tool for the assessment of sustainability, efficiency, and equity in water allocations and consumptions. Accordingly, a detailed calculation is proposed for supporting tier 1 for pollution accounting. They took into account leaching-runoff fraction for diffuse pollutions sources. By this method, they could increase the accuracy of accounting GWF of agricultural activities that use fertilizers and pesticides. However, more recent modeling and simulation tools such as the soil and water assessment tool (SWAT) are capable of measuring leaching, runoffs, pollution exports, and consequently water footprints (Ahmadzadeh et al. 2016; Luan et al. 2018; Veettil and Mishra 2016). Therefore, the pollution exports of agricultural purposes can be modeled more reliably by integrated farm-basin modeling (Hu et al. 2018). However, this type of shortcoming is still unresolved for point sources that may not use centralized treatment and water reuse systems. For example, service activities, such as waste processing and disposal in rural areas, may have some discharges of pollution to the environment in which the leaching-runoff fractions cannot be estimated.

Another important issue that is neglected in GWF is that this indicator is conventionally unable to account the environmental concerns or probable ecological damages in basins where the production process is located. This is an important issue because GWF is the only fraction of WF that directly considers environmental aspects, as water quality, in accounting (Meena et al. 2020). About this subject, some recent studies have highlighted the role of GWF for indicating the environmental issues. Quinteiro et al. (2018) emphasized that a production process may change land-use and consequently impose long-term environmental impacts in basin. Likewise, a manufacturer may put the ecosystem at risk by the overexploitation of water from basin. This can violate the minimum river environmental flow and degrade water quality (Lovarelli et al. 2018). It can also result in reducing the self-purification potential of river and changing the values of C_{nat} (Liu et al. 2016). These examples show that the WFs of products need to be different between the polluted or ecologically damaged areas and environmentally clean areas. Regarding this shortcoming, the methodology has been recently developed by Jamshidi (2019a, b) to consider the environmental concerns of receiving water bodies in GWF accounting. It is emphasized that using integrated simulation tools for the determination of AWQS is inevitable. Besides, this study has proposed a new approach to upgrade GWF to an environmental indicator by including an alteration coefficient.

Therefore, this section discussed a set of challenges and weaknesses of GWF that may introduce it as an indicator without an identical methodology. The GWF can be variable from one crop/product to another in two different regions with the same production processes. This is due to the fact that some uncertainties are originated from the principles and definitions of GWF. Figure 8.7 summarizes the four reasons that introduce GWF as a non-identical indicator. In two regions, the two similar farmers or manufacturers may use two different types of treatment and reuse systems. They may possibly adopt two different methodologies for water quality standardization and monitoring (C_{max}). They may work in regions where the historical time series of water pollution are not available for a long period to define the natural water quality (C_{nat}). Moreover, one region may accept new approaches in GWF accounting to include environmental concerns in calculations, while the other region may use the conventional approach. The last cause would be more discussed in this chapter.

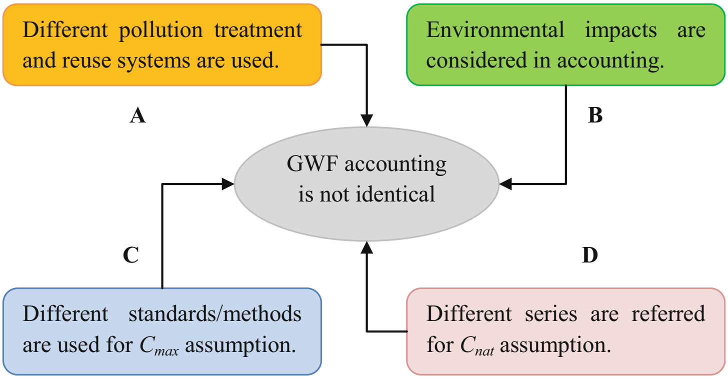

Fig. 8.7 Some sources of uncertainties in the grey water footprint of products

Therefore, the purpose of this chapter is to introduce the developed methodology of GWF accounting by its equation and testify its application through a hypothesized study area with a rural emission source. Here, the results are compared with respect to the grey water content in different scenarios calculated by the altered equation. In this equation, an alteration coefficient is included in calculations to take the regional environmental concerns in GWF accounting.

8.4 Development of Grey Water Footprint Accounting

8.4.1 Study Area

This study uses hypothesized emission sources in a basin to discuss different aspects of the new methodology of GWF accounting. Here, it is assumed that rural wastewater is discharged from irrigated farmlands with an average flow of 7000 m^3/y and directly enters a river-lake basin. The main pollutants of effluent are biochemical oxidation demand (BOD), chemical oxidation demand (COD), ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), total dissolved solids (TDS), electro-conductivity (EC), and some toxics like diazinon and malathion are assumed as detected. In addition, the dissolved oxygen (DO) is also important for the aquatic life of receiving water. For simplicity, it is assumed that the wastewater is discharged in the form of runoff, while the effect of sediment, as a potential diffuse pollution source is neglected.

In the study area, the river basin itself has some environmental concerns. First, this river requires 16 m^3/s of basin minimum environmental flow. However, the steady flow of river ranges between 10 and 18 m^3/s in summer and winter periods, respectively. The river flow is obviously variable due to the water allocation demand strategies upstream where it is controlled by an embankment dam. Second, the natural lake downstream encounters algal bloom and consequently eutrophication. The average concentrations of DO in this lake in summer and winter periods are

4 and 6.5 mg/L, respectively. Third, the level of groundwater interacted with this river basin is low and its quality is threatened by saline intrusion from the coastal areas. In order to focus on the verification of the new methodology, the maximum (C_{max}) and natural (C_{nat}) concentrations of different pollutants are determined according to the international standards. The whole hypothesized data would be discussed as results.

8.4.2 Proposed Methodology

The GW of the most of pollutants and water quality parameters (i) can be accounted by Eq. (8.2). However, the pollution load is meaningless for DO. The DO-related *GW* should be accounted by Eq. (8.4) which was firstly introduced by Jamshidi (2019a).

$$\mathrm{GW_{DO}} = \frac{Q \times (C_{\mathrm{BOD}} + C_{\mathrm{NH4}} + C_{\mathrm{NO2}})}{C_{\mathrm{sat}} - C_{\mathrm{min}}} \tag{8.4}$$

In this equation, C_{BOD}, C_{NH4}, and C_{NO2} are attributed to the concentrations of carbonaceous BOD, ammonium, and nitrite in the effluent, respectively. C_{sat} represents C_{nat} which shows the saturated concentration of DO in the surface waters, while C_{min} is the minimum allowable concentration of DO for ecological protection. The last parameter is usually determined between 5 and 6 mg/L in surface waters. It should be noted that Eq. (8.3) follows the main form of GW assessment as Eq. (8.2). However, it sums up the pollution loads of parameters that are directly effective on DO. For example, the BOD content of water can reduce the DO level of surface waters. Likewise, NH_4 and NO_2 demand oxygen through the nitrification process (Jamshidi and Niksokhan 2016).

The developed equation of GW assessment is shown in Eq. (8.5). This was introduced by Jamshidi (2019a) to include the environmental issues in calculation of GW. Here, a new dimensionless coefficient is included to convert any possible embedded ecosystem damages into equivalent freshwater volume.

$$\mathrm{GW} = \frac{1}{\omega} \max \left[\frac{Q \times C_d}{C_{\mathrm{max}} - C_{\mathrm{nat}}} \right]_i \tag{8.5}$$

where ω is a factor ($\omega < 1$) that alters/changes the definition of GWF. It is dimensionless and adds the amount of embedded freshwater required for recovering the receiving water body where the aquatic ecosystem experiences some impairments. Here, ω is defined as Eq. (8.6) as the minimum of five indicators. Each indicator focuses on one ecological concern in water resources. It should be noted that whenever any of these five indicators is calculated more than 1, that specific type of ecological concern can be neglected in GWF accounting, while the other four types of recovery may still be required in assessments.

$$\omega = \min\left(\omega_1 = \frac{Q_{act}}{Q_{env}}; \omega_2 = \frac{DO_{act}}{DO_{std}}; \omega_3 = \frac{\left(N_{req}\ or\ P_{req}\right)}{\left(N_{act}\ or\ P_{act}\right)}; \omega_4 = \frac{EC_{req}}{EC_{act}}; \omega_5 = \frac{MP_{req}}{MP_{act}}\right) \tag{8.6}$$

In this equation, ω_1, ω_2, ω_3, ω_4, and ω_5, respectively, refer to five ecological concerns of the minimum environmental flow (E-flow) of rivers, the minimum water quality required for the aquatic life, eutrophication, saline intrusion, and eco-toxicity which are defined as follows.

ω_1 represents the concern of minimum E-flow in water resources. This indicator evaluates the embedded freshwater volume required, as the compensation of the current river flow (Q_{act}) for its enhancement to at least the minimum E-flow in the receiving water body (Q_{env}). Here, Q_{act} should be monitored and referred based on the hydrometric data of checkpoints. As a consequence, this indicator would become indispensable when the river experiences high water allocations for agricultural or industrial purposes, unsustainable operation of dams or wells, long-term drought, or climate change (Jamshidi et al. 2018; Meena et al. 2020a, b). If a crop is not perennial and raised in seasons when the average river flow (Q_{act}) is below the annual E-flow (Q_{env}), it should include ω_1 in its GWF accounting.

ω_2 can be used for indicating the basic favorable condition of aquatic life in water resources (not used for groundwater). DO_{std} is the least approved DO concentration of surface waters required for the conservation of the aquatic life. The value of DO_{std} can be assumed above 5 mg/L by default. Provided that rivers, streams, or lakes receive larger pollution loads from the production area and simultaneously experience DO<5 mg/L, it requires some embedded freshwater volume to virtually rehabilitate the quality of surface waters and increase the current minimum concentration of DO (DO_{act}) to the required level (DO_{std}). It means that crops produced in this type of basin should account the lack of DO in their GWFs. It can increase the applicability of GWF as an indicator that also accounts the concerns of aquatic life and ecosystem services about DO deficiency ($DO_{\text{act}} < DO_{\text{std}}$).

ω_3 specifically points to the eutrophication problem of lakes, reservoirs, and estuaries. On the condition that a crop is produced in a lake basin with eutrophic condition, some embedded freshwater volume is required for virtual dilution of the nutrients and rehabilitation of the water quality of lake. Therefore, it is recommended that the concentrations of N and P of lake (N_{act} or P_{act}) should be reduced by adding some embedded freshwater volume (N_{req} or P_{req}) such that the trophic state of lake improves at least one level. For instance, the eutrophic condition of lake is enough to be improved from eutrophic to the mesotrophic condition. Thus, the minimum N and P concentrations of the mesotrophic condition of lake are, respectively, reflected as N_{req} and P_{req} in ω_3. It should be noted that usually one of the two pollutants of N or P would be the limiting factor of eutrophication in lakes (Chapra 1997). This can consequently bound the calculations of ω_3 to only the limiting pollutant between N and P.

ω_4 points to the problem of saline intrusion in surface water and groundwater resources. These problems are common in coastal areas or aquifers under water stress. The over-pumping and extraction of groundwater for agricultural or industrial applications can cause salinity intrusion. The hydraulic gradient formed by overexploitation may lead freshwater to be replaced with the saline water in aquifers. As a result, the soil property is destroyed as an ecological concern and may have long-term effects on both the ecosystem and society. Therefore, some embedded freshwater volume should be virtually charged to groundwater to reduce the EC concentration (EC_{act}) to the required levels (EC_{req}). This indicator can be accounted in areas where crops are raised by groundwater having the experience or risks of saline intrusion. In addition, the industrial products which use desalination plants for water extraction can also account ω_4 in their GWF analysis.

The final indicator is attributed to the eco-toxicity. ω_5 highlights the existence of micropollutants (MP) in the receiving water bodies. MPs may directly or indirectly cause health and ecological risks or remain for long term in the ecosystem. Different products manufactured by industries or agricultural crops may partially discharge toxic materials in the production processes like heavy metals, micro-plastics, or even pharmaceuticals (Martínez-Alcalá et al. 2018) to the water resources. Therefore, it is recommended that an embedded freshwater volume should be allocated for these basins that virtually dilute existing MPs and increase the AC of the receiving water bodies. For this purpose, the current concentrations of hazardous MPs (MP_{act}) are required to be reduced below the limits that may expose short- or long-term health or environmental risks (MP_{req}). Maybe producing a crop or product has not discharged any MPs. Despite the fact that the production process is not responsible for the MP concentration of the river nearby, it still requires to account ω_5 in GWF accounting because it has used the natural resources of the area where the ecosystem is already damaged by the MPs.

8.5 Analytical Results

Table 8.1 summarizes the typical quality of rural wastewater discharged from farmlands to a river-lake basin. The flow rate of discharge is variable but in average it is assumed annually 7000 m^3.

As shown in Eq. (8.2), the GW is the ratio of pollution loads to the AC of receiving water body. In this equation, GW is the maximum of this ratio for multiple-pollutant assessment. However, the pollutants may be different with respect to their units or they may have specific C_{max} or C_{nat}. These differences may limit the conventional evaluation of pollution loads and the AC. In the following, the points and calculations of some pollutants are separately discussed.

8.5.1 Dissolved Oxygen

DO is not a pollutant but the lack of DO reflects a low water quality. Therefore, it is meaningless to calculate the load of DO for GW assessment. In addition, DO has a minimum standard limit instead of $C_{\max}$, which differs from the conventional definition for the assessment of the AC. Jamshidi (2019a) recommended that the pollution load assessment for including DO in multiple-pollutant GW accounting is necessary, particularly for aquaculture in which the production yield is reliant on DO (Kariman et al. 2017). Here, DO-related GW is calculated by Eq. (8.4) and equals 19.6 km^3/y. It also should be noted that in cases where any of the three items that are effective on GW_{DO} such as BOD, NH_4, or NO_2 are not available or tested, its value can be neglected.

8.5.2 Total Solids

The assimilative capacity assessment of pollutants like TSS and TDS is case-specific. In rivers, TSS can be naturally variable due to sediment transport and flooding. Likewise, TDS can be naturally variable in estuaries or rivers with high erosions. Therefore, C_{nat} may be not accountable (NA) for these pollutants or it can be more than $C_{\max}$. This can limit the accounting of related AC.

8.5.3 Toxics

On the contrary to the total solids, C_{nat} of toxics, pesticides, and fungicides is zero as naturally they do not exist in water bodies. In other words, toxics are mostly anthropogenic. However, $C_{\max}$ for some micropollutants may be determined zero as well which means they should not remain in water body at all. For example, any application of Malathion may be prohibited in an area and consequently it should not be detected in water bodies. In this condition, the AC and GW are not accountable.

8.5.4 Other Parameters

The GW of parameters like BOD, COD, NH_4, NO_2, NO_3, TP, and EC can be easily calculated by the conventional equation. Table 8.1 illustrates that parameters with even different units, such as EC, have no problem with GW assessment if their standards ($C_{\max}$ and C_{nat}) are in the same unit of water pollution concentrations (C_d).

In another scenario where wastewater is discharged for recycling and reuse, pollution load can hardly be assessed (Gomez-Lianos et al. 2019). Pollution load is conventionally defined as discharges to the water bodies. Imagine the effluent of fish farms is reused for crop irrigation and then drained to the water bodies. NH_4 concentration of fish farm is 3 mg/L, while its concentration in drainage is 1 mg/L after reuse. The volume of total effluent is also reduced due to the

Table 8.2 Discharge quality and related conventional GW

Discharge parameters	Concentration		Pollution load		Assimilative capacity			Conventional GW (m^3/y)
	Value	Unit	Value	Unit	C_{max}	C_{nat}	Unit	
BOD_5	13	mg/L	91	kg/y	25	2	mg/L	3956
COD	20	mg/L	140	kg/y	50	5	mg/L	3111
DO	2	mg/L	–	–	–	10	mg/L	NA
DO-related	By Eq. (8.4)							19,600
NH_4	0.85	mg/L	6	kg/y	0.5	0.1	mg/L	15,000
NO_2	0.15	mg/L	1	kg/y	0.1	0.01	mg/L	1010
NO_3	6	mg/L	42	kg/y	10	1.5	mg/L	4941
TP	0.5	mg/L	3.5	kg/y	0.25	0.01	mg/L	14,583
TSS	450	mg/L	3150	kg/y	500	–	mg/L	NA
TDS	500	mg/L	3500	kg/y	1000	–	mg/L	NA
EC	800	μs/cm	0.56	s.m^2/y	1500	1000	μs/cm	11.2
Diazinon	100	μg/L	700	mg/y	0.1	0	μg/L	7000
Malathion	20	μg/L	140	mg/y	0	0	μg/L	NA

evapotranspiration, infiltration, and plant uptakes. Consequently, the final pollution load of NH_4 is less than the effluent of fish farm and it cannot be easily shared between the two sequential producers. In this condition, GW of fish production may be ignored or accounted as blue water for crops. Here, any local environmental concerns would not be accounted in WF assessment.

Regarding the calculations of Table 8.2, the annual GW of rural discharge is 19,600 m^3 as it is the maximum value of the proportion of pollution discharged loads to the AC. This may imply that the rural discharge has DO deficiency as its main quality problem. It sounds true with respect to the conventional GW assessment unless the environmental concerns are included in calculations. In this area, other parameters may be more critical for decision-makers, such as micropollutants or TP, due to their health risks or local environmental protection policies.

There are two approaches to consider the environmental concerns in GW assessment. The conventional approach believes that C_{max} is enough for reflecting the environmental concerns. This is indisputable that C_{max} should be determined as AWQS and through an integrated simulation tool. However, it has some shortcomings, particularly for multiple-pollutant GW assessment. Some of these

Table 8.3 Calculation of alteration coefficient in different environmental issues

Surface water parameter	Value	ω_1	ω_2	ω_3	ω_4	ω_5
Q_{act} (m^3/s)—summer	10	0.625				
Q_{env} (m^3/s)—summer	16					
Q_{act} (m^3/s)—winter	18	1				
Q_{env} (m^3/s)—winter	16					
DO_{act} (mg/L)—summer	4		0.8			
DO_{std} (mg/L)—summer	5					
DO_{act} (mg/L)—winter	6.5		1			
DO_{std} (mg/L)—winter	6					
TP_{act} (mg/L)	0.5			0.2		
TP_{req} (mg/L)	0.1					
TN_{act} (mg/L)	7			0.43		
TN_{req} (mg/L)	3					
EC_{act} (µs/cm)	2600				0.57	
EC_{req} (µs/cm)	1500					
$Diazinon_{act}$ (µg/L)	0.65					0.15
$Diazinon_{req}$ (µg/L)	0.1					
$Malathion_{act}$ (µg/L)	0.05					0.2
$Malathion_{req}$ (µg/L)	0.01					
Alteration coefficient		0.625	0.8	0.2	0.57	0.15

shortcomings are discussed in Table 8.2. For example, TDS and malathion related GWs are accounted as NA but their environmental impacts of salinity and toxicity may not be ignored. Chiefly, C_{max} focuses on parameters separately. If they are not continuously sampled, examined, or have specific standards, GW may not detect its related problems. Moreover, some environmental issues are reliant on two or more parameters. For instance, eutrophication in lake has impacts on TSS, DO, and BOD of water, while it originates from high TP and TN concentrations in lake (Imani et al. 2017; Dodds and Smith 2016; Istvánovics 2009). In addition, eutrophication has different levels which may be controversial if it is indicated only by a constant C_{max}. It points to the fact that the environmental protection policies such as lake rehabilitation, prevention of saline intrusion in groundwater, or ecological status enhancement should be reflected separately from AWQS and C_{max} in GW assessment. Likewise, indirect or last-longing environmental issues should be accounted in GW of products. The new approach recommends that primary environmental concerns in a production area should be considered in addition to the conventional approach. Here, multiple-pollutant GW assessment would not be only dependent on C_{max}. In this condition, GW can be developed from a *discharge accounting indicator* to an *environmental indicator*.

Table 8.3 summarizes accounting GW by Eq. (8.5). Here, the five possible environmental concerns in a production area are checked and compared. For example, river flow rates and DO concentration of lake are in appropriate condition during winter. However, these two factors are environmentally disturbing during the

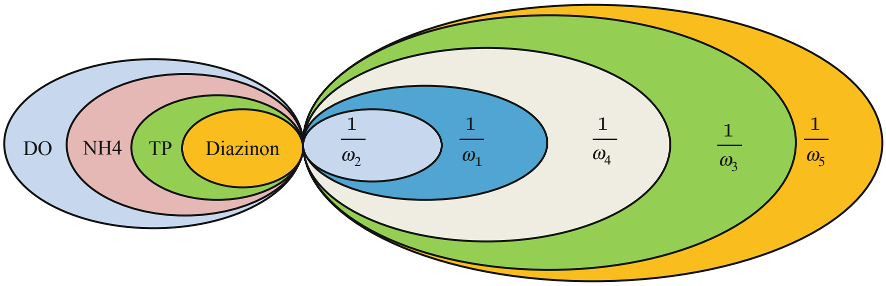

Fig. 8.8 Intensifying conceptual model of multiple-pollutant assessment with environmental concerns in grey water footprint accounting

farming periods of summer. Consequently, ω is 0.625 and 0.8 for these two parameters, respectively. This shows that low river flow in summer is more critical than DO deficiency in the production area. However, these concerns are not as severe as other three environmental issues. For example, the groundwater interacted with basin currently has higher salinity which may be due to the overexploitation of groundwater for irrigation or effluent discharges. This represents a requirement for higher embedded water for salinity control in comparison with ω_1 and ω_2 because ω_4 is 0.57. Nevertheless, lake eutrophication and the remaining of micro-pollutant in water bodies are more important regarding their actual and required concentrations of related pollutants. Here, ω_3 is 0.2 because TP is the determining parameter for eutrophication rather than TN as described in Eq. (8.4). Likewise, ω_5 is 0.15 in which diazinon reduction is more highlighted than malathion. It is interesting to note that C_{max} (0 μg/L) and C_{req} (0.01 μg/L) of malathion are very less than diazinon but ω reflects the importance of environmental concerns regarding both actual and required concentrations of pollutants. Therefore, diazinon is chosen by Eq. (8.4) for ω_5 as the ratio of required to the actual concentrations in water body is smaller.

Figure 8.8 schematically illustrates the intensifying effect of different components of altered equation of GW assessment. It shows that GW accounting and its value is reliant on both multiple-pollutant assessment and environmental coefficient of ω. In this study area, DO, NH_4, and TP are the pollutants with the highest GW-related. Nevertheless, the highest alteration coefficient is attributed to the toxics of diazinon. It means that a single-pollutant GW accounting without considering the environmental concerns may lose lots of WF of products. Alternatively, these two waves can not only highlight the importance of environmental issues in decision-making but also provide a framework to compare products with their environmental impacts. For example, the environmental policy-makers should focus more on toxics and eutrophication problems in the study area by inducing farmers/manufacturers to abate the related pollutants while simultaneously control BOD, NH_4, and NO_2 discharges in the study area.

By accounting ω as 0.15, the conventional GW of 19,600 m^3 should be increased to 0.13 million m^3. This is the final GW of products in which both the environmental and discharge characteristics are included in accounting. It also implies that not only

DO, NH_4, and TP are important in water quality management (Table 8.1) but also diazinon and malathion (Table 8.2) should be dealt with for environmental protection. Consequently, decision-makers need to cooperate with farmers to reduce GW by controlling nutrients and pesticides in farmlands. In long term, provided that these pollutants are reduced significantly in discharges and related environmental conditions are reached to the required level, it can be expected that GW would be BOD-related (3956 m^3) and EC determines ω as 0.57. As a result, GW of this area can be reduced from 0.13 million m^3 to below 7000 m^3.

8.6 Policy and Legal Framework

WFs of agricultural products, mostly the blue and green WFs, have been assessed in Iran since Hoekstra et al. (2011) published the guideline. In addition, the standard of ISO 14046 has been defined from 2014 in this country. Despite these documents, WF analysis is still not common for the manufactured and industrial products. Few industries use WF assessment tools for their annual reporting and efficiency analysis. This is due to the fact that these guidelines and standards are optional. As a consequence, GWF assessment can hardly enforce polluters economically. The monitoring of water quality standards and wastewater discharges are the only ongoing environmental tool for controlling pollutions in water bodies. Therefore, GWF still requires more development, case studies, and data gathering for the definition of comprehensive legal framework.

8.7 Conclusion

GWF is simple in definition and easy in accounting. However, this chapter highlighted a set of shortcomings and challenges of this indicator that may limit its application. For example, it is concluded that GWF is the environmental fraction of water footprint assessments but it cannot include the environmental issues of basins into accounting. In addition, GWF may be high/low in different regions regardless of their pollution discharges. This is due to the fact that the environmental standard limits, C_{max} and C_{nat}, would be defined based on different methods or data. As a consequence, the lack of proper wastewater treatment systems can be covered by less strict standardizations, or likewise, water allocation policy-makers can manipulate standards to justify the exports of embedded water of products. Therefore, the GWF of products with similar production yields and processes can hardly be identical in different regions. It recommends that further studies are required to develop its accounting methodology toward a more applicable and reliable indicator.

8.8 Future Trends

GWF is the least assessed and most complex fraction of WF. In comparison with the blue and green WFs, this indicator has a wide range of potentials for future analysis. This is mainly due to the fact that GWF is more influenced by multidisciplinary issues in water quality management. These issues can be classified into two main subjects: (1) principles and methods, (2) applications for GWF, as shown in Table 8.4. Here, principles and method is a trending class that includes basic assessment pillars of GWF such as multiple pollutants, assessment and standardization methods, and related uncertainties. On the contrary, the application focuses on the new trends of using GWF as an environmental or decision-making tool. For example, trading virtual water, sustainability assessment, water cycling and reuse, the optimal operation of wastewater treatment plants (WWTPs), and industrial products are some examples for the new applications of GWF in future studies.

Multiple-pollutant GWF requires studying different pollutants and contaminations. The emerging pollutants can extend the viewpoint of this indicator which can possibly add more modifications, new accounting equations, and supplementary calculations. For instance, Martínez-Alcalá et al. (2018) have recently accounted the pharmaceutical GWF in a region. They concluded that ordinary pollutants such as organic carbon, nitrate, and phosphate may have larger GWF in municipal areas in comparison with pharmaceuticals.

GWF can be assessed by the volumetric, stress weighted, and life cycle assessment (LCA) approaches (Kumar and Joshiba 2019). This chapter used the conventional volumetric method for problem-solving and updated its methodology. However, LCA is currently recognized as an integrated approach for long-term environmental assessment of products. Its methodology is still updating for comprehensive environmental impact assessments (Jolliet et al. 2016).

Standards play a key role in GWF assessment. They have critical effects on the conventional and developed methodologies explained comparatively in this chapter. However, their appraisal is globally or locally oriented. From conventional viewpoint, standards are directly referred to the global criteria as OECD, WHO, etc. (Istvánovics 2009; Wetzel 2001). On the contrary, total maximum daily load

Table 8.4 Future trends and roadmaps of grey water footprint

Main category	Sub-category subjects	Main directives
Principles and methods	Multiple pollutants	Emerging pollutants
	Standardization method	Local WLA and assessment
	Assessment method	LCA
	Uncertainty analysis	Problem-solving
Applications	Virtual water trading	Integrated assessment
	Sustainability assessment	Integrated assessment
	Water recycling and reuse	Integrated assessment
	Wastewater treatment plants	Integrated assessment
	Industrial products and activities	Integrated assessment

(TMDL) is an approach that sets regionally optimized standards under waste load allocation (WLA). Here, the self-purification of the receiving water bodies is included in standardization. It also has the potential to consider the economic, social, and technical limitations in standardization. For example, Feizi Ashtiani et al. (2015) have considered equity for environmental violation in pollution discharges, while some technical and operational limitations of WWTPs for making practical pollution abatement strategies have been highlighted by Jamshidi and Niksokhan (2016). Furthermore, WLA is able to present some incentives to motivate the users toward more cooperation (Jamshidi et al. 2014). It is obvious that regional standards are more precise but comparing the results for GWF is much easier based on global standards.

Accounting GWF is dependent on various parameters. The multiple pollutants, pollution abatement technologies, production yields, different standardization (global or local), in addition to different assessment methods (direct or life-time assessment) input uncertainties. Therefore, the quantification of GWF of products is not necessarily absolute but has relatively larger variations than the blue and green WFs. Studying about the values and origins of uncertainties, particularly by developing this indicator, is another subject of future researches (De Girolamo et al. 2019).

Since GWF completes the WF of products, it is influential on the quantification of embodied freshwater of products and consequently the virtual water trading. The global network of export–import of products is basically an economic system that transports virtual water, including grey water (Antonelli et al. 2017; Chen and Chen 2013; Oki et al. 2017). It means that the pollution, and now the regional ecosystem problems by the new methodology, can also be traded through the products. This subject requires further studies and may bring new integrated policies for exporting products from polluted or environmentally damaged areas. Likewise, trading the blue and green WFs has been recently studied for optimizing the crop patterns regionally for the mitigation of water stress (Mojtabavi et al. 2018).

Environmental footprints are not limited to WF or GWF. There are other indicators as carbon footprint and ecological footprint that each indicates one specific subject. For example, carbon footprint has been highlighted as a policy-making and protection indicator (Cucek et al. 2015). A trending scientific approach is to co-evaluate these indicators under an integrated index or to develop combined formulations and assessment methods. This approach is interesting as it establishes a shared mechanism of carbon and water footprint for assessing the sustainability of decisions and policies (Liu et al. 2017; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b).

Industries have different activities, products, and production processes. Kumar and Pavithra (2019) have shown that the equations required for the assessment of crops WF are different with the manufactured products in mining, textile industry, paper industry, food, and beverages. These formulations follow the principles and fundamental definitions of blue and grey WFs but are different in formats. This is due to the fact that each industrial and service activity, such as even thermal power plants (Chakraborty 2019), needs special considerations in WF assessment.

Generally, WWTP is recognized as pollution abatement centers for domestic and industrial discharges. These systems are necessary for pollution abatement and consequently have impacts on the GWF of products. Yet, these facilities can also manufacture clean water, in addition to the biogas, organic fertilizers, and raw materials (Jamshidi 2019b). Reusing the products of WWTPs, particularly water reuse, can additionally reduce the GWF of manufactured industrial products and is highly recommended (Zhang et al. 2019). However, the performance of WWTPs and the quality of products are considerably reliant on their operation. Accordingly, Gomez-Lianos et al. (2019) have recently introduced an operational indicator for GWF of WWTPs. This trend has also some originality and requires further researches.

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Water Footprint in Rice-Based Cropping Systems of South Asia

9

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Abstract

Global population is increasing at an alarming rate, need to produce more food grains with the shrieking infinite natural resources, and water security is a major problem on the planet. In the agriculture various level of water pollution due to urbanization, industrialization, changing dietary habits, higher trends of food wastage, etc., its management is a need of hour. In the present scenario reducing the water footprint (WF) for the future generation is a key factor for the society welfare and sustainability on the planet, and agriculture is a big sector that is exploiting the quality water on the earth. There is an urgent need to focus on the ecofriendly water saving approaches with efficient use in the agricultural systems. Rice–wheat cropping system (RWCS) is covering a major area ~12.5 Mha in South Asia; it is using a huge amount of water compared to the other agriculture systems. Scientists across the region are working for reducing the share of the WFs in agriculture and in this regard, many technologies known as resource conservation technologies (RCTs) are advocated in the region. Among different RCTs—laser land levelling (LLL), short duration cultivars, timely transplanting of rice, irrigation scheduling through tensiometers, direct seeding of rice, crop diversification, raised bed planting, mechanical transplanting are the main technologies recommended for the RWCS. Hence, these technologies are not universally effective in reducing the WFs, hence, their proper selection at farmer's fields in their conditions is a must for reducing the WFs. Further, among all, only two, viz., short period cultivars and appropriate transplanting reduce the drainage (which could be reused) share instead of reducing the share of evaporation (which cannot be reused). Further, as evaporation reduced its reduced share diverted to transpiration which further improves the nutrient inflows and finally yields. This chapter is focused on the integrated invented, tested approaches, those are recommended for the south Asian farmers', and practicing in the rice-based cropping systems. It can help in reducing the WF to improve the land and water productivity for their livelihoods security.

Keywords

Grain yields · Resource conservation technologies · Rice · South Asia · Water footprint

Abbreviations

$\theta(t-1)$	Soil moisture content at $t-1$ days (mm)
$\theta(t)$	Soil moisture content
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
CST	Climate Smart Technologies
CCWU	Consumptive Crop Water Use
CWU	Crop water use
DI	Drip Irrigation
DSR	Direct Seeded Rice
E	Evaporation
ET	Evapotranspiration
$ETc(t)$	Crop consumptive use (or crop evapotranspiration) at t days (mm)
$IR_{eq}(t)$	Net irrigation at 1 day (mm)
LLL	Laser Land Levelling
MI	Micro-irrigation
MSP	Minimum Support Price
MT	Million tonnes
N_2O	Nitrous Oxide
PRB	Permanent Raised Beds
RCT	Resource Conservation Technologies
$R_{ef}(t)$	Effective rainfall
RWCS	Rice–Wheat Cropping System
SA	South Asia
SDI	Sub-surface Irrigation
SI	Surface Irrigation
T	Transpiration
WFs	Water footprints
ZTW	Zero Tilled Wheat

9.1 Introduction

Water is a critical resource which must be used sustainably for the benefit of the mankind (Bhatt and Kukal 2016, 2017; Bhatt et al. 2020a, b). Globally water and particularly underground water table is exploited to significant levels for meeting needs of the ever increasing population. As per Bruinsma (2009), world land productivity has to be boosted by 70% up to next three decades and too with our shrinking resources of land and water with their diminishing quality which looked to be both difficult as well as challenging tasks. For this, our target for the hike in average annual cereal production comes out to be 43 million metric t year^{-1}. Global cereal production trends from 1960s delineate a constant rise but we have to increase it, otherwise getting target an annual increase of 43 MT year^{-1} looked difficult against the current rate of 31 MT year^{-1}. Inner mirror of Fig. 9.1 delineates the global cereal harvested area and productivity which revealed that productivity increased with almost same cereal area (Wu and Ma 2015; Wheller and Braun 2013). Therefore, production levels have to be increased as area may even be decreased for urbanization, industrialization, change in the feeding habits, food wastage, etc. (Lal 2008). Further, global water footprint particularly in the rice-based cropping sequence needs to be cut down by replacing the flood irrigation with alternate wetting or drying irrigation as excessive irrigation with excessive

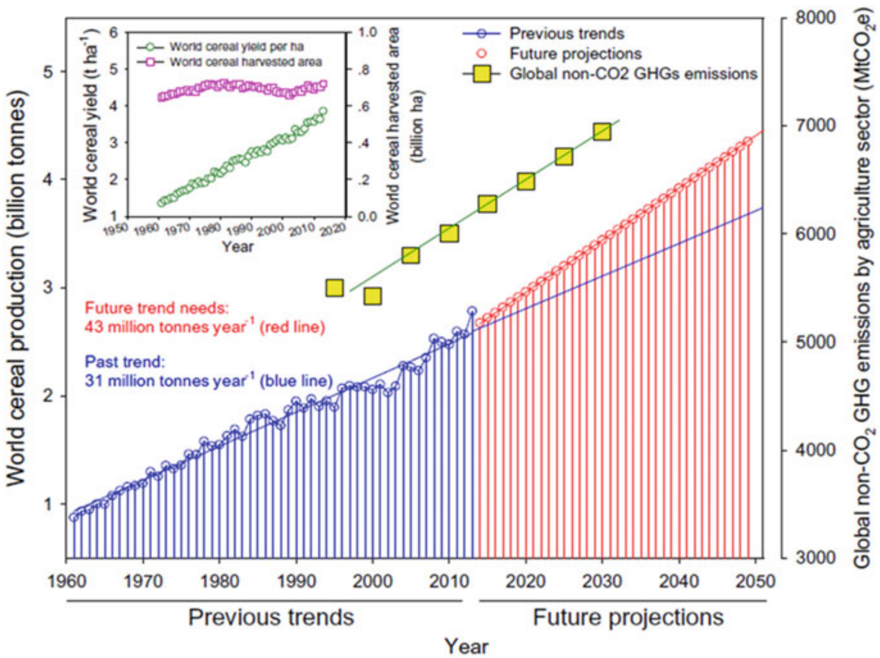

Fig. 9.1 Cereal production targets and global non-CO_2 greenhouse gas emissions by agriculture sector at global levels (http://faostat.fao.org/)

fertilization will promote the insect-pest and diseases attack which further cut down the yield levels and finally water and land productivities in the region. Conventional crop establishment of particularly rice is required flood irrigations which further responsible for the emission of greenhouse gases, viz., CO_2, CH_4, etc. (Fig. 9.1) which is causes for global warming. If anyhow, by adopting efficient technologies for greenhouses gases (GHGs) management, it can help to reduce the WFs.

As per fourth assessment report of IPCC in 2007, global greenhouse gas emissions enhanced up to 49.5 giga tonnes of CO_2eq (carbon dioxide equivalents) in the year 2010, highest in the history (IPCC 2014), which needs to be cut down by reducing WFs for the rice-based cropping sequence. Further, GHGs emissions because of puddle flooded conditions of rice are responsible to release the NO_2, CO, CO_2, CH_4, etc., under changing climate, which further enhances the irrigation inputs and WFs (Simpson et al. 2014; Meena and Lal 2018). Therefore, rice flooded irrigation conditions, GHGs emission, higher dry spells and higher irrigation inputs, and WFs all are interlinked. Consequences of the climate change, viz., comparative higher CO_2 and ambient temperatures complicated the situations, particularly in the rainfed regions. Therefore, an integrated approach must be invented for reducing the WFs in South Asia which involves almost all the disciplines, viz., plant breeders (for new plant cultivars with lesser WFs and which could stand in stressed conditions), agronomist (to discover new planting techniques), soil scientist (to invent new irrigation techniques under texturally divergent soils), entomologist or pathologist (to cut down the insect-pest or disease attack), politicians (for frame-up policies), and ultimately the farmer—the end-user (after keeping in mind the socio-economic conditions). There is a need to enhance the water use efficiency in field crops by retaining crop residues on the surface, cementing the water channels or underground irrigation pipelines.

Moreover, under solo crops reported reduced water inputs due to any adopting technique might result in higher water inputs in the next crop, which results in almost the same water inputs for the whole systems. From the last decade, most studies published in higher-rated journals, viz., Field Crop Research, Agricultural Water Management, etc., dealing with one crop only, mostly rice, viz., direct seeded rice, tensiometers, raised beds, etc., with decorated conclusions/recommendations for reducing WFs, without considering intervening period or the next upland crop. Therefore, there is a need to identify the importance of the last two uncovered areas, only then effective outcomes will be there for cutting down the WFs. Hence, water saving technologies must be invented, tested, and recommended to the farmers for practicing at their fields (Hossain and Bhatt 2019; Bhatt et al. 2020a, b). Further, N-use efficiency also decreased, which might be responsible for the higher use of the chemical fertilizers, which further causes the environmental and underground water pollution (Davidson et al. 2014) (Fig. 9.2).

In South Asia, rice-based cropping sequence is intensively cultivated and has many sustainability issues, out of which higher WF is the main due to excessive use of the irrigation water in rice for creating the anaerobic conditions (Bhatt and Kukal 2016, 2018; Bhatt et al. 2016, 2020a, b). Rice is the main culprit as around 4 m^3 of irrigation water required for producing only 1000 g of rice grains, due to inherent

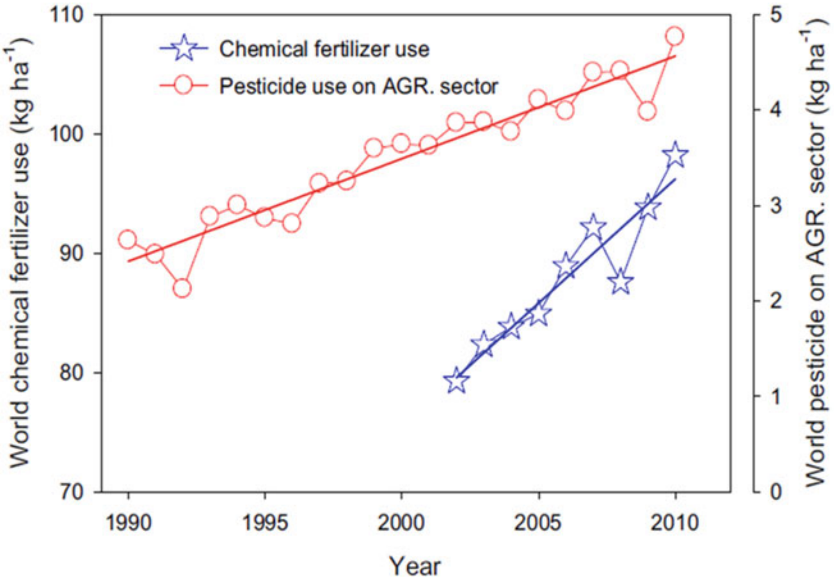

Fig. 9.2 Global pesticide and chemical fertilizer use trends in the crop production sector (adopted: http://faostat.fao.org/)

behaviour of the farmers to create pounded conditions throughout the season and the brief calculations for this is presented in the following way. Second problem is the adoption of Pusa-44 by the farmers which is a long duration cultivar, has longer stay in fields, and has huge WFs; therefore, these cultivars should be replaced by the short duration cultivars.

Declining underground is the main issue which must be addressed at the earliest. Freshwater competition continuously increased during current years because of urbanization, industrialization, increasing trends of food wastage, particularly in marriage or different ceremonies, changing of the dietary habits from vegetarian to non-vegetarian (Strzepek and Boehlert 2010) and this brings problems for reducing the WFs (Rosegrant et al. 2009). Further, global water withdrawal will grow up to 53.3% up to 2030 (from 4500 billion m^3 $year^{-1}$ today to 6900 billion m^3 $year^{-1}$ by 2030) (McKinsey 2009). Therefore, judicious use of water is a must for having reduced WFs.

In literature different terms, viz., blue, green, gray water are used to delineate the different types of water available as per their source and availability. Rainwater directly enters to the lakes and recharges the underground water table referred as ‘Blue water’, while moisture/water retained in the soil pores is referred as ‘Green water’ (Falkenmark 1995). Further, gray water could be reused for different purposes thereby helps in reducing the WFs (Lu and Leung 2003; Al-Hamaiedeh and Bino 2010; Meena et al. 2020). Rice cultivated in 22.9% of the global cultivable area is an important staple food (FAO 2020), cultivated mainly under upland rice and lowland rice ecosystems. It could be cultivated at variations of altitudes, viz., from

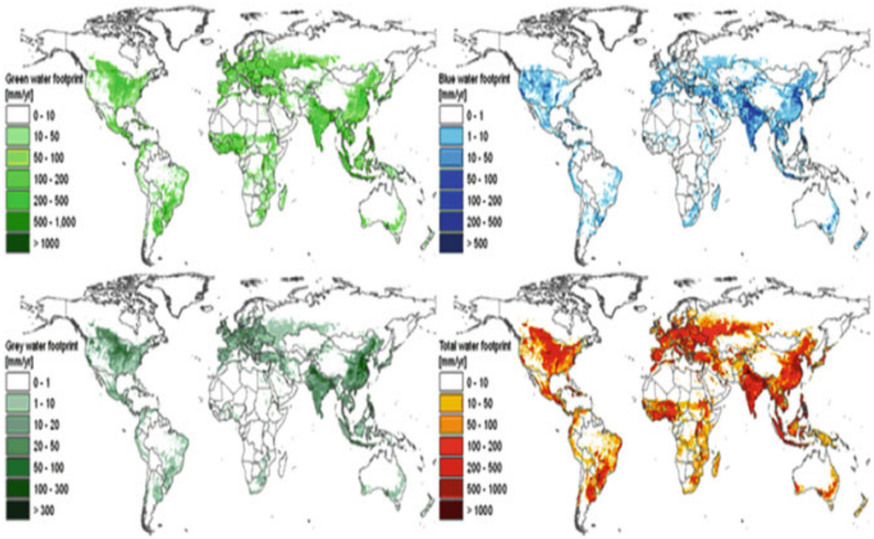

Fig. 9.3 The green, blue, gray and total water footprint of crop production estimated at a 5 by 5 arc minute resolution. The data are shown in mm $year^{-1}$ and have been calculated as the aggregated water footprint per grid cell (in m^3 $year^{-1}$) divided by the area of the grid cell. Period: 1996–2005

3 m (Kerala, India) to over 300 m (Bhutan and Nepal) (Khush 1984). The global WFs, viz., blue, green, or gray varied under different agro-climatic conditions and under texturally variable soils depending on their primary particles proportion and finally with special variations (Fig. 9.3).

Low land rice cultivation dominated on 85–90 M ha areas, responsible for 75% of global productions and played an important role for financial strengthening of any country (IRRI, Africa Rice and CIAT 2010). Often, conventional crop establishment methods of rice are suffering from many issues, viz., declining underground water and soil health, production of GHG emissions, eutrophication, global warming, low efficiencies of N-fertilizers, underground water pollution, etc. (Wu and Ma 2015). Farmers used to apply more and more fertilizers, particularly N-fertilizers for feeding ever increasing stomachs as up to 2017 from 1960, N-fertilizer use jumped to 9.13 times (IFA 2019). One reason could be for this might be reduced N-use efficiency to just 30% (in 2000) from 80% (in 1960) (Russenes et al. 2019). Further, injudicious use of N-fertilizers led to pollution of air, water, and soil which further has got its own consequences (Neubauer and Megonigal 2015). N-fertilizer blamed to be one of the main causes for higher emissions of GHG from flooded soils under reduced conditions (Bouwman et al. 2002; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b), which further affected by the form, amount, and fertilization method of N-fertilizers (Dobbie and Smith 2003; Ma et al. 2010; Liu et al. 2011). Cereals reported to have only 33% N-use efficiency worldwide (Raun and Johnson 1999) and thus rest 67% is free for causing any pollution while lowland rice is reported to be about 40% (Fageria 2014) which highlighted a significant loss to ecosystem

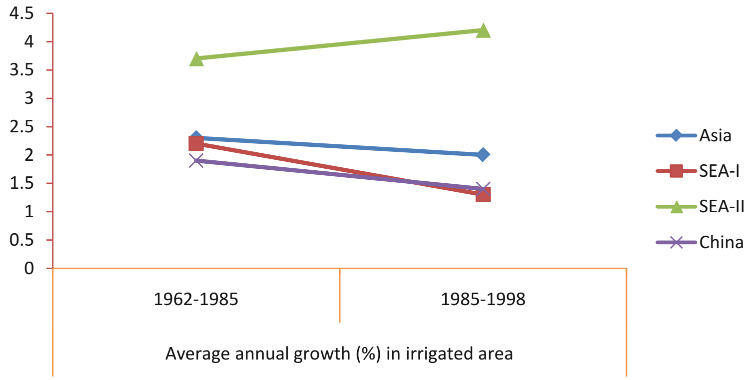

Fig. 9.4 Annual growth in irrigated area in Asia and in the countries of its subregions, 1961–1999. *Notes:* Calculations are based on three-year averages centred on the years shown. SEA I = Indonesia, Malaysia, the Philippines, and Thailand. SEA II = Cambodia, Lao PDR, Myanmar, and Vietnam. *Source:* Barker and Molle (2004)

which causes pollution. As per Khalil et al. (2011) fertilizers supplied around 70% of all plant nutrients even at global level and providing adequate moisture will certainly improve the nutrient use efficiency and reduces the total WFs. Hence, improving N-use efficiency by the judicious use of irrigation water is the first step which brought sustainability in the low land rice cultivation (Singh et al. 1995; Blackshaw et al. 2011). Therefore, excessive water inputs must be brought down for improving the nutrient use efficiencies, which further has favourable impacts on the underground water table and finally reduced the WFs, more particularly in the water stressed regions of the South Asia. Therefore, an integrated approach is required to be recommended which is location specific for reducing the WFs in the region (Meena et al. 2020a, b).

Particularly for meeting the irrigation water demands, most of the large irrigation systems in Southeast Asia have been developed under supply-driven mode. However, due to conventional puddle transplanted system generally adopted in the region, the final water productivities reported to be lower. Further, population growth and changing dietary also reported to hike water inputs to many folds. Higher urbanization reported in the Southeast Asia in the next thirty years. The evolution of irrigation in Southeast Asia generally followed a variable path as shown in the following Fig. 9.4. During the 1970s, in Indonesia, Malaysia, the Philippines, Thailand, and China construction phase. However, growth rate in these countries declined after 1985. During the current years, there was a comeback in Malaysia, China, and Thailand, generally focused on system rehabilitations. During the last two decades, in Cambodia, Lao PDR, Myanmar, and Vietnam there has been continued strong growth as far as irrigation projects were concerned (Barker and Molle 2004).

9.2 Concept of Water Footprint

Some certain volume of irrigation water is used for producing any agricultural products and WF is a parameter to measure it and every attempt is being made to reduce it so that saved water could be used for producing more grains or services or could be diverted to other potential sector, viz., industry, etc. The term coined first by A.Y. Hoekstra in 2002 with an objective of assessing the WF of goods and techniques to made food production or goods production more sustainable. Further, WF is a multi-dimensional indicator delineating water volume consumptions in production and polluted with industrialization specially and temporal. Scientists around the region, working in the direction to find out new crop establishment methods which finally cuts off the share of the WF and improving or maintaining the yields thereby enhances the land as well as water productivities (Bhatt et al. 2020a, b).

9.3 Types of Water Footprint

The water footprint of a product (good or service) is the volume of fresh water used to produce the product, summed over the various steps of the production chain. 'Water use' is measured in terms of water volumes consumed (evaporated) and/or polluted. The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations and timing of water use. Depending upon water categories, three types of water footprint (WF) divided into the

9.3.1 Blue Water Footprint

In this category, surface and sub-surface water consumption patterns for producing goods are expressed which are affected by many external and internal factors. Here the loss of water from a particular location is referred as consumption. Among the evapotranspiration (ET) losses, our concern is to reduce the share of the evaporation (E) and shift it to the transpiration (T), as greater the share of T, which further enhances nutrients uptake in the plants through the roots and greater is the water productivity (Hossain and Bhatt 2019).

9.3.2 Green Water Footprint

It comprises the rainwater, which instead of going waste must be used for recharging of underground water tables, which further cuts down the power required to withdraw underground water to the surface.

9.3.3 Gray Water Footprint

It delineates the quantitative water required for making the polluted water for reuse which further reduces the WFs by one or other mean. It is important as it increases the total volume of water by including the once polluted water.

As far as measurement of WFs is concerned, then it could be expressed as water volume used for producing per kg of product. However, the classical way of its representation is as m^3 ton^{-1}. Normally, two types of WFs expressed as direct (as person composed of consumed water) and indirect (person comprised of consumption of products) water footprint.

9.4 Water Footprint in Rice-Based Cropping Systems

Rice is the main food grain for the poorest people in the world, mainly in undeveloped or developing Asian people, of those 30% earn more than US$1 a day (Zeigler and Barclay 2008; Bouman et al. 2007). It is the second staple food crop for approximately 70% populations across the globe (Laborte et al. 2017; Sravan and Murthy 2018); where more than 3 billion people in the region consumed rice as a human nutrition and caloric intake (Maclean et al. 2002; Chapagain and Hoekstra 2010; Sravan and Murthy 2018). In many Asian countries, rice intake is exceeding 100 kg per capita annually as compared to other western countries; for example, the USA average intakes 10 kg per capita annually and the reason could be its easy access at the cheap rates. As a result rice-based cropping systems are increasing day by day, particularly in the underdeveloped or developing countries, though later proved to be very costly in terms of soil health and WFs. Therefore, WF for rice-based cropping systems is relatively significantly higher in SA countries. Since, most of the WF is rooted in the rainy season (monsoon rice) in these countries, thus most of the water requirements is filled from the rains. Whereas in the case of irrigated rice (boro-rice in winter season) water scarcity is high and as a result production cost is more than monsoon rice; but production is also greater than monsoon rice. Till now, not only farmers but countries of the region too focused on the yields but now their diversion shifted to reducing the water inputs and hence WFs so that the saved water could be used in producing more grains or to other potential sectors. For achieving that objective, crop establishment methods have to be advanced with proper use of CST (Bhatt et al. 2019).

As per previous studies reported by Hoekstra and Chapagain (2008), Hoekstra et al. (2009), and Chapagain and Hoekstra (2010), the WF delineated the quantitative approach for the water used for producing any product or service and expressed in (m^3 $unit^{-1}$). Findings of IRRI (2007) reported that generally irrigated lowland rice usable water ranges between 675 and 4450 mm; since the ranges depend on several factors including the soil textural class, adopted irrigation practices, cultivation system of rice, management of water use, etc. IRRI (2007) also reported that the current system of irrigated rice in most of Asian countries, viz., flood irrigation requires huge amounts of water to meet the water requirements of rice plants. For

Table 9.1 Calculations of rice water footprint (Bhatt Personnel communications 2017)

1 acre	4000 m^2
I irrigation	10 cm or 0.10 m
25 irrigations	250 cm or 2.5 m
Total water used	4000 × 2.5 = 10,000 m^3
1 m^3	1000 l
10,000 m^3	10,000,000 l
3000 kg paddy grains	10,000,000 l
1 kg paddy grains	3333 l

Table 9.2 Top fifteen countries with the largest water footprint related to rice consumption (Mm^3/year) (period 2000–2004). (Source: Chapagain and Hoekstra 2010)

Countries	Total water footprint (Mm^3/year)				Water footprint/capita (m^3/cap/year)
	Green	Blue	Gray	Total	
India	133,494	102,425	14,385	250,305	239
China	65,154	86,050	20,680	171,884	134
Indonesia	31,097	26,005	6262	63,364	299
Bangladesh	20,560	21,674	3846	45,980	317
Thailand	19,640	11,654	2421	33,714	547
Myanmar	18,989	8483	1118	28,591	612
Vietnam	9860	6496	4074	20,430	256
Philippines	11,736	6020	1137	18,893	238
Brazil	9186	7869	757	17,812	99
Pakistan	2480	13,935	521	16,936	117
Japan	4084	4923	748	9755	77
USA	1924	5779	719	8422	29
Egypt	3467	3203	599	7269	105
Nigeria	3478	3005	548	7031	54
Korea, R	2491	2732	592	5814	122

example, for 1 kg rice production, India and the Philippines generally use on an average 3333 l irrigation water. An attempt is being made to justify these calculations in Table 9.1. If long duration rice cultivars replaced with short duration cultivars, then the total water demands will certainly be reduced which further delineated in the reduced WFs. The representative global configuration of the WFs is generally directly proportional to rice area in a particular country (Table 9.2) and their trends come out to be highest in India and lowest in the USA, because of better water particularly underground management policies (Chapagain and Hoekstra 2010). Here, crop diversification will also serve the purpose but it needs a favour from the government side.

As far as WFs components are concerned, it comprised of green (linked with rainwater evaporation), blue (linked with irrigation water evaporation), and the gray (linked with the fresh water volumes required for treating the polluted waters) WFs (Chapagain and Hoekstra 2010). Further, regarding calculations of WFs, only green and blue WFs delineated (Chapagain and Hoekstra 2004).

South Asian countries normally under conventional systems had higher WFs which need to be cut down as soon as possible by several measures, viz., adopting short duration cultivars, timely transplanting probably after 10th of June, laser levelling, direct seeding of rice, zero till rather double zero till systems in both crops, raised beds especially fresh beds, tensiometer based irrigations, etc. (Bhatt et al. 2019, 2020a, b). Normally, the WFs, viz., green and blue have equal shares and therefore both are important and need considerations though prior one has lower opportunity cost.

Blue WFs in rice cultivation depend on several factors deciding irrigation water use, which could be investigated and addressed (Chapagain and Hoekstra 2010). For addressing the WF_{Blue}, some new techniques, viz., mulching particularly in zero till direct seeding of rice followed by zero till wheat must be adopted as mulch loads hinder the hot sunrays to reach the bare soil surface, hinder the escape of water vapours from the ground to atmosphere, and lastly reduce the vapour lifting capacity of the wind by reducing its speed (Bhatt et al. 2019, 2020a, b). Nowadays, after considering huge WFs of rice, most countries, viz., EU prefers to import it from other countries and escapes from the ultimate damage of rice cultivation, viz., degraded soil structure, water pollution, etc.

Mostly, heavy subsidy provided to the rice farmers by the state government especially on the irrigation systems, as in Punjab, India power is totally free for the farmers, thereby they use it non-judiciously. Governments too bothered about the farmers vote bank as if they charge the power for agriculture especially for withdrawing the underground water from deeper and deeper depths, then things might not for the governments. Therefore, this free power like reservation system cannot be removed even after recognizing its limitations. Further, rice price for the importing countries varies as per the countries of its origin and climate of its production (Chapagain and Hoekstra 2010). Generally, green WF not affecting our ecosystem and is free; therefore, rain water harvesting is very important in this context to reuse this water, otherwise it may wash away the productive soils and could cause the siltation of dams and other reservoirs which further resulted in the floods during the rainy season in the downward areas. Hence, if green water is restored and reused for the irrigation purpose for fulfilling the evapotranspiration demands of global crops, then certainly pressure on the underground water will certainly be reduced which further helped us in reducing the blue WFs (Chapagain and Hoekstra 2010).

In total, around six irrigation water are used for the field preparation through puddling, which could be cut down directly in the direct seeding of rice as no puddling operations are there (Cabangon et al. 2002), but care should be taken while selecting the fields as they must be of medium to heavy textured soils, viz., sandy loam, loam, clay loam, and silt loam soils. Further, after adopting the different climate smart technologies the WFs in the rice cultivation could be reduced (Hossain and Bhatt 2019; Bouman et al. 2007). Further, System of Rice Intensification (SRI) also claimed to be such technique, as it applying water as per plant need (Gujja et al. 2007).

9.5 Water Footprint Measurements and Equations

Although water footprint (WF) is a multi-dimensional indicator this chapter will focus majorly on assessment of crop WF. Hoekstra et al. (2009) identified different water phases for assessment of WFs which further helps in formulating action plan. The goals are the objectives which one intends to achieve for embarking on WF assessment while the scope is the extent or the coverage boundary of the WF assessment. The stage of data collection and development of the accounts is referred to as the accounting phase while evaluating WF from an environmental perspective is the sustainability assessment phase and measurement of the response options and strategies to formulate policies arising from WF projects is the last phase of the WF assessment (Hoekstra et al. 2009).

In between, a different type of water, one most relevant and directly connected generally to agriculture and particularly to rice production is the green water. This is important because the historical engineering emphasis on blue water has resulted in underestimation of green water as a vital production factor (Falkenmark 2003; Rockström 2001) not minding the fact that about 86% of humanity WF is attributable to the agricultural sector (Hoekstra and Chapagain 2008). Nonetheless, blue water measurement cannot be totally ignored when considering agricultural issues as the blue water becomes more relevant in relation to water withdrawals under irrigation agriculture (Hoekstra et al. 2009). Similarly, accounting for gray water becomes necessary in agriculture owing to the agrochemicals (fertilizers, herbicides, and pesticides) usage in crop production. The practical method for determining direct amount of water consumed by a crop (rice in this case) involves measurement of crop evapotranspiration, measurement of irrigation water requirement, and direct calculation of water consumption (Kim and Kim 2019).

A WF is expressed as volume of water used on the temporal scale, viz., daily, monthly, or yearly basis (usually $m^3\ t^{-1}$ or $l\ kg^{-1}$) (Hoekstra et al. 2009). As reported by Xinchun et al. (2018) and Hoekstra et al. (2009) the total WF in agriculture ($m^3\ kg^{-1}$) is the water status of the field at full growth stage of the crop. It is the total sum of blue WF (WF_{blue}), green WF (WF_{green}), and gray WF (WF_{gray}):

$$\mathrm{WF} = \mathrm{WF}_{\mathrm{Blue}} + \mathrm{WF}_{\mathrm{Green}} + \mathrm{WF}_{\mathrm{Gray}}$$

Effective rainfall and irrigation water needed can be estimated by calculating the difference between total rainfall amount and crop ET. Effective rainfall can be calculated using Kim and Kim (2019) equation as follows:

$$R_{\mathrm{ef}}(t) = \theta(t) - \theta(t-1) - \mathrm{IR}_{\mathrm{eq}}(t) + \mathrm{ETc}(t)$$

where $R_{ef}(t)$ is the effective rainfall at t days (mm), $\theta(t)$ is the soil moisture content at t days (mm), $\theta(t-1)$ is the soil moisture content at $t-1$ days (mm), $\mathrm{IR}_{eq}(t)$ is the net irrigation at 1 day (mm), and $\mathrm{ETc}(t)$ is the crop consumptive use (or crop evapotranspiration) at t days (mm).

The direct water consumption is estimated by converting the required irrigation water after bearing in mind the consumption rate by the source of water used by the crop. The converted surface and ground water usage are changed into direct water consumption by Further, after multiplying the water source by the water scarcity index, WFs could be delineated. The water scarcity indices are 1, 2.5, 6.9, and 35.1 for rainfall, river, reservoir, and ground water, respectively (Kim and Kim 2019).

The consumption crop water use (CCWU, $m^3\ ha^{-1}$) which includes the WF_{blue} and WF_{green} is described as consumptive WF by Hoekstra et al. (2011). The CCWU is evapotranspiration (ET) over cropping period divided by the yield of crop. The 'blue and green' crop water use is the water evaporated from the irrigation waters and rainfalls from the field for producing agricultural products (Mekonnen and Hoekstra 2014; Hoekstra et al. 2009).The blues or green WF of growing crop (WF_{blue}/WF_{green}, $m^3\ t^{-1}$) is intended as the blues or green component in plant water use ($CCWU_{blue}/CCWU_{green}$, $m^3\ ha^{-1}$) divided by the yield of crop (Y, $t\ ha^{-1}$).

$$\mathrm{WF_{Blue}} = \mathrm{CCWU_{Blue}}/Y$$

$$\mathrm{WF_{Green}} = \mathrm{CCWU_{Green}}/Y$$

The gray WF of growing crop (WF_{Gray}, $m^3\ t^{-1}$) is calculated as the leaching fraction (α) multiply by application rate of the chemical per hectare (AR, $kg\ ha^{-1}$). Further, this figures in totality divided by the concentration limits (C_{max}, $kg\ m^{-3}$) minus the concentration of pollutant under natural conditions (C_{nat}, $kg\ m^{-3}$) then divided by the yield of crop (Y, $t\ ha^{-1}$).

$$\mathrm{WF_{Gray}} = \frac{(\alpha \times \mathrm{AR})/(C_{\max} - C_{\mathrm{nat}})}{Y}$$

For example, gray WF for nitrogen fertilizer was calculated by Mekonnen and Hoekstra (2014) using the application rates of nitrogen, leaching-runoff fractions, and nitrate water quality standards.

The green and blue parts of the crop water use (CWU, $m^3\ ha^{-1}$) are determined by summation of daily ET (ET, mm/day) over the entire growing period as given by Hoekstra et al. (2009):

$$\mathrm{CWF_{Green}} = 10 \cdot \sum_{d=1}^{\mathrm{lgp}} \mathrm{ET_{Green}}$$

$$\mathrm{CWF_{Blue}} = 10 \cdot \sum_{d=1}^{\mathrm{lgp}} \mathrm{ET_{Blue}}$$

where ET_{Green} and ET_{Blue} are evapotranspiration losses of green and blue water, respectively. The value 10 stands for the conversion factor for depths of water (mm) into volumes of water per soil area ($m^3\ ha^{-1}$). The summation is done to cover the period from planting date (day 1) to the harvest date (lgp means length of growing period in days). Naturally, diverse crop cultivars may differ significantly in growing period time. Therefore, this aspect can substantially affect the crop water use calculated.

Field evapotranspiration can be determined or measured using an empirical model. However, because direct measurement of ET is costly, estimation of ET indirectly by using a model that incorporates climatic and soil data as well as crop parameters as input is common. Apart from the Penman–Monteith equation which is recommended by FAO (Richard et al. 1998) there are many alternative models that can be employed to measure net evapotranspiration. For instance, the EPIC model (Williams 1995) is used frequently and a grid-based form is also available (Liu et al. 2007). Further, it could also be delineated from the water balance equation after estimating the rainfall, irrigation water inputs, seepage, drainage, and change in profile moisture storage (Bhatt and Kukal 2018).

9.6 Resource Conservation Technologies and Their Impacts on Water Footprint

The RCTs are the innovative, improved, and scientifically proven technologies that have helped the farmers to practice sustainable RW systems in the region. Among recent RCTs, laser land levelling (LLL), short duration cultivars, irrigation scheduling through soil matric potential (SMP), crop diversification, and raised bed planting, etc., are of paramount significance in improving livelihoods of the farmers without putting much stress on the natural resources (Fig. 9.4) (Bhatt et al. 2016, 2019). RCTs, however, require a set period of around 6–7 years to have significant effects on productivities (Bhatt and Kukal 2015). Nonetheless, RCTs are highly site-specific, and their performance varies widely in different regions with diverse soil texture and multiple agro-ecological conditions (Bhatt et al. 2016). RCTs provide a wide display of profit, including improved grain yields, reduced crop production costs, increased irrigation WUE, improved nutrients use efficiency, efficient insect pests' measures, and reduced GHGs emissions (Kaur et al. 2010; Rahman et al. 2015). Among different RCTs selection of cultivars, proper time of sowing/transplanting, laser levelling, mulching, direct seeding of rice, laser levelling, tensiometer based irrigation, bed planting, zero tillage, double zero tillage are the main for decreasing water footprint in the regions (Bhatt 2015).

9.6.1 Short Duration Rice Cultivars

Short duration cultivars have comparative lesser stay in the field, lesser required number of irrigations, lesser atmospheric demands, and ultimately have lower WFs, viz., rice cultivars as PR-126 and PR-127, while long duration cultivars, viz., pusa-44, have longer stay in field, lesser evaporation demands, and finally higher WFs. Therefore, for reducing WFs in the region, short duration rice cultivars must be popularized and sown on the maximum area (PAU 2020, https://www.pau.edu/content/pf/pp_kharif.pdf).

9.6.2 Date of Rice Transplanting

Timely transplanting of rice crop, viz., after 10th of June is a good and a must recommended one for the rice farmers of the South Asia for reducing the WFs. In the early transplanted rice crop, a significant share of water lifted by the atmosphere, thereby irrigation water has to apply again and again and finally resulting in the higher WFs. However, in case of timely transplanting, viz., after 10th June, upcoming months from July to September, encountered with monsoons, thereby moist the dry air which not able to evaporate much of water. Thereby intervals in between irrigations increased and ultimately, WFs (Bhatt and Kukal 2017).

9.6.3 Direct Seeded Rice (DSR)

DSR is propagated as RCT responsible for reducing the WFs, because it involves no puddling operations thereby directly cut down six full irrigations directly as compared to the conventional puddle transplanted rice. But here it is worth to mention that DSR performs best on the medium to heavy textured soils and at light textured soils, it may not fulfil the purpose (Fig. 9.4). Therefore, before adopting it farmers must test their soils. Under heavy textured soils, DSR is really effective in reducing the WF share (Bhatt and Kukal 2015). In the coarse-textured soils, DSR plots suffering with severe iron deficiency, significantly higher weed competition, and finally had higher WFs (Mahajan et al. 2011; Bhatt and Kukal 2015).

9.6.4 Laser Land Levelling (LLL)

LLL has been the most widely and rapidly accepted and adopted technology (Fig. 9.5) among different RCTs recommended for the region for reducing WFs and improving both land and water productivities (Bhatt and Sharma 2009). Levelling might improve the water coverage area, reduces weed pressure and hence finally, enhances the water application/use efficiency, and reduces the WFs (Ahmad et al. 2001; Jat et al. 2006).

9.6.5 Permanent Raised Beds (PRBs)

To increase WUE and to reduce the WFs share in the conventional flat sowing, permanent raised beds (PRB) system has been developed (Connor et al. 2003; Ram et al. 2002a, 2013). PRBs have been recommended as an important RCT (Fig. 9.5) for enhancing system sustainability in the IGP of South Asia, primarily through

Fig. 9.5 Field view of different RCTs recommended in the region for reducing the water foot print (Bhatt 2015)

improving soil structure and reducing WFs (Hobbs et al. 2002; Connor et al. 2003; Humphreys et al. 2008). When PRBs are aged, reshaping of beds is required for optimal results. But, reshaping the PRBs with tractors causes compaction of side slopes of PRBs with tyre pressure Increased age of PRBs exerted restriction on root proliferation due to increased bulk density, which further decreases the water infiltration and promoted runoff particularly on the sloppy lands. Therefore, fresh beds might result in reducing the WFs while with time WFs increased due to decreased infiltration because of compaction of the side slopes with tractor tyres while reshaping the old beds (Kukal et al. 2009).

9.6.6 Irrigation Scheduling Based Using Tensiometers

Irrigation scheduling in rice based on SMP using a tensiometer has been reported as an effective technique for cutting down the water inputs and hence, the WFs (Bhatt and Meena 2020; Bhatt et al. 2014). Soil matric potential based irrigation planning leads to need based irrigations and significantly reduces the irrigation water inputs (Fig. 9.5) without adversely affecting the grain yields than traditional flood irrigation (Kukal et al. 2005). In comparison to the flood irrigation, tensiometer reduced the WFs In a sustainable manner, on the plant need based approach.

9.6.7 Zero-Tilled Wheat

The ZT wheat has gained considerable acreage under RW systems of South Asia, more particularly in the NW IGP because of higher yields due to shared mulch benefits and reduced WFs of wheat crop, as no pre-sowing irrigation required here while in case of the conventional tillage, pre-sowing irrigation is required (Fig. 9.5) (Erenstein and Laxmi 2008; Ladha et al. 2009) but only with previous rice residues on soil surface as mulch hinders hot sunrays to hit the soil surface, reduces vapour pressure gradients, vapour escapes from the soil surface, and finally reduces wind speed and hence its vapour lifting capacity of the air.

9.6.8 Crop Diversification

Crop diversification, i.e. cultivating lower water requiring crops will also reduce the WFs (Jalota and Arora 2002; Arora et al. 2008). In many studies, ET losses decreased to a considerable extent when the cropping system was changed from rice-based cropping sequence to non-rice cropping sequence (Jalota and Arora 2002; Arora et al. 2008). Therefore, in shifting of cropping system from RW to M-W systems, WFs decreased. The WFs of maize were significantly lesser than that of rice (Gathala et al. 2013a, b). Further, soybean–wheat can also be a potential crop rotation for reducing WFs and having higher profitability in the region (Hari et al. 2006).

9.7 Desired Technologies to Improve Water Productivity in the South Asia

Among different discussed technologies, except short duration cultivars and timely transplanting, all RCTs committed to reduce the drainage losses by decreasing the irrigation water inputs which could recharge the declining underground water tables. However, under the water logged conditions, these might be effective. Generally these are known as power saving technologies which otherwise could have used for withdrawing the water from the deeper depths. But for the water stressed regions, our objective is to cut the evaporation share but not the drainage share as drainage recharges the declining water tables. Hence, technologies, viz., short length cultivars and appropriate transplanting known as real water saving technologies because of their tendency to reduce evaporation without cutting the drainage losses and promoting the transpiration which supplementary responsible for the higher land as well as water productivities with reduced WFs in water stressed regions (Bhatt et al. 2020a, b; Hossain and Bhatt 2019).

9.8 Factors Affecting Performance of Resource Conservation Technologies

The role of different proposed RCTs in the South Asia is to reduce the WFs and to produce a set targeted rice yields. However, all of the RCTs are condition sensitive pertaining to location and circumstances. Further, their concert depends upon the several factors in reducing the WFs. Some factor have been short listed as below which must be considered while adopting any of the RCT for having reduced WFs and improved rice yields in the South Asia (Bhatt 2017; Personal communications).

9.8.1 Soil Texture

It is the most important factor for deciding the fate of any RCT in reducing the WFs, as it controls soil aeration, infiltration, and moisture status which further affecting any of the RCT. For example, direct seeded rice (DSR) a wonderful technology for reducing the WF as it omits the puddling operations and continuous flooded conditions of conventional system, but effective only at the medium to heavy textured soils (Bhatt and Kukal 2015; PAU 2020). However, under the light textured soils, the story in totality changes and system collapses because of significantly higher weeds and severe iron deficiency (Bhatt and Kukal 2016). Further, sandy soils may have higher WFs requirements as compared to the medium to heavy textured soils.

9.8.2 Proper Rice Cultivar

Selection of the long duration cultivars, viz., Pusa 44 has higher WFs than the short duration cultivars, even under any RCT. Hence for reducing the WF, farmers must select the short to medium duration rice cultivars for reducing the WFs.

9.8.3 Risk Bearing Ability

It is the main cause which decides adoption rate of the farmers for new RCTs, as most of farmers could not be willing to divert from the old lines. Around three to five years back, lead farmers (mostly sarpanches/rich people) were selected by the state departments for DSR cultivation at their fields under the pressure from the government departments for reducing the WF without caring of their texture, which later become a failure under light textured soils. Hence, farmers have to till their DSR crop fields and later go for basmati. These are the rich farmers who bear this loss, without much hue and cry, otherwise may not be possible for poor or medium class farmers (Bhatt 2017, personal communications).

9.8.4 Annual Income

If a farmer having good income due to any reason (might his children settled in abroad or having heavy wealth of his fore-fathers), he is able to take risks and could be mould towards any new RCTs for the name and fame in his village. Generally, farmers adopting RCTs, viz., DSR, tensiometer, mechanical harvesting, raised beds selected by the state departments or universities and awarded to create interest among others. However, only rich farmers could bear risks and eager to have his name in the newspapers, etc., while poor farmers even willing not able to bear risks.

9.8.5 Mass Media Exposure

Mass media, viz., newspaper, TV, or radio also have an important role in alerting the farmers regarding the present scenario of water scarcity and also highlighted RCTs as an option for getting higher land as water productivity by reducing the WF. Further, under the present scenario of COVID-19, role of media increased to manifolds for brining awareness to the farmers. Generally farmers adopting new RCTs are under the frequent contact with these mass media.

9.8.6 Land Holdings

Big farmers with higher land holding commonly are the first to adopt new RCTs. Further, they got the bank loans or access to the cooperative implements, viz., laser leveller than the farmers with smaller land holdings. However, mostly prior farmers with big land holdings generally be selected by the different government agencies because of their risk bearing ability.

9.8.7 Education Status

Education is the main mantra towards the awareness as illiterate farmers remained in his circle and not willing to adopt new methods of crop establishments. Further, family size is also another factor affecting the adoption. In Punjab, new generation flying to European countries and older ones remained back in the villages, which have almost nil interest in adopting the new RCTs. Mostly, for meeting their children foreign requirement they sell their agricultural lands near the roadsides for construction of malls, marriage palaces, or colonies. Under this scenario, adoption rate of RCTs really under doubt. Hence, government must come out with some law which protects the sale of the good quality agricultural lands to a permanent end.

9.8.8 Extension Officer's Visits

Responsibility of the extension officer is to equip the farmers with the new technologies, viz., RCTs by demonstrating them at their fields as mostly farmers believe on watching at their fields. But limited staff of extension officers might not able to visit all the farmers. Hence, it becomes a need to propagate the message through the mass media. Further, extension officer must prepare some group even on the WhatsApp to educate the large number of the farmers simultaneously. Even he could reach to the farmers through the Facebook as mostly farmers nowaday has android mobile phones with them. Further, in the present scenario of COVID-19 conditions, this works well as going to farmers' house is not advisable.

9.8.9 Participation in Farmers' Fairs/Kisan Melas

Mostly state agricultural universities are organizing the farmer's fairs for the sale of seeds of new cultivars and to keep the farmers aware of new RCTs for cutting the share of the WF. Punjab Agricultural University, Ludhiana, Punjab, India organizing two state level fairs known as 'KISAN MELA' where thousands of farmers not only from the state but also the neighbouring states visited the fairs for the purchase of new seeds and to get knowledge regarding new RCTs, and to get the farm literature. University also brought out two publications during two 'Kisan Melas' for Kharif and Rabi seasons of each year. Further, all the technical details from sowing to harvesting of almost all the crops with all new prospective provided in these publications.

9.8.10 Farming Experience

Experience matters for picking any technology for enhancing the profits and to go for sustainable agriculture. As already discussed in Sect. 9.3 of this discussion, farmers who till their DSR crop under light textured soils will not again go for it rather he become now torchbearer for the farmers with the sandy soils. Similarly, bed planting is successful under the fresh beds but with time due to reshaping sides become compacted and reported with higher bulk density which hinders the root growth. Therefore, this thing that only fresh beds are effective to cut off the WF and to improve the yields comes with the experience. Therefore, with his experience he taught others farmers regarding which RCT to adopt and which RCT not to adopt.

9.8.11 Extension Centres Linkages

Most of the South Asian countries have their extension centres for the farmers. Punjab Agricultural University, Punjab, India set up extension centres even at the district levels known as 'KRISHI VIGYAN KENDER' which itself acts as a mini university and farmers who could not afford or who has limited time, get the almost similar benefits from these KVKs. Farmers who use to visit KVKs were obviously well-known with the latest RCTs or new cultivar seeds than farmers who do not used to visit KVK. Hence, adoption rate of different RCTs will depend upon the farmer's visits to the KVKs.

9.8.12 Innovation Proneness

Sometime farmers have innovative proneness and he is willing to experience new things or practice some new crop establishment methods. Such farmers quite easily adopt the new RCTs and tried to rub the old lines. There innovative proneness behaviour of the farmers is favourably diverted to him for rick bearing and to try new things by practicing new crop establishment methods or RCTs. Such farmers through their experience will guide the others in the next year that which RCT will work under which conditions and thereby further improves the rate of adoption of the new RCT advocated for cutting the WF and to improve the land as well as water productivity in the South Asian regions.

Hence, above factors will certainly effecting the adoption rate in the region; therefore, adoption programmes should be more focused and targeted in accordance with the requirement of the specific area.

9.9 Technologies Towards Reducing Water Footprint in Rice-Based Cropping System

Available freshwater is a natural-resource which is now going to endanger due to an increasing and extensive demand for agricultural, industrial, and domestic usage. The availability of quality water is declining with time, particularly water stressed regions (Sharafi et al. 2011). Agriculture is fronting the growing stress to fulfil the rising demands for food, fibre, and water. Researchers found that rainfed agricultural productivity can be achieved double through irrigated agriculture (Lascano and Sojka 2007). They also projected that to meet the food security by the year 2025, crop productivity should be increased by 40% through increasing irrigated area more than 20% (Lascano and Sojka 2007). Since, faulty irrigation practices, viz., flooded ones are the main user of the available water resources as more than 70% of the total water extractions and up to 80% of the total consumptive water is used via irrigation (Huffaker and Hamilton 2007). Where rice-based, particularly rice–wheat (RW) system is the most important agricultural systems for meeting the food security for millions in the region (Ladha et al. 2009; Sidhu et al. 2019).

However, continuous intensification of traditional RW system deteriorates the soil health; since RW system needs huge available fresh irrigation water (about 1800–2400 mm) for soil puddling for seedling transplanting (Chauhan et al. 2012; Jat et al. 2017). Similarly, IRRI (2007) also reported that generally irrigated lowland rice usable water ranges between 675 and 4450 mm; although the usable ranges vary on several factors including the soil properties, cultivation system of rice, and methods/management of water use. IRRI (2007) also reported that the current system of irrigated rice in most of Asian countries requires huge amounts of water. For example, for 1 kg rice production, India and the Philippines generally use on an average 3000 l irrigation water.

Considering the burning issues, it is important to use the natural water optimally. The acceptance of next generation irrigation techniques is of great importance to decrease the WFs, particularly in rice-based cropping sequences (Fischer et al. 2007; Meena et al. 2018; Sidhu et al. 2019). To shrink the WF in the RW system, recently several water conservation techniques are suggested by various findings, which are discussed below:

Agronomic management such as using short duration crop varieties/cultivars, adjusting sowing/planting time of rice, conservation tillage options such as zero/strip-tillage, straw mulching, and crop residues management are found effective for efficient use of irrigation water in RW system (Yadvinder et al. 2014a, b; Jat et al. 2017; Sidhu et al. 2019; Meena et al. 2020). The DSR system claimed to be an alternate to puddled-transplanted rice (PTR) in RW system, particularly on the medium to heavy textured soils (Chauhan et al. 2012; Bhatt and Kukal 2015). It is the cost effective, labour saving, and environmental friendly technology. Full irrigation by check basin methods is being widely used by farmers in abundant as well as in scarce areas of water availability; since in this method, crops obtain full ET to produce the higher yield but nowadays, full irrigations are measured an indulgence use of water and no effect on lucrative yield (Kang and Zhang 2004; Meena et al. 2015).

9.9.1 Micro-Irrigation

The supplementary water saving and increase water productivity (WP) methodology recognized for different crops is micro-irrigation (MI) systems than traditional flood irrigation systems (Yadvinder et al. 2014a). It can be an effective tool for improving WP in the RW system (Meena et al. 2015). Irrigation water application by MI systems (drip and sprinkler) becomes the need of the hour and practical. The results revealed that drip and sprinkler irrigation systems are efficient and could be adopted for irrigation in rice and wheat crops for improving the WP. Favourable water regime created by MI results in higher crop yield (Meena et al. 2015). With MI, WP was recorded more than 50%; it was conceivable by preserving accessible moisture in the soil at low tension of available water during the whole growth period of crops (Patel et al. 2006). The MI systems deliver water to the plants which match the crop ET demands and also distribute best soil moisture at precarious growth stages of crops resulting in high WP (Kipkorir et al. 2002).

9.9.2 Surface-Irrigation (SI)

SI approaches are applied for more than 80% irrigated lands across the globe but its field-level use efficiency is only 40–50%. However, in the case of drip irrigation (DI) system, the effectiveness ranges between 70–90% through minimizing the surface runoff and deep percolation losses of water (Postel 2000; Meena et al. 2015). The DI is the maximum operative way to transport directly water and nutrients to plant roots which not only save water but also increase the crop yield such as row crops (Chen et al. 2015; Sharda et al. 2017; Sidhu et al. 2019). Recently researchers recognized that the MI (drip and sprinkler irrigation) system is more effective than DI and SI systems due to its higher WP (Meena et al. 2015).

9.9.3 Sub-surface Drip Irrigation (SDI)

In recent years, sub-surface drip irrigation (SDI) systems have increased substantially. The SDI is a potential irrigation system for crop production systems through improving the water use efficiency than other forms of irrigation systems; predominantly in the soils where water is deficit/limited (Sarker et al. 2020). Since, SDI has a negative impact around the crop rhizosphere (root-zone of crops) through disregarding the soil air (oxygen in the root-zone); which is responsible to reduce root function, finally alter the physio-biochemical process of the plant. Besides these, lack of soil oxygen content in the root-zone leads to damage to the root tissue, altering the growth and development of vegetative and reproductive organs, changes in plant internal cell structure (Schäffer et al. 1992; Drew 1997; Gil et al. 2009). Positively, oxygation in the root-zone assures the ideal root function, also delivers molecular oxygen for aerobic digestion of microorganisms (Zappi et al. 2000; Petigara et al. 2002; Gil et al. 2009) availability of nutrients and improves water use efficiency that ultimately leads to boost the growth and development of plant process finally yield (Bhattarai et al. 2004). However, to ensure the oxygen readiness in SDI system and also to progress the water use effectiveness, SDI system should be accomplished with the oxygen (aerating) in the rhizosphere of the crop. Earlier studies recommended that the oxygen can be introduced into the irrigation stream of SDI through the way of the Venturi principle, or by using solutions of H_2O_2 (HP) through the air injection system (Bhattarai et al. 2004; Abuarab et al. 2012). The HP has been effectively used as an oxygen source for in situ remediation in a wet aquifer (Gil et al. 2009).

9.9.4 Drip Irrigation (DI)

Drip irrigation has highest water use efficiency and with dissolved fertilizers (fertigation) has highest nutrient use efficiency and reduced fertilizer use (Hagin et al. 2003; Sidhu et al. 2019). Further, among drip fertigation, there are two systems, viz., surface and sub-surface fertigation. Later system has an edge because of its stability, cutting down weed pressure which further cut down the WFs in a sustainable manner. Further, environmental pollution could also be checked as nutrients are supplied as per plant needs (Ayars et al. 1999). Conservation agriculture is also promoted in the region for reducing the WFs by minimum tillage, retaining of residues, and proper diversification of crops (Gathala et al. 2013a, b; Jat et al. 2014). As far as spacing between drip lines concerned Chen et al. (2015) and Chouhan et al. (2015) revealed that in wheat crop theses drips at a spacing of two ft serve the purpose at fine textured soils. However, for depths at which this drip pipes establishment was concerned, Lamm et al. (1997) reported its placement from 15 to 70 cm acceptable in maize.

Mostly water stressed conditions discussed without putting much light on water quality as latter deteriorated under intensively rice-based cropping sequences of South Asia and more attention and research required in this direction (Elliott et al. 2014; Qadir et al. 2010). Soil salinization considered to be one of the main factors for declining water quality particularly in the low lying coastal regions (Daliakopoulos et al. 2016; McFarlane et al. 2016). As per one study by leading research organizations, viz., FAO and the UNEP around half of crop land suffering from the problem of high salts, which further has its own environmental consequences (Rozena and Flowers 2008).

Bangladesh and India shared a representative salinity area where good quality irrigation is always problem along with drinking water (Parvin et al. 2017; Rahman et al. 2017). Under these conditions, crop failure is common if land irrigated with this saline water and hence, a significant area remained idle which could be brought under agriculture under the availability of fresh water (Hoque and Haque 2016; Huq et al. 2015). In Indian, Punjab, governments are quite concerned and rivers with fresh water diverted to such areas for uplifting water and land productivity and livelihoods of farmers (Bhatt et al. 2019). Underground water must and will be used judiciously (Murad et al. 2018). Experiments delineates that some interventions such as alternate use of good and salt affected water, cultivating salt stressed cultivars of different crops as developed by leading institutions, viz., Central Soil Salinity Research Institute, (CSRI) Karnal, India, etc. help a lot to the farmers for having potential yields (Murad et al. 2018). Hence, on one side we need to reduce the WFs particularly in the water stressed conditions while on other dealing with saline water problems is equally important for bringing sustainability in the rice-based cropping systems of South Asia.

9.10 Policies and Legal Framework for Implementing Technologies for Reducing Water Footprint Under Rice Cropping System in South Asia

In South Asia, by promoting low water consuming crops and by adopting correct irrigation methods water use efficiencies could be enhanced to many folds which further resulted in declining the water footprint. There is around 73% less water than flooded rice cultivation in jowar and barley. Therefore, crop diversification is one of the practical options to reduce water scarcity in water stressed areas by increasing agricultural WUE in the region. Further, it is quite clear that a water footprint in the South Asia is significantly higher particularly in the rice crop due to its faulty crop establishment and irrigation system. Though, scientists across the region suggested many techniques to cut down the water footprint. But all the programmes or policies will not serve the purpose if not supported by the government policies. In India, Punjab is a major producer of rice (Dhillon et al. 2010) (though its inhabitants not fond of rice) deteriorated its soil as well underground water resources and reason behind is provided minimum support price and free power to withdraw water from deeper depths. Under such conditions, why farmers adopt techniques which cut down the water footprint under free electricity conditions? Therefore, government must charge some token money from the farmers for the power used for irrigation and hence the saved power could be then diverted to the industries or to the urban colonies.

Secondly, state government must provide subsidy to the farmers for purchasing heavy machinery such as laser levellers, happy seeders, lucky seed drills, zero till, etc. After once purchase other might benefitted from him on payment basis.

Thirdly, only some states, viz., Punjab, Haryana, etc., are offering minimum support price for the rice, thereby a large area covered under rice every year. However if there are MSP also for the oilseed and pulse crops, then farmers no doubt shifted to theses crop which not only cut down the water footprint but also improves the soil health.

Fourthly, growing other potential crops such as gram, barley, jowar, soybean, groundnuts keeping rice aside reduced the water footprint to many folds, particularly in water stressed zones.

Fifthly, government must frame policies for improving the adoption rate of water saving technologies including micro-irrigation, laser land leveling, direct seeded rice, etc.

Fifthly, subsidies must be shifted from electricity supply to water saving technologies. As only then farmers attracted towards them. Moreover such farmers should be awarded at different functions for being a role model for the other farmers.

9.11 Gaps and Future Thrust Research Areas

The task of addressing issues surrounding WF is all-encompassing, most especially as it relates to agricultural productivities. It has been shown that reducing WF to sustainable levels is a possibility (Ercin and Hoekstra 2014) provided that more attention is put into actors playing important roles in this scenario. Changes in water extractions in the agro-ecosystem (Shen et al. 2008), alternative approaches for achieving rising water and food demands by 2050 (De Fraiture and Wichelns 2010; De Fraiture et al. 2007), and altering dietary habits affected the water resources. Rosegrant et al. (2002, 2009) have been studied together with the links between trends in consumption, trade, social and economic development (Ercin and Hoekstra 2014). To this end, how changes in WF will influence future soil carbon stock has not been given consideration. Therefore, the future study can explore the relationship between WF, land footprint, and carbon footprint and how their interactions can be manipulated to increase food security (Lee 2015). In literature, there is reported a decline in water footprint in South Asia due to higher yields for most crops occasioned by crop yield improvements (Zhuo et al. 2016) and slightly lower rates of evapotranspiration (Kayatz et al. 2019) but the corresponding effects of this decline on soil carbon stock has not been fully examined. We can think of carbon offsetting (Ercin and Hoekstra 2012) to further buttress the need for soil carbon stock study concerning WF. Carbon offsetting refers to measures taken externally to compensate for carbon footprint using some form of carbon capture or reduction elsewhere (Ercin and Hoekstra 2012). One of the best ways of capturing carbon is making the soil serve as a sink rather than a source (Busari et al. 2016; Ogle et al. 2004). Though a contextual approach has been made to integrate ecologically, carbon and WF to create a concept tagged 'Footprint Family' (Galli et al. 2012) but how WF relates with soil carbon stock and other soil physical processes (soil thermal regimes and interaction between reduction in soil moisture consumption (WF) and soil fauna activities) have not been fully integrated into this family. This suggests that studies involving WF and its implication for soil carbon stocks and soil physical processes are worthwhile.

Again, a global WF benchmark values were developed for 124 crops (Mekonnen and Hoekstra 2013), rice inclusive. Most of these WF efforts on cereals and other crop families presented issues mainly mono-culturally ignoring the possibility of growing these crops as intercrop or in a mixed cropping system thereby creating a knowledge gap as per effect of rice intercrop on WF. Intercropping involves growing two or more crops or genotypes together on the same piece of land and is one way by which the functional diversity of an agroecosystem can be increased (Brooker et al. 2015) and finally results in higher livelihoods through higher tiller numbers and raised net photosynthesis (Vos and Bellu 2019). Intercropping two or more functionally diverse crops can minimize weed infestation by optimizing resource utilization (Lowery and Smith 2018) by the companion crops and this will have an impact on the WF. The direction of this impact can only be determined by robust scientific research.

9.12 Conclusions

South Asian rice-based cropping systems involve non-judicious use of water resources and thus have huge water footprint which further coupled with reduced water use efficiency and land and water productivity. Moreover, conventional methods of field preparation, viz., puddling or intensive tillage and irrigation, viz., flood irrigation further intensified the WFs. This is the serious conditions, particularly in the water stressed regions, where underground water table declining at much faster rates as in NW India. Many technologies such as laser leveller, short duration plant cultivars, timely sowing of rice seeds and transplanting of its seedlings in the field, bed planting, zero tillage with residue retention, tensiometer based irrigations to rice, cemented or underground water channels, etc., suggested for reducing WFs in the region without adversely affecting the yields.. Moreover, there is a need to recognize the real water saving technologies which does not cut the drainage losses while cutting the share of the unproductive evaporation to promote transpiration share and finally yields. Further, evaluation of these technologies for reducing the WFs in the SA must involve rice-based cropping systems as a whole and not with sole crop, viz., rice or wheat which also consider the intervening periods, as it is very important for legume or other fodder crops cultivated in between. Future research programmed for reducing WFs in the region must focus on producing more and more quality grains with less and less of water drops by improving the water use efficiency in the field, and by reducing conveyance losses by cementing the water channels, providing subsidies to the farmers for the purchase of machinery, viz., happy seeder, zero till, laser leveller, charging some token money to the farmers for every litre of withdrawal water and at the last government policies which are the most important and played a key role in the successful adoption of any programme recommended in the region for reducing WFs.

9.13 Future Prospective

For sustainable reducing the WFs in the region, the following future prospective must be focused in the upcoming action plains formulated for South Asia.

1. By involving local farmers in different schemes framed for reducing water inputs so that they feel not ignored and evaluate them in the true sense, otherwise such schemes got failed period to its launching. Therefore, local farmers must be kept in confidence after considering his socio-economic and cultural holdings.
2. By planning a research based on the rice-based cropping systems as a whole including the intervening periods and next crop. Further, research outcomes must be demonstrated to the farmers at their soils in their conditions. Once satisfied, then he becomes an ambassador of that technology in between other farmers to which others relied much upon as he if from them.
3. By considering climate change impacts, viz., higher CO_2 levels and ambient temperature in different research trials carried out for reducing WFs in the region, particularly rice-based.
4. Proper platforms either at the village, regional, national, or even international level will be there for having healthy discussions in between farmers, scientists, and policymakers regarding underground water scenario and how to reduce WFs in the region.
5. The fate of all the technologies must be tested and their successful operation conditions must be conveyed to the farmers. For example, direct seeded rice is propagated in the region for reducing the water footprint but that is true only under the soils with higher clay contents while DSR is a complete failure in the sand dominated soils because of significantly higher weed pressure and severe iron deficiency. Similarly, zero tillage suffering from significantly huge weed

pressure and reported to be even inferior from conventionally tilled plots due to severe competition faced by plants from these weeds. Therefore, before reaching to the farmers, all these aspects should be taken care off for its successful and long-lasting adoption of any technology in their fields.

6. The WFs concept and its importance will be and must be incorporated in higher standard textbooks, regular magazines, national reports, and communication documents for creating awareness regarding the seriousness of the issue. Moreover, newspapers and TV/radio must frame some regular programmes for showing the importance of water and ways for its sustainable use.
7. The government must propose some MSP (minimum support price) for other crops, viz., legumes, maize, or other less water requiring crops for successfully diverting the farmers to lesser water requiring crops. Similarly, farmers must be charged for the withdrawal water for flood irrigation, only then he thinks for reducing WFs in his fields.
8. Awarding farmers adopting new recommended techniques, viz., laser leveller, tensiometers, etc., for reducing their WFs must be identified and awarded by the state government departments or universities at different functions, viz., farmer's fairs (Kisan Mela), etc., and by publishing their cover stories in newspapers or different agricultural magazines, viz., progressive farming (English) or change kheti (local language) of PAU., Ludhiana. This practice also encourages other neighbouring farmers for reducing WFs of their crops. If this is the case, then certainly targeted objective will be achieved sustainably.

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Contents

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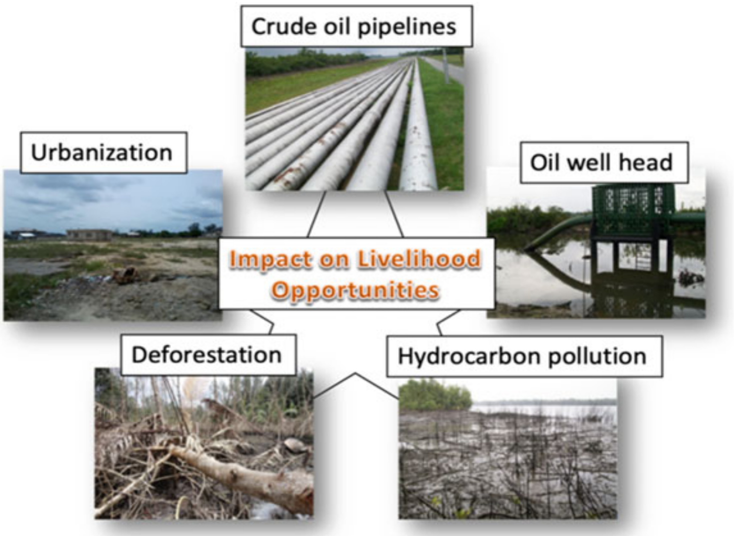
Abstract

In the field of economics there is a popular saying that opportunity cost, which include lost man-hour and lost opportunity. In the Niger Delta, oil and gas exploration and urbanization lead to the loss of livelihood opportunities of rural dwellers such as fishing, farming, hunting, manufacturing, and processing. This is as a result of the forceful ejection of the people from their land and the plundering of their resources by oil companies and government agencies through systematic deforestation, pollution, and construction activities. Conversion of agricultural land into industrial land leads to loss of jobs and thus income, which increase the poverty level of rural dwellers. Land, air, and water pollution lead to health and safety disasters that threaten the well-being of local inhabitants. Furthermore, destruction of livelihood opportunities leads to income losses, increase in antisocial activities, and rural-urban migration. The resultant effect of mangrove forest destruction is the increase in ecological footprint through the disappearance of ecological services.

Graphical Abstract



Keywords

Exploration · Income · Livelihood opportunities · Urbanization

Abbreviations

CO	Carbon monoxide
CO_2	Carbon dioxide
EIA	Environmental impact assessment
GIS	Geographic Information System
H_2S	Hydrogen sulfide
PAT	Population-affluence-technology
ROW	Right of way
TLV	Threshold limit value

10.1 Introduction

Crude oil is what is popularly called the "black gold "based on its black color and for the fact that it is a natural resource that is expensive and costly (Gumus and Kiran 2017). Therefore, crude oil is a natural resource that comes from sedimentary rocks that formed thousands of years ago. It is formed from the decomposition of plant and animal matter, which over the years had become embedded within the sediments of the soil to form black peat. Exploration is the act of adventurism aimed at searching for new things, which may be natural resources or new invention that is beneficial to humans (Meena et al. 2018). Crude oil exploration is the act of geologically looking for and identifying oil-bearing earth crust and tapping it for the benefit of humanity. Niger Delta region in Nigeria is sitting directly on top of throve of oil-bearing sedimentary rocks, which had been formed millions of years ago. Because of its sedimentary nature, thousands of oil wells had been discovered in many communities in this region. That is why the Niger Delta is regarded as the resource base of the nation, which had made Nigeria the largest producer of crude oil in Africa and the third largest in the world (Numbere 2018a). Since the first oil well was struck in a community called Oloibiri in the Niger Delta in 1956, numerous oil wells have been discovered and explored, while many more are yet to be discovered and explored (Egbebulem et al. 2013). These oil wells are found in offshore and onshore areas. The exploration of crude oil in these communities had been a curse rather than a blessing because of the level of devastation that had been inflicted on the land. Most of the rural communities had lost their land and rivers leading to the loss of their livelihood systems (agriculture, fishing, trading, local craft, etc.) due to crude oil exploration. For instance, a vibrant community such as Oloibiri, where the first oil well was struck, had been so devastated that it has been converted from being a thriving fishing settlement to a place of national museum of oil and gas with non-existent livelihood opportunities for the indigenes. This had resulted in the rural-urban migration of the people in search of white collar jobs that they are not qualified for, while the youths have been tempted to remain in the rural areas to perpetrate negative vices to survive. These vices include prostitution, artisanal refinery, militancy, kidnapping, cultism, etc.; all these acts are the results of loss of livelihood opportunities.

Land use system in Nigeria is basically controlled by the "Land Use Act" that was enacted in 1976, which states that all the land in Nigeria belongs to the federal government; this includes offshore and onshore regions (Fabiyi 1984). This means offshore areas that are 200 nautical miles into the sea belong to the federal government. This law practically takes away the ability of the indigenous people to control their own resources. It means that farm lands which are supposed to be private property of the members of the community belong to the government; even the fishes caught in the sea within the 200 nautical miles practically belong to the federal government. This faulty land use system is what has resulted in the loss of the livelihood system of members of the Niger Delta communities. The oil and gas industry, which is a multibillion dollar investment, has had a field day over the landowners as a result of the company's partnership with the government to carry out crude oil exploration (Hall 2011). The land tenure system practiced in the Niger Delta is mainly hereditary or by purchase. Most land is owned by individuals, families, and communities. But because of the Land Use Act, many communal or family lands are forcefully acquired by the government to enable them to execute urban renewal projects. Similar mechanism is used to acquire vast land for industry or agriculture without adequate compensation to members of the community (Ogedengbe 2011; Kakulu 2008).

Urbanization involves the transformation of a rural area to an urban area (Liu et al. 2010; Khan et al. 2020a, b) by the establishment of modern infrastructure such as industries, highways, schools, hospital, pleasure parks, residential quarters, and universities. The provision of these facilities is germane, but the manner in which the land on which they are established is acquired is the problem (Meena and Lal 2018). This is because due to poor town planning, many facilities that are provided within the cities are sited at the wrong places. For instance, because of the congestion of the city due to poor town planning, areas that should be left alone as greenbelt to house vegetation such as trees, plant, and farm settlement are converted to housing projects or areas for the construction of industries and roads (Oladele and Oladimeji 2011). This gradual pushback by industrialization of rural areas takes away the source of livelihood for the rural population (Kitching 1983). People that reside in the villages don't have college degree, but possess the skill to farm and generate food items they consume or sell to make money. So when their land is forcefully taken away from them or devastated by pollution, they lose their only source of livelihood. This makes them resort to self-help, which may be antisocial activities.

A footprint perspective or ecological footprint refers to the impact of human and industrial activities on the environment. The proliferation of industries in the Niger Delta due to its rich natural resources has had serious impact on the environment in the area of hydrocarbon pollution and generation of excess carbon footprint in the form of soot. In the Niger Delta, multiple factors contribute to carbon footprints; apart from oil and gas industries, farming activities (e.g., animal, crop, poultry, etc.) have taken over most of the rural and urban areas. This is because of the lack of employment as a result of overpopulation that has made thousands of college graduate to be in the job market (Chris 2015).

10.1.1 Conversion of Mangrove to Firewood Increases Carbon Footprint

Firewood is a major cooking material in the Niger Delta region, and it is derived from the stems and branches of red mangrove trees (*Rhizophora* spp.) (Numbere 2020a). The unregulated cutting of the trees is a major primer for accelerating carbon footprint in this part of the world. This is because the removal of mangrove trees has serious implication on the environment, for instance, mangroves act as atmospheric filters by siphoning and absorbing carbon soot that comes from stacks of industries and exhaust from vehicles. Therefore, when these trees are removed, their function of purifying the environment is eliminated, which creates excess atmospheric pollutants. Secondly, the burning of firewood for cooking emits smoke and soot into the environment, which neagively impacts public health.

This chapter therefore discusses the impact of urbanization and crude oil exploration on the livelihood system and the health of the people of the Niger Delta.

10.2 Scenario of Urbanization and Land Use of Mangrove Forest Areas in the Niger Delta

10.2.1 Geography and Physical Determinism

All norms are influenced by physical environment such as technology of production, industrialization, and urbanization (Wangwe and Semboja 2003). The geography of the area determines the kind of activities that would go on in that area. For instance, if it is a flat land, it would be good for the establishment of industrial complexes that doesn't require a sloppy area, whereas if the project is hydroelectric project, it will require a sloppy land to enable a natural waterfall to drive the turbines of the plant. A slanting topography is also needed for natural drainage to evacuate waste material from industries to point of collection and disposal. Furthermore, the physical environment can influence the culture of production. For instance, the kind of houses built in a location depends on the climate of the area; cold climate requires heat-conserving apartment, whereas hot climate requires high ventilation apartment.

10.2.2 Principle of Land Utilization

(i) This involves supply and demand for land, (ii) land appropriation, (iii) economic process of land utilization, and (iv) land rent and income distribution. It is very expensive to acquire land in cleared mangrove forest because of its closeness to the sea, which is an ideal location to have a property that can be used as a seaside resort. Similarly, mangrove forest is a juicy area for industrialist because of its possessing of some natural resources such as crude oil, fishery, and firewood. Mangrove forest is also highly prized economically because it can be cleared and used to establish oil and gas industries. Furthermore, its proximity to the sea makes it an attractive place for sitting industries, which requires raw materials to be transported through sea. This is because for any resource the price is very important, and the lower the price, the more consumers will tend to buy. Land derived from mangrove forest can be used for the following purposes:

(i) Housing-residential
(ii) Transportation
(iii) Vegetation production
(iv) Grazing
(v) Recreation
(vi) Shopping complex
(vii) Refuse disposal

Rural areas are places where we have most of the mangrove forest; however, due to urbanization, these forests are converted to locations for housing projects or agricultural activities (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). The use of the land for the purposes outlined above is on the basis of three factors: (a) First is relative suitability for the intended business. Some businesses require lands that are close to river to enable the transportation of raw materials and heavy-duty equipment through the sea. (b) The second reason is the size of the enterprise, which will enable one to know the amount of land to be acquired from the mangrove forest. For instance, the establishment of an estate will take vast amount of land space. (c) Third is the physical property of the land such as natural, which may be swampy, rocky, sloppy, and loamy, or chemical property, e.g., soil pH, plasticity, structure, composition, etc. which is determined before erecting a building, for instance, before erecting high-rise building, soil test needs to be done to determine if the land can bear the weight of the structure. (d) Fourth, the landownership system needs to be known, whether by government, community, or individual (Famoriyo 1984; Udoekanem et al. 2014).

10.2.3 Demand and Supply

Similarly, the higher the price, the higher the supply. In summary, the demand is negatively sloping, whereas supply is positively sloping (Fig. 10.1).

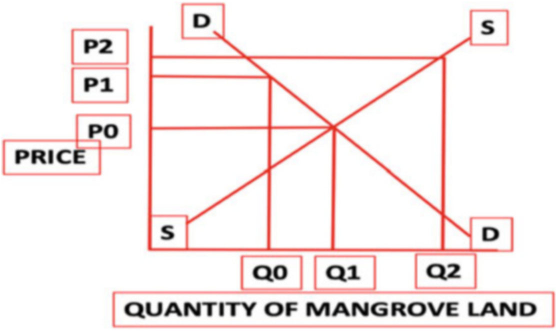


Fig. 10.1 Supply and demand for mangrove in the Niger Delta, Nigeria. Demand: at point P0–Q1 and P1–Q0, it is negatively sloping. Supply: at point P0–Q1 and P2–Q2, it is positively sloping

Government policy and culture can also influence mangrove land acquisition. Government can come up with a policy to protect the mangroves by enacting laws that will require adequate environmental impact assessment (EIA) before the execution of any project. The law will also allow for compensation of landowners to help them fund the diversification of their livelihood system. Land can be physical or economic. Physical land covers the earth crust such as land surface, subsurface, underneath water, and super surface, i.e., weather, but most times humans are interested in the economic aspect of land (i.e., income); that is why mangrove forest is cut and sand filled to erect building or sold for financial gain. The demand for land can be direct or indirect. It is direct if the land is acquired for building houses, which is mostly observed when mangrove forests are cut down. It can also be used directly for recreational purposes such as beach resort or playground. Land can also be acquired indirectly for the sake of what it can produce such as agriculture, e.g., rice farming, fishpond, etc. There is a rising demand for land; therefore, land utilization is dependent on land availability, which is a necessary factor of food, feed, and wood production globally (Kampman et al. 2008).

10.2.4 Types of Land Classification

10.2.4.1 Physical Land Classification

Land classification is based on the natural attributes of the land, for instance, land can be rocky, clayey, or humus. Other factors considered in classifying land include topography, type of vegetation, soil characteristics, chemical or physical properties, and rainfall. Thus, multivariate techniques are best used to classify land into map units (Rowe and Sheard 1981). Topography is essential for human movement such as in road transportation, whereas vegetation is essential for type of agricultural practice and grazing activities that is possible on the land.

Mangrove forest areas are not good site for vehicular transportation; rather, it can be traversed by foot because of the jungle nature of the environment. There is also serious damage that will be inflicted on the biodiversity of the mangrove forest. Swampy soil will be a nightmare for any vehicular movement. However, mangrove forest being one of the most productive systems in the world is ideal for agricultural activities, which supports livelihood system for local people. Mangrove forest is used for rice (*Oryza sativa*) farming and aquaculture in many parts of the world, which supports the local economy. In the Niger Delta area in Nigeria, rice farming is not too popular, which has one of the largest mangrove forests in Africa. However, rice farming through irrigation is more prominent in the northern savanna area of Nigeria. Rice cannot be cultivated in the Niger Delta because of the high saline and ammonium contents of the soil. However, this area can be explored by local farmers after some soil conditioning had been done such as desalinization to recover the land for agriculture via agro-silvicultural projects to feed the large population of people in this region. It can lead to the employment of the large army of jobless youths in the area (Ayinla 2004).

10.2.4.2 Use Classification

It has to do with how land is used to satisfy human needs. This aspect is significant in modern day because of the misuse of land for the sake of supporting all kinds of livelihood system. Three areas of use classification include (i) current or present use, (b) land use capabilities, and (c) recommended use.

(i) Current or present use: it has to do with the immediate use of land, whereas recommended use is what the land is recommended for based on its attributes and capabilities. However, use classification is focused on the following:

(1) Market accessibility
(2) Size distribution and composition of the population
(3) Location of infrastructure, e.g., road, power lines, factories, schools, and hospitals
(4) Type of properties in the area
(5) Types of ownership of properties

10.2.5 Land Conversion and Its Effects

Land is the foremost natural earth resource because it can be used to produce one's satisfying goods and services through agriculture, industry, commerce, and urban renewal projects. However, due to urbanization and oil and gas exploration, land that is usually available for agricultural purposes had been usurped (Van Suu 2009a). Most rural areas depend solely on farming and fishing as their sources of livelihood, but urbanization due to population explosion and technological advancement have made both the private and government authorities to encroach into rural areas, most especially coastal communities, to set up new housing projects and industrial estate (Meena et al. 2020a, b, c). These activities suck up the land originally used for agriculture and drain river used for fishing through dredging and reclamation. Eventually, losses in economic power of the rural dwellers precipitate agitations by community members which snowball into social upheavals that destabilize the community. To solve this problem of increased communal strife, the youths need to be meaningfully engaged through aggressive agrarian activities that will bring back their livelihood opportunities so as to put food on their table (Aiyedogbon and Ohwofasa 2011).

Coastal areas dominated by intense human activities can be restored to their original form by freeing up some spaces through planned removal of man-made structures, which occupy coastal lands to enable the land to be reused for agriculture. Similarly, dredged rivers can be opened up through canalization to enable rivers to flow and to allow fishing activities to begin. These are long-term projects that require adequate planning and execution aimed at restoring the lost livelihood opportunities of rural dwellers. The extension of city limits into rural areas had wiped out a lot of natural land used for agriculture and hunting and river used for fishing; however, planned land restoration can create safe corridors for wild animals that migrate from one part of the forest to another that had been fragmented by road construction work (Banerjee et al. 2018; Jhariya et al. 2018a, b). This can create employment for rangers and park guards that will help protect the forest against further encroachment by hunters and poachers. In order to integrate locals into protecting the forest, specific areas can be carved out for farming such as subsistence agriculture and places of tourist attraction to generate revenue. Urbanization is advantageous because it modernizes the city and increases wealth through provision of numerous small-scale to large-scale jobs. It also provides modern facilities that make life more comfortable and prolong life span through the setting up of twenty-first-century hospital facilities to cater for the sick. Nevertheless, this advantage can be overshadowed if the lives of the people are cut short through reckless environmental practices that result in pollution of air, land, and sea. For instance, connecting roads to rural areas can open up the hinterland to rapid development, but on the flip side, it can accelerate the plundering of natural resources through forest destruction and bastardization of fertile agricultural land. Deliberate attempt can be made to protect nature by creating conservation zones that harbor seriously endangered and rare species. There are limited uses of forest products such as firewood from mangrove stem (Numbere 2020a) and game animals for subsistence and commercial purposes. This will help reduce land degradation and create opportunity for farmers to feed their families through crop farming or animal husbandry.

Coastal areas can be protected from dredging and sand filling if overhead bridges are constructed across rivers to connect rural towns. This is because sand filling of rivers is a major environmental threat that had eliminated small rivers and creeks in the Niger Delta. Conversion of aquatic to terrestrial environment automatically takes away the livelihood opportunity of fishing and also destroys rare pelagic and benthic species within the water. Most rural dwellers are faced with double problem when their land is used to build infrastructure and their rivers are dredged. Nevertheless, pollution of the land and water by industrial effluents takes away fishing and farming activities, which are two key professions of the people. Besides loss of income, ripple effect of converting areas to land causes rising water level and seasonal flooding during the rainy season. Flooding submerges the available land for farming. Rural dwellers are then faced with loss of food, income, and accommodation (Week and Wizor 2020).

Table 10.1 Activities that cause loss of livelihood opportunities and impact on income in the Niger Delta

Activities	Lost opportunities	Effect	Impact
Deforestation	Wild life/game keeping/ hunting	Elimination of rabbit, bush rat, etc.	Subsistence and income loss
Deforestation	Boat making	Loss of tourist attraction	Income
Deforestation	Research	Loss of research opportunities	Income
Tree loss	Basket and raffia palm weaving	Elimination of trees and plants	Income
Tree loss	Logging	Job losses	Income
Tree loss	Boat making/trawling	Elimination of tree	Subsistence and income loss
Tree and animal loss	Herbal medicine	Plant and animal species loss	Income
Tree loss	Dyeing	Local craft	Income
River dredging	Shell fishing	Fishery loss	Subsistence and income loss
Industrial operation	Communal festival: wrestling matches, boat regatta	Job losses and loss of tourist attraction	Income
Industrial operation	Communal life	Lack of unity, communal strife, e.g., wars	Subsistence and income loss, loss of homes

10.2.6 Oil and Gas Exploration

Oil and gas exploration activities dot almost every community in the Niger Delta because of its rich supply of crude oil, which had attracted industrialist and giant oil companies, who are involved in exploration. Coastal areas are rich in crude oil resource because of the high sedimentation which facilitates decomposition of plant and animal matter to form peat from where crude oil originates. In the Niger Delta, crude oil exploration rights are owned by government and private investors without members of the community playing any major role. The presence of crude oil within a community is a blessing, but poor social responsibility and environmental recklessness of the industries had made it seem to be a curse. Lands in many communities had become wasteland because of years of dumping of toxic effluents from industries. This has totally eliminated farming activities because of years of pollution from toxic substances, which are harmful to the people. Similarly, rivers too are polluted due to oil spillages, which result in the death of fishes and other aquatic organisms. Oil exploration had also generated communal conflict where community members protest against the companies who often operate in these communities without adequate compensation or provision of infrastructural development (Ukiwo et al. 2011). Exploratory activities in the past 50 years had resulted in the loss of livelihood opportunities that are listed below (Table 10.1).

Oil wars had led to the proliferation of various cult and militant groups wreaking havoc in the communities, which had further eliminated the basic source of livelihood. The creation of territories by these groups prevents the people from freely going to their farms or fishing because of harassment by members of these gangs leading to starvation and increase in poverty level.

10.3 Theoretical Basis of Land Use

There are two models to be considered in this chapter; they are Alfred Webber and Von Thunen models:

10.3.1 Alfred Webber Model

It propagates the spreading out of cities (e.g., Fink 1993) towards areas of resource availability and labor. The main assumptions of this theory are:

(1) Fixed source of raw materials – Industries are found where they have their resource base. This is the reason why many oil industries are found in coastal regions of the Niger Delta, which has rich supply of crude oil resources. Oil industries have their field bases such as offshore and onshore platforms situated in the Niger Delta. They build bases directly where their oil wells are sited.
(2) Fixed labor centers and points of consumption – Many oil companies have their field bases in rural setting to enable them to hire unskilled labor. In addition, transportation of raw materials via the river does occur easily in coastal areas to consumers of the product abroad.
(3) Uniformity of culture, transport, political, and economic system – In rural areas where livelihood system is farming and fishing, industrial job is a big wealth creator. The companies exploit the people by dangling cash and jobs for some members of the community. The cost of this exploitation is poor infrastructural development in the community. Uniformity of culture reduces rancor among the people especially where there is one natural community head. This is because communal dispute affects industrial activities and leads to job losses.

Factors that determine the establishment of industries in a given location include:
(i) Transport cost.
(ii) Labor cost.
(iii) Agglomerative or deglomerative force.
(iv) Raw materials and power.
(v) Availability of flat and extensive land and proximity of river for sea transport of raw materials.
(vi) Availability of skilled and unskilled labor force.
(vii) Market, i.e., location of plant at the point of consumption where the threshold population exist and purchasing power is very high. This is usually in

urban areas. The need for more consumers is a key driver for urbanization of rural settlements to bring in the well-paid people into the cities.

(viii) Cost of transportation which determines the location of industry.

(ix) Agglomeration, linkage, and external economies. Spatial concentration of industries benefits from urban industrial centers which have well-developed infrastructures, e.g., airports, utilities, research organizations, and universities.

10.3.2 Von Thunen's Model

This model analyzes the relationship between differences in spatial location and land utilization patterns (Hahvey 1996). This model highlights isolated state and village-type settlements but also proposes uniform climate and soils, uniform topography, and relatively uniform transportation facilities. Apart from difference in land use, other factors considered in this model include transportation ease and costs, nearness to market, and perishability of products sent to market. The model also considers land use pattern near the market, for instance, needed land that can be used to produce crops and livestock that are highly perishable or heavy to transport. This is because far distance takes more cost for transportation. In line with this theory, the concentric circles of land are used for the following functions:

First zone: garden and crops
Second zone: forest products
Third zone: field crops with intensive farming for potatoes, root crops, grain, and heavy and bulky crops
Fourth zone: cereal, fallow, and pasture
Fifth zone: used mainly for grazing purpose
Sixth zone: wilderness area, hunting zone (Fig. 10.2a)

Adjustment of Von Thunen's simple model can be modified through the following many assumptions:

(i) If navigable stream flows through water, transportation will change land utilization.
(ii) The zone will be an elongated pattern (Fig. 10.2b) and has area for forest production along a navigable stream from the city (Fig. 10.3c).
(iii) Introduction of improved transport route leads to star-shaped land utilization (Fig. 10.3d). Other factors that influence land utilization include fertility, topography, number of cities, markets, and settlement patterns.

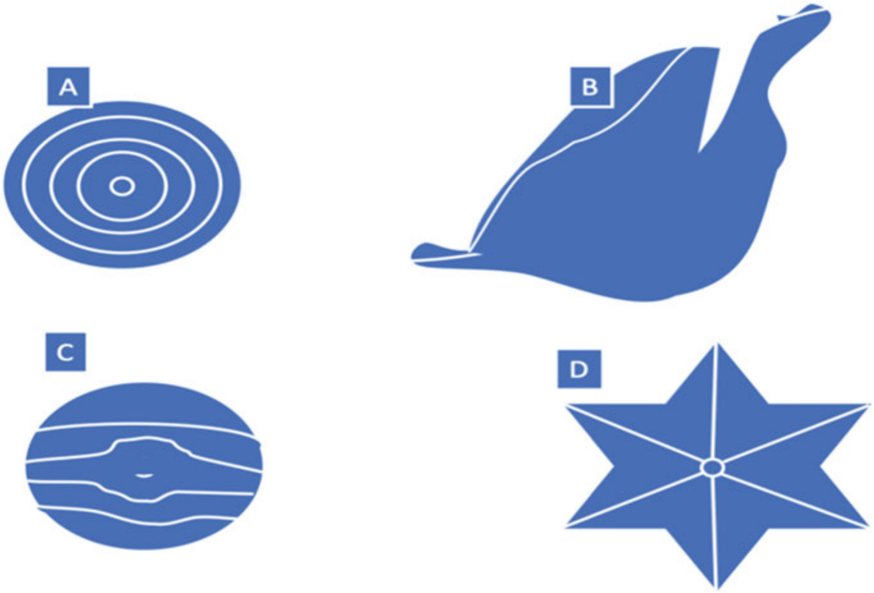


Fig. 10.2 Different land use systems under Von Thunen's Model, where **a** is wilderness area for hunting; **b** is elongated pattern used for forest production; **c** is a navigable stream from the city limits; and **d** is a star-shaped land utilization pattern, which has improved transportation network

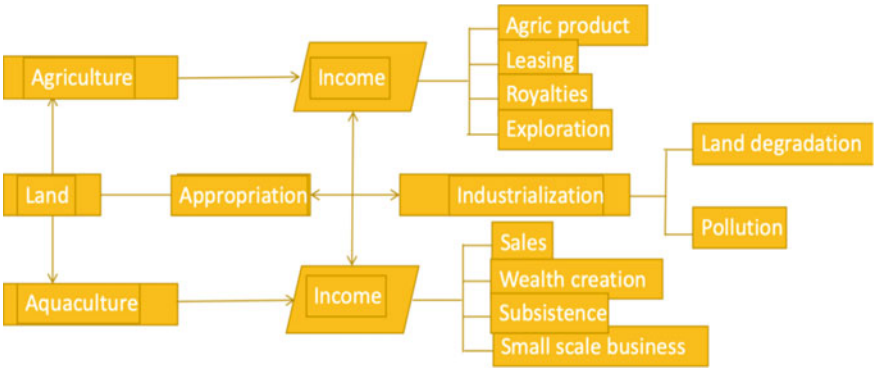


Fig. 10.3 The effect of land appropriation on income generation

10.4 Land Appropriation and Livelihood System

10.4.1 Land Appropriation

It means setting aside of a piece of land for personal or private property and to be used directly or indirectly. Land can be appropriated based on social structure and relationships such as nuclear or extended families and communities. Family land acquisition is based on known tradition where elders are given the authority to share land in line with seniority. This can be done through communication and consensus taking. A law-abiding society establishes link between individuals and groups and also between the habitats. Human communities are dominated by tacit competition for resource, and land being one of the major resources of nature is competed for by different interest groups within the hierarchical system in the society. It is a winner-takes-all policy where the fittest survives in line with Charles Darwin's theory of evolution. This means the strongest appropriates all the land to themselves or to their generations yet unborn. However, this is not always the case because humans have insatiable need; therefore, there needs to be a way of distributing natural resource so as to maintain sanity in the society. According to Maslow's Theory, humans have biological and social motivation that shape their needs such as physiological need, safety need, belongingness, self-esteem, and self-actualization. Since land resource is scarce, different cultures establish ways of distributing this resource in space and time. This is called human ecology. This is because biological motivation operates through ecology, while social motivation operates through social process of interaction (Sjaastad and Bromley 1997).

Livelihood system has to do with trade or business the people are engaged in that guarantees their survival. This can be farming, fishing, hunting, commerce, tourism, and manufacture of artifacts. It can also refer to securing the most basic necessities (e.g., food, water, shelter, and clothing) of life. Sustainable livelihood has to do with ownership of access to resources and their management within their capacity to recover; thus, land appropriation as a result of industrialization and urbanization takes away livelihood from rural dwellers (Van Suu 2009b). Resource in this context has to do with access to land. This is because land is the basis for achieving other forms of livelihood system such as agriculture that depends fully on landownership and is the basis of food production and other agro systems (de Vries 2001; Wirsenius et al. 2001).

Ownership of land translates into the funding of production via agriculture or can generate income through the sale of its product through large-scale farming. Land can also generate income through leasing out to farmers or investors who pay to own land for an accepted period of time. Therefore, the owner of vast plot of land is in principle wealthy because of the income that would be derived if the land is sold or leased (Fig. 10.3). Ownership of land that is rich in crude oil resource can lead to sustainable wealth that will last for future generations when such land is leased out to oil and gas companies and payment of royalties are made. Communal land appropriation by government for the purpose of setting up oil industry can lead to loss of livelihood system especially if such land is fertile for agricultural purpose (Li et al.

Table 10.2 Land distribution pattern and livelihood opportunities in upland and coastal communities of the Niger Delta (author's unpublished data)

Land use/distribution	Livelihood opportunities	Land cover in upland area (%)	Land cover in coastal area (%)
Industrial land	Manufacturing, processing	8	4
Agricultural land	Crop and animal farming	70	1
Developed land	Human habitation: houses	20	15
Unused land	Herbal medicine	10	20
Water bodies	Fishing, aquaculture	2	60

2011). Fallout from exploratory activities can pollute the land and damage its ability to be used for farming. Forceful acquisition of land by government or private companies is rampant in the Niger Delta and is the major cause of communal strife.

This is because once the land is acquired by government and given out to oil companies, the communities no longer have the right to that land which leads to loss of income and other benefits that accrue from ownership of land. Apart from the land loss, the operations of the company also lead to further degradation of the land for future agricultural use or other livelihood purposes. Livelihood opportunity can be lost when there are conflicts between companies and members of communities. An example is the expulsion of Shell Petroleum Company from Ogoni land in the Niger Delta in the 1990s due to over 20 years of exploration without infrastructural developments in the communities. Fingerprints of industrial operations in these poor communities have increased poverty, land spoilage, water pollution, and loss of means of livelihood. Although Shell had left Ogoni land for a long time, the abandoned land had remained in a state of comatose with no benefit to members of the community in terms of royalties paid from the lease of land to oil companies. Secondly, the land cannot be used for agricultural activities because of the extent of pollution from the oiling activities. Thirdly, there is a loss of job opportunities for members of the community for skilled and unskilled labor. Fourthly, there is also a loss of revenue to the local, state, and federal government. It will also lead to lost opportunities in contract by members of host communities as well as small business entrepreneurs that depend on the big industries for their supplies and sale of food and other items (Oetzel et al. 2009).

Land use in rural areas of the Niger Delta shows that the Niger Delta area can be split into upland and coastal communities (Twuamsi and Merem 2006). The upland area is mainly made up of land cover with fewer water bodies, while the coastal areas are mainly surrounded by rivers and streams. The distribution of land cover and water bodies dictates the kind of livelihood activities that go on in a given location. For instance, the livelihood opportunities in upland areas are agricultural activities such as farming and animal husbandry. In this area large percentage of the land is used for agriculture, while limited fishing is done if there are small streams or rivers (Table 10.2, Fig. 10.4). In coastal areas large percentage of the area is covered by

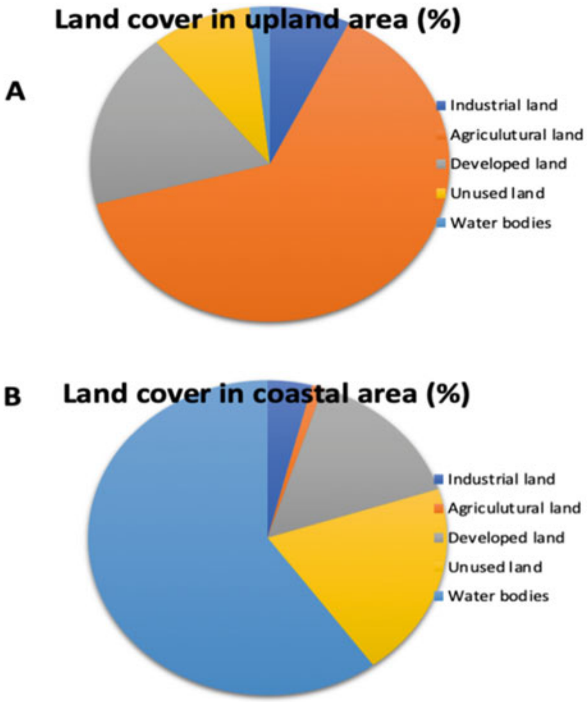


Fig. 10.4 Percent land distribution and utilization in upland and coastal areas of the Niger Delta

water bodies; therefore, the main occupation of the people is fishing and aquaculture. There is also firewood production from the rich mangrove forest found in the area.

10.4.2 Land as an Institution

An institution is a long established social structure which guides the behavior of humans in that environment or within which people act collectively. The ownership of property such as land is the most important institution which conditions land utilization. The availability of land doesn't create problem in the society; there is, however, a problem in the society when land becomes scarce. This situation leads to the establishment of institutions that will distribute the land equitably for the purpose of farming, building, or leasing. Land is a factor of production; that is why it is important to have economic land than physical land. For instance, the right to sell a land depends on the ownership. The ownership of the land can be private, industrial, or public such as local, state, and federal government. Communal land can be given out to indigenes for farming purpose, after which it is rotated between families. Utilization of land is temporary; however, the law of acquiescence states that a person who occupies a land for 10 years becomes the de facto owner of that land. This is the reason why land is often given out for short-term agricultural activities such as planting of crops that take some months to a year to mature and be harvested

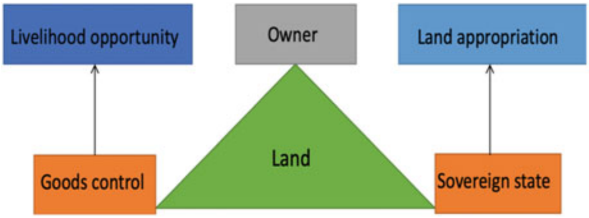


Fig. 10.5 Competing land uses by individuals and government through livelihood opportunities and land appropriation, respectively

(e.g., maize, cowpea, and cassava) rather than cash crops that take a long time to mature such as cocoa, rubber, and date palm. This provides livelihood opportunities for members of the community (Toa and Wall 2011).

10.4.3 Land as a Property

Property institution regulates between owner of property and others. Land as a property has the following characteristics:

1. Property has value: this is because it is a utility and can be used directly for the construction of houses, industries, and recreation centers. It can also be used indirectly to generate basic needs such as food, clothing, and shelter known as derived demand.
2. Human control: property cannot exist except when it is controlled by humans who apportion it accordingly for various uses.
3. Land is a resource: this is because it satisfies the three principles of a resource; therefore, it can become a property. These principles include the following: (i) it satisfies human need or want, which is called a good or service, (ii) property is capable of appropriation, and (iii) property is capable of being scarce or limited in service; otherwise, it would be a free good and service.

Property is the right to control, which means the right to use, lease, and dispose of an economic good and service subject to limitation established by laws and regulation of the community, village, county, or family. Land as property has three converging points, namely, owner, goods control, and sovereign state (Fig. 10.5).

It is the duty of the institution to protect ownership right. It is meant to protect individuals from freely utilizing the land for their livelihood and to guard against exploitation by private companies or government authorities (Ross et al. 2011).

10.4.3.1 Types of Property

There are two types of properties based on classes of ownership; they are (1) property subjects and (2) property objects.

(1) Property subjects: owners of property are private, public, and group. Groups include family, institution, marriage, and religions. However, qualified property

subject includes nongovernmental organizations (NGOs), government, or private organizations.

(2) Property objects: under this we have real estate or realty, personal property, and relative mobility.

Land property is an asset, which when sold generates money. Therefore, those who control land have authority over its use and sale. Its sale can generate greater income, which can be diverted to other investments that would be beneficial to the landowner (Bromley 1997).

10.4.4 Characteristics of Land

Land has four characteristics; they include:

(1) Originality or non-reproducibility: land anywhere is always unique because it cannot be counterfeited. Land takes thousands and millions of years to form and when formed remains original despite human adverse impact.
(2) Indestructibility or permanence: land cannot be completely destroyed, but degraded (Scherr and Yadav 1996); therefore, it has a permanence value which means it can only be transferred from person to person. It is physical and is fixed, but economic land is not fixed. Land permanence confers the following qualities: (i) ultimogeniture, inherited by first sons; (ii) primogeniture, inherited by last sons; (iii) inheritance, transferring ownership of land to children and forebears; (iv) deed restrictions, supposedly done to bind future users of the land. It specifies ownership for a number of years and cannot be sold. The part of the land owned varies from one country to another. For example, we have (i) surface land; (ii) subsurface land, i.e., minerals and other resources below; and (iii) super surface land, i.e., air and space above one's surface holding.
(3) Immobility: land cannot be moved from one place to another, so when damaged can only be remediated in situ to improve its quality. For instance, mangrove forest can be removed from coastal terrain.
(4) Wide variability in quality: different lands have different qualities depending on the use value. For instance, land in a coastal plain, as is the case in many Niger Delta communities, is fertile and can be used for agricultural purpose. Next, the site of the land determines its quality, which is dependent on the position of the land. Therefore, a land that is well located attracts high value in terms of purchase. The presence of access road also improves the quality and the value of the land because it can easily be used for developmental projects such as urban renewal and industrial projects (Numbere 2020b).

Table 10.3 Impact of anthropogenic activities on livelihood opportunities in aquatic and terrestrial area in the Niger Delta

Livelihood opportunities	Environmental context	Impact type[a]	Category[b]
Fishing	Aquatic	H	I
Farming	Terrestrial	H	I
Wildlife	Terrestrial	H	I
Hunting	Terrestrial	H	I
Game keeping	Terrestrial	H	I
Entrepreneurship	Terrestrial	L	G
Manufacture	Terrestrial	L	G
Industrial jobs	Terrestrial	M	I
Artisanal refinery	Terrestrial, aquatic	L	G
Labor	Terrestrial	L	I
Leasing	Terrestrial	L	I
Local craft	Terrestrial	L	I
Weaving	Terrestrial	L	I
Tourism	Terrestrial, aquatic	H	G
Research opportunities	Terrestrial, aquatic	H	I, G
Logging-firewood	Terrestrial	H	I
Sculpturing	Terrestrial	H	I
Pottery	Terrestrial	L	I
Furniture making	Terrestrial	H	G
Marine transport	Aquatic	M	G
Dyeing	Terrestrial	M	I
Brick making	Terrestrial	L	I
Salt making	Aquatic	L	I
Boat making	Terrestrial	H	G

[a]Impact type: H = high, M = medium, L = low
[b]Category: G = group, I = individual

10.5 Livelihood Opportunities in the Niger Delta: Impact of Urbanization and Crude Oil Exploration

10.5.1 Impact of Urbanization and Crude Oil Exploration

To understand the extent and impact of urbanization and crude oil exploration, two aspects of the environment would be considered, namely, terrestrial and aquatic. The terrestrial hosts livelihood activities that occur on land, while the aquatic hosts livelihood activities that do take place in water (Table 10.3). In addition, there are some activities that occur in the interface between the land and the sea such as mangrove areas. Some livelihood activities that occur on land or water are discussed below:

(1) Fishing: this activity occurs in the aquatic environment such as rivers and seas and is affected by both urbanization and crude oil exploration. To create urban areas, rivers are dredged and large amount of mangrove forests are cleared to make way (ROW) for the establishment of developmental projects. Dredging activity eliminates both pelagic and benthic organisms in the river. Spillages from offshore or onshore exploration site pollute the water and lead to fish kills, which impact the fishing industry leading to loss of income and revenue. Anthropogenic activities affect both the fin- and shellfish industry. Fisherfolk cannot fish because the river is polluted; even when they fish, the fish caught would not be healthy to consume because of contamination by crude oil. There would also be a drop in fish population because the oil spill will cause mutation and deformities that would affect the reproductive ability of the fish leading to population decline.
(2) Farming: all agricultural activities such as cropping and animal husbandry occur on land and take care of the feeding need of the people. Farming also generates income for the local people. However, the land will become useless and incapable of supporting agricultural crops if it is polluted as a result of onshore oil and gas exploration activities, which emit toxic waste and crude oil products on the land. The impact on animal husbandry is the limitation of land for rearing animals due to contamination of grasses used to feed animals such as goats and cow.
(3) Hunting: deforestation eliminates forest cover that serves as habitat for wildlife; therefore, the removal of forest leads to a decline in the population of wild animals that are hunted by the locals for food. The forest also serves as site for collecting medicinal herb products; therefore, the cutting down of forest to create urban centers and for oil exploration purpose eliminates some rare plant and animal species that can be used to cure some diseases and/or serve as food, respectively.
(4) Entrepreneurship: the elimination of forest takes away business opportunities for those locals that trade on forest products such as bush animals that are a stable food for many. It also causes trade losses in forest products such as herbs and local crafts, e.g., basket and hats. There are also losses of jobs for some native profession such as weaving, dyeing, and herbal medicine manufacture.
(5) Tourism: in many communities tourism generates revenue for the natives and the local authority, so removal of the forest because of exploration and urbanization makes the forest bare and drives away wild animals that migrate elsewhere. The destruction of the forest also takes away jobs from forest guards and guides who earn income by performing these services to visitors.
(6) Research opportunities: the Niger Delta mangrove forest is a natural research laboratory because of the numerous rare species that are found within the forest ranging from microbes, invertebrates to vertebrates. Destruction of the forest eliminates these species some of which have not been identified or classified. Destruction of the forest also takes away the research opportunities for young scientists who are curious to study rare species and willing to carry out natural experiments so as to answer some research questions. Also affected are

community members who loss royalties and incomes in maintaining and protecting field research sites and also acting as guides for scientists.

(7) Logging and firewood manufacture: firewood production from mature red mangrove (*Rhizophora* spp.) trees is a million dollar business that is thriving in the Niger Delta. It is the most common trade embarked upon by the locals apart from fishing and farming activities. Firewood is the main source of cooking energy and is used by almost every household in the rural and urban areas (Numbere 2020a). About 90% of rural dwellers use firewood for cooking, while 50% in urban areas use firewood as a second option for cooking. Therefore, the destruction of the forest as a result of anthropogenic activities eliminates this source of livelihood and plunges the people into deeper poverty, which may have a ripple effect in the society through increase in crimes by jobless youths.

(8) Furniture making: destruction of mangrove and rainforest eliminates trees from where different species of wood for furniture are produced. This takes away raw materials and job opportunities for local furniture and craft makers. Reduction of raw materials for furniture making leads to buying from other places, which drastically increases the production cost and thus the price of local crafts.

(9) Marine transportation: dredging of rivers to construct bridges or platform for building temporary offshore exploration sites constrict the coast lines, which reduces marine transport activities and causes boat mishaps. It also takes away livelihood opportunities from boat operators who lose their jobs because of the elimination of their sea route as a result of dredging. The reduction in the depth and width of the river prevents large ocean-going ship from accessing and berthing at the wharf of the communities' waters, leading to loss of job and business opportunities. Some opportunities lost include skilled and unskilled labor, small-scale trading, and supplying of goods and services and security.

(10) Dyeing: dyes are derived from red mangroves which are used to color fabrics and fishing nets. This product is lost when the forest is eliminated as a result of urban expansion or oiling activities.

(11) Local crafts: this includes the manufacture of thatch roof, basket, and mat from mangrove, nipa palm, and raffia palm parts. Therefore, the elimination of mangrove and other forest species takes away the raw materials used for the manufacture of these products. This can lead to job losses when production cost is more than income generated.

(12) Boat making: log of wood derived from mangrove and rainforest is carved into small and large canoes. This provides job opportunities for local craft makers skilled in the art of boat making. It also generates income through the sale of the finished boat, which is used for transportation business (Numbere 2018b).

10.5.2 Impact on Agriculture

Crude oil exploration impacts agricultural activities by appropriating land that is to be used for farming (Obayelu 2013; Elum et al. 2016). Even when the land is available in most cases, the soil is polluted, which makes it impossible for farmers to use. In the Niger Delta, exploratory companies buy up, fence, and gate large acre of land and prevent access by members of the host communities. Offices and residential quarters are built on the acquired land for the company staff. Despite the development of the land, large areas are still left without having any visible structure; it is thus used for landscaping where flowers and ornamental trees are planted. Other areas the size of hundreds of football fields are left untouched and overgrown by bushes, which is a loss to agriculture. Many villages have land scarcity because of this land appropriation action by industries and the government. Only small fractions of the communal land are left for agriculture, which is not adequate for large-scale farming. It is also observed that large expanses of land in rural areas are occupied by crude oil pipelines. People are prohibited from farming 10 m away from the pipeline right of way. The pipelines occupy large areas of the communal land because they cover hundreds of kilometers from the oil wells to the refinery and from the refinery to point of evacuation by ships. Because of the health and safety hazard inherent along the pipeline route, many farmers are discouraged from farming far away from the pipelines. This is because the pipelines usually have periodic spillages which pollute adjoining land and water destroying its fertility or capability for being used for agricultural purposes (Onyena and Sam 2020).

Urbanization, on the other hand, also affects agricultural activities when city expansion and urban sprawl encroach into land spaces that are to be used for farming. Conversion of rural to urban areas involves a lot of projects such as road and bridge constructions which take up a lot of land spaces. The opening up of virgin forests by land developers introduces other problems for rural dwellers such as criminal activities that threaten the people from going to their farms or increases pollution from vehicle exhaust and soot that settle on soils and crops. Road construction also fragments the land into smaller bits which affects large-scale agriculture. It also creates numerous edges that facilitate the entry of invasive species and parasitic organisms that destroy agricultural crops. Urbanization brings in wealthy land investors who come in to buy up large amount of land from poor rural dwellers. For instance, wealthy investors build fun centers, seaside resorts, and estates close to coastal areas to promote the use of the sea for beach parties and fun boat rides. Construction of industries and business centers right in the middle or outskirts of rural communities is too tempting for local inhabitants who abandon farming activities to seek for jobs in such areas that they feel will pay them more (Ofuoku and Chukwuji 2007).

10.5.3 Impacts on Public Health and Safety

Crude oil exploration impacts both public health and safety in the following ways.

10.5.3.1 Public Health

Crude oil exploration releases noxious gas into the atmosphere, which impairs the respiratory functions of humans, animals, and plants (Lippmann and Leikauf 2020). It can also lead to industrially related diseases, which include the following:

1. **Infectious diseases**: these are diseases that spread from one person to another, known as contagious diseases. They are mainly caused by bacteria, viruses, rickettsiae, mycoplasmas, and parasitic organisms, e.g., amoeba and roundworms. In a crowded industrial environment, workers can infect one another who in turn will affect members of their household. This continues the cycle of infection leading to loss of livelihood opportunities. Viral infection spread diseases such as measles, chicken pox, poliomyelitis, common cold, and coronavirus (covid-19). The later infection has become a global pandemic with millions of people infected across the world leading to job losses, increased sick leave, shutdowns, and deaths. Diseases can be caused by parasitic organisms such as plasmodium from anopheles mosquitoes or zoonotic organisms which are infected by insects found in forests where exploration activities occur. Diseases transmitted by vectors include malaria, yellow fever, typhus, bubonic plaque, leishmaniasis and schistosomiasis, and coronavirus. Diseases that are transmitted by contact with an infected animal or its excretory product include brucellosis, tularemia, and psittacosis. Apart from infestation by contact, the consumption of animal products caught in the forest while carrying out exploration can lead to salmonella and tapeworm infection. Workers in the hospital section of industries are also not spared from infection because they can contract these diseases from infected patients or workers. Company workers can get infected with cholera during construction work in the forest when they drink contaminated water from contaminated well or borehole. Schistosomiasis can also be spread to site workers and members of the host community when they consume infected snails picked up from site of a dredging project. The key host of this parasite is the *Bulinus* snail found in aquatic environment.
2. **Immunological diseases**: this has to do with the natural reaction of the body to foreign objects or protein leading to immune response. Under this we have the following diseases:
   (i) Respiratory diseases – it is caused by exposure to dusts of grains, husks, coconut fibers, tea, tobacco, cotton, hay, and wood in industries and can lead to diseases such as byssinosis, bagassosis, farmer's lungs, asthma, and hay fever.
   (ii) Dermatosis – it is caused by hypersensitivity to certain industrial products resulting in contact dermatitis and eczema.
   (iii) Industrial cancer – it occurs in the form of neoplasm or tumor, which is the uncontrolled growth of abnormal tissue at the expense of normal tissue. They are either benign or malignant. Industrial cancers are caused by carcinoma which is fallout of smoke and other harmful industrial products which affects the worker or members of the host community when inhaled. Some of the diseases here include cancer of the lungs, heart, and kidney.

Others include silicosis and siderosis. Cancer is also caused by radiation from industrial machines, e.g., x-ray welding equipment.

3. **Congenital and metabolic diseases:** in the nucleus of every human cell, there are 23 pairs of chromosomes each consisting of DNA (deoxyribonucleic acid). They contain hereditary material of the cell. Defects are caused by alteration of the chromosome due to some harmful industrial operations. Sickness or death resulting from these diseases can greatly impact livelihood system of members of the host community as well as industrial workers.
   - (i) Diseases of growth and development: this mainly affects the unborn through the pregnant mother. Deformed and abnormal children are born due to the working habit of their parents, which changes the chromosome content. Diseases here are caused by:
     Gases: examples include carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), etc. Exhaust from industrial stack and heavy-duty machinery, e.g., bulldozers used for clearing forest pollute the air and water. Decomposing industrial waste and agrochemical can also vaporize into the atmosphere leading to air pollution.
   - (ii) Dust or inorganic dusts: this includes coal dust, silica, asbestos, iron, and black soot. They can cause anthracosis, silicosis, asbestosis, and siderosis. Other chemical agents include organic dust, metals, chemicals, and solvents.
   - (iii) Diseases due to physical agents: physical agents such as light, pressure, and radiation cause occupational cataract, miner's nystagmus, Caisson disease, leukemia, and aplastic anemia. These diseases are prevalent in industries that use nuclear plant for generation of power. Leakage or accidental discharges of radioactive material can lead to instant death or diseases.
   - (iv) Endocrine diseases: this is the industrial processes that affect the pituitary and thyroid gland. This leads to a disease condition called hyperthyroidism, which is the overproduction of thyroid hormones resulting in the enlargement of the gland.
   - (v) Circulatory diseases: this has to do with the diseases of the heart and blood vessels. It is mainly caused by industrial pollution. Examples include arteriosclerosis, heart disease, cerebrovascular accident (stroke), and hypertensive heart disease.
   - (vi) Mental disorders: stressful work environment caused by pollution is toxic to the body, and noise, infection, drugs, poisons, and hereditary deficiency syndromes can lead to psychotic disorders such as manic depression, psychosis, schizophrenia, and paranoia. These conditions can lead to job losses and result in loss of livelihood opportunities.

10.5.3.2 Safety Impacts

Safety is the process of being safe, and it is a key issue in developmental projects such as urbanization and industrialization (e.g., oil and gas exploration). Oil and gas exploration involves the prospecting for crude oil in the earth crust. It has pre-exploratory, exploratory, and post-exploratory stages (Numbere 2018a). At the

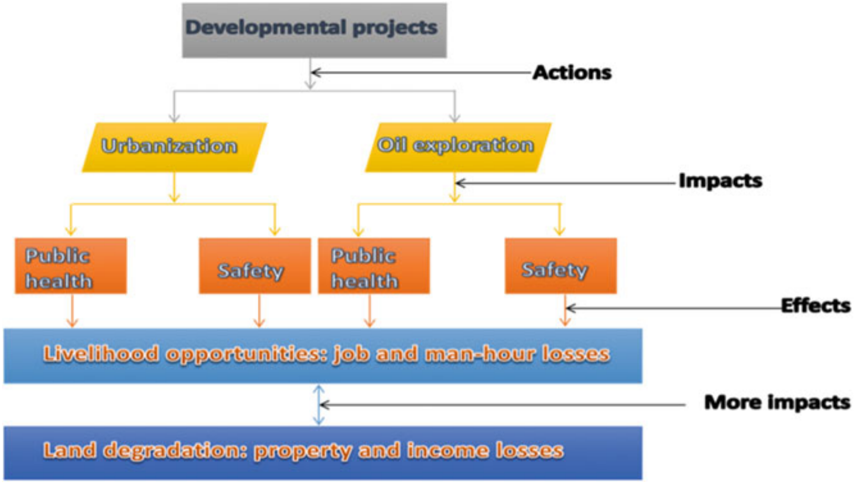


Fig. 10.6 Effects of developmental projects on safety and health and their impact on land and livelihood opportunities

pre-exploratory stage, the forest is cleared for the seismic party to gain access into the forest to establish explosion site for the blaster men and booth camps for the workers. This can lead to a lot of safety issues such as injuries and death. For instance, the felling of trees can cause severe injury or death when they fall. In addition, pollution from construction equipment such as bulldozers can cause health and safety issues. Workers can also be attacked by wild animals or stung by venomous organisms such as snakes and scorpions, which can lead to hospitalizations or instant death.

The exploration phase involves the blasting of dynamite to locate oil wells via seismic readings. This activity is dangerous because there can be mishaps such as fire leading to severe injury or death. Once crude oil is discovered, an oil rig is set up to tap the oil at offshore or onshore locations. A rig is the equipment needed for prospecting oil or gas. The drilling machine is a motor drive device fitted with a rotary cutting tool that bores hole inside the ground. The two types of rigs are offshore and onshore oil rig. Offshore oil rig is situated in the ocean where drilling is done by a rotary rig supported by a derrick. When an oil well reaches an oil-bearing layer, crude oil and gas blast up into the air under high pressure and pollute the environment. In the course of drilling, fixed platforms are set up with permanent structures to accommodate drilling crew personnel. Safety implications of this setup include:

1. Oil spillage, which contaminates the water and kills fishes
2. Explosions on the platform leading to injuries and death of workers
3. Boat mishaps
4. Rig fire

Table 10.4 Safety issues and their impacts on livelihood opportunities in the Niger Delta

Safety issues	Group affected	Type of impact	Livelihood opportunities
Crude oil spillage (offshore)	Personnel and natives	Fish kills, water contamination, marine transportation	Marine transporters, fishermen
Crude oil spillage (onshore)	Personnel and natives	Land pollution, death of crops	Farmers
Deforestation	Personnel and natives	Biodiversity loss, habitat loss	Hunters, local craft, herbalist traditionalist
Explosions (methane)	Personnel and natives	Injury and death, loss of job, loss of man-hour	Industrial work
Rig fire	Personnel	Property loss, injury and death, loss of job, loss of man-hour	Industrial work
Burns	Personnel	Injury and death, loss of job, loss of man-hour	Industrial work
Noxious fumes	Personnel and natives	Injury and death, loss of job, loss of man-hour	Industrial work, farmers and fisherfolk
Falls	Personnel	Injury and death, loss of job, loss of man-hour	Industrial work

Onshore oil rig is the form of oil or gas exploration that is done on land. Oil-bearing rocks are identified by aerial photography, examination of surface rocks, core drilling, and mapping of the earth’s rock layers. All these activities have their associated safety and health risk. There are some safety issues that affect company workers and members of the host community that seriously impact their livelihood opportunities (Fig. 10.6, Table 10.4) (Omorodion 2004).

Some heavy metals detrimental to health that are released into the environment as a result of oil and gas exploration include aluminum, arsenic, cadmium, lead, mercury, and cyanide. These metals have teratogenic and carcinogenic effect when the concentration released into the environment is above the threshold limit values (TLV) in food or water. Different kinds of occupational hazard may occur in an industrial environment ranging from minor to major accidents (Montana 2014).

Minor accident – this is a type of accident which occurs when there are no deaths, no serious damage, and no serious injuries recorded, for example, collisions of construction vehicles, burns from handling hot industrial machines, falls from rig tops or high platform, and sprains resulting from improper lifting of heavy load (Calvin and Joseph 2006).

Severe accident – in this type of accident, many people die and some are seriously wounded or injured leading to a very serious destruction to properties and equipment (Khan and Abbasi 1999). Examples are major collisions involving highly accelerating vehicles, collapse of a storey building in an industrial complex, fire outbreak in an oil rig resulting in several deaths and destruction, and release of radioactive material in nuclear plant due to accidental discharge and meltdown. Explosion of methane gas in gas-producing industry results in the loss of lives and properties. Similarly, electrocution does occur from the use of industrial machines and high tension wires during construction work; boat mishap involving collision of two boats conveying working crew results in the drowning of some occupants and the loss of properties. Industrially related accidents during oil and gas exploration and urbanization projects are bad for livelihood opportunity because of two major effects (Egbebulem et al. 2013) namely:

Loss of man-hour: this is because accidents lead to death and incapacitation of workers, which impede industrial activity and hence productivity. Incessant accidents in industrial sites will scare away workers and investors because of the great liability involved in working. This will ultimately lead to loss of job opportunity and reduction in productivity.

Loss of revenue: injuries and deaths lead to loss of revenue in paying for compensation and hospital bills for the injured worker. In addition, deaths lead to loss of manpower, which results in problem of replacement for knowledgeable or experienced persons for the particular job description.

10.5.4 Impact of Radiation Hazard in Exploration Work Environment

Radiation is the transmission of energy by electromagnetic waves through a substance or vacuum with the speed of light (3×10^8 ms^{-1}) and in a straight path and causes numerous health effects among which is cancer risk (Journy et al. 2017). Radioactive substances represent an increasing hazard in workplace due to technological advancement such as industrialization and urbanization, for instance, the Chernobyl disaster (Beresford et al. 2020). To assess the impact of radiation and its effect on livelihood opportunities, it would necessary to look at it in short and long terms.

1. **Short-term effect**: this has to do with an immediate and short-term exposure to radioactive substances. Example of this effect is present in an area where there is nuclear power generation. These include:
   (i) Instant death – high doses of radiation from radioactive material (e.g., uranium) lead to suffocation and death.
   (ii) Risk of cancer – denaturation of body protein by radiation can increase the chances of developing cancer-causing agent called carcinoma.
   (iii) Property damage – radioactive release from nuclear station leads to the contamination of an area equivalent to an area of circle with 30 mile radius. This will lead to the relocation of residents who will forfeit their farmland and forest, which serve as their source of livelihood.
   (iv) Skin dermatitis and injuries – radiation causes skin burns and diseases.
2. **Long-term effect:** this impact refers to the type of radiation that has a long-lasting incubation period in man. There is cumulative degeneration of health after a long period of time. Examples of this type of radiation include the following:
   (i) Genetic disease – long-term exposure to radiation material can change the gene configuration, which would lead to genetic disease in later generations.

(ii) Mutation – this is the alteration in the number of chromosome of man due to radiation. It causes a change in the structure of the DNA, which causes hereditary defects in offspring.

(iii) Greenhouse effect – ultraviolet radiation from the sun get trapped in accumulated carbon dioxide and other atmospheric pollutants released by industries to increase the global temperature and heat the earth leading to biodiversity migration and loss, which in the long run affect fish population and agricultural products leading to loss of livelihood opportunities.

10.5.5 Security Threat

This is another safety issue in the oil- and gas-producing communities especially when there is a misunderstanding between the oil companies and their host communities. Civil disturbances in communities can affect industrial operation and livelihood opportunities. This is because if crisis erupts as a result of disagreement between the company and youths concerning employment, the entire economic activity will come to a halt leading to loss of income and revenue (Watts 2008).

10.6 Footprints in Niger Delta Mangrove Ecosystem in Relation to Land Use and Livelihood Management

The concept of ecological footprint was developed in the 1990s by environmentalists Mathis Wackernagel and William Rees. It expresses environmental impact in terms of cumulative area of biologically productive land and water required to provide the resources a person or population consumes and to dispose of or recycle the waste the person or population produces (Wackernagel and Rees 1996). It means the total area of earth's biological productive surface that a given person or population "uses" once all direct and indirect impacts are totaled up. Globally, mangrove loss is

Table 10.5 Global loss of mangroves in different regions (adjusted from IUCN 2018)

Region	Loss km^2
Australia and New Zealand	370
East and Southern Africa	424
East Asia	12
North and Central America and the Caribbean	2196
Pacific Islands	146
South America	1106
South Asia	435
Southeast Asia	3308
The Middle East	19
West and Central Africa	422
Total km^2	8, 437

Table 10.6 Mangrove landscape loss from 1984 to 2007 in the Niger Delta, Nigeria (Wang et al. 2016)

Land cover	Area (km^2)	Proportion (%)
Mangrove	1444.7	42.0
Low-density mangrove	572.4	16.6
High-density mangrove	872.3	25.4
Water	974.5	28.3
Swamp	356.7	10.4
Mixed forest	304.5	8.9
Palm	192.9	5.6
Urbanization	185.7	5.4

precipitated by human activities, which leads to gradual disappearance of its ecosystem services (Table 10.5). In the Niger Delta, the type of resource derived and consumed is from agriculture, forestry, and fisheries, which is derived from land or water. Land and water in Niger Delta are used for different purposes such as fresh water and marine system, aquaculture, forest products, agricultural crops, crude oil exploration, natural gas, coal mine, copper, aluminum, etc. The agricultural and forestry products are renewable resources that can be replaced easily in few years. This makes their depletion rapid as a result of increased consumption from the large population of people migrating into the city as a result of urbanization (Table 10.6). Urban dwellers, therefore, have greater footprint on the ecosystem than rural dwellers because of their high demand on the environmental resources. Moreover, urban dwellers are wealthier than rural dwellers, which make them have high buying and consuming capability than the rural dwellers who are subsistence farmers and fishermen that eat from pocket to mouth. Furthermore, increase in affluence as a result of industrialization produces wealthy and well-paid people in the society who tend to afford more, thereby putting more demand on the environment. Well-paid urban dwellers also have the financial strength to buy choice land in urban areas close to coastal environment or mangrove swamp where they build mansions, estates, or hotels and seaside resorts. These projects have huge impact on the environment because before they are accomplished, large amount of forest would have been cleared to make way for construction work. Rich urban dwellers also have the ability to buy agricultural land and convert it to playground for their flamboyant lifestyle (Squires et al. 2020).

The amount of mangroves removed for its ecosystem services (e.g., firewood, aquaculture, etc.) from the Niger Delta far exceeds the amount replanted via afforestation, which may result in local extinction if the situation is not reversed. Some anthropogenic activities that impact the mangroves are:

1. Firewood manufacture – it is derived from red mangrove tree stem and generates cooking energy. To get enough firewood for commercial purpose, large amount of mangrove trees are cut down. In the last few years, more than 60% of mature mangrove trees had been cut down with 0% replacement in many localities (Mmom and Arokoyu 2010). A continuation of this habit will lead to a total loss of mangrove forest in the Niger Delta in the next 50 years.

2. Aquaculture – the use of fishery product for subsistence and commercial purposes had skyrocketed over the years because of the increase in poverty level. Rearing of fish is done with flagrant disregard for the environment. There is overfishing leading to the capture of fingerlings. Fisherfolk after their catch cut mangrove branches and place them in the container bearing the fish because there is a belief that red mangrove leaves attract fishes and give them the impression that they are still in their natural environment even after capture. Fisherfolk also kill and use the parts of fiddler crabs as baits during fishing. All these activities increase the ecological footprint of the environment. The negative aspect of aquaculture is that it converts a diverse environment to a monoculture, thereby reducing the biodiversity. However, sustainable agriculture can be practiced where fish farm and agricultural crop farm are set up in the forest, which saves the environment from deforestation and is less harmful to the environment since fish farming is the major occupation of the coastal dwellers in the Niger Delta (Akinrotimi et al. 2015).
3. Urbanization – this is one of the biggest land degradation agencies in the Niger Delta. This is because for schools, hospitals, highways, and housing projects to be executed, large amount of forest are cut down. The removal of the forest takes away other organisms that live in the forest such as birds, fish, ants, microbes, etc. This leads to loss in biodiversity and high ecological footprints.
4. Oil and gas exploration – it is also a major cause of ecosystem footprints in the Niger Delta through the removal of large number of mangrove trees as well as other organisms that live in the forest.

10.7 Research and Development for Management of Niger Delta Mangroves

Mangrove forest can contribute to urban ecology to improve sustainability. For instance, there is sustainable aquaculture in mangrove forest areas of Thailand, which guarantees a safe and healthy environment (Sampantamit et al. 2020). Management of mangrove forests is good because they share boundaries with urban areas in most communities in the Niger Delta. The effective management of mangrove forests contributes to the elimination of atmospheric pollutant because of their role in carbon sequestration. The inclusion of urban ecology in mangrove studies is significant because urban ecology is a scientific field that views cities explicitly as ecosystems. Researchers in this field seek to apply the fundamentals of ecosystem ecology and systems science to urban areas. Urban areas have great impact on the environment because they produce and consume large amount of raw materials which create large ecological footprint. This ecosystem model is significant for the Niger Delta mangroves because it maximizes efficient use of resources and recycles them, develops environmentally friendly technologies, accounts fully for external costs, uses locally produced resources, and encourages urban agriculture. Research labs can be established in the mangrove forest to aid the production of pharmacological products that can be used to treat common ailments. For example, a species of mangrove, *Acrostichum aureum*, is used to produce antiviral, antiparasitic, antibacterial, and anticancer products. Mangrove forest distribution and land use system can be effectively studied through the use of GIS and remote sensing (Balogun et al. 2011; Wang et al. 2016).

How the footprints of on mangrove ecosystem can be reduced is to adopt solar energy, which utilizes energy from the sun unlike firewood that increases the rate of deforestation and crude oil that increases pollutants in the environment. Solar energy production doesn't pollute the environment and is more sustainable. Again nuclear energy though very hazardous is sustainable because it can provide energy for a long time with little or no pollutants emitted into the environment if well managed.

A policy of establishing mangrove protected areas of the Niger Delta (MPAND) is very important at this time to save the mangrove from utter destruction. The setting up of forest guard will also reduce encroachment into the forest for those who cut the trees for firewood production and carry out overhunting and overharvesting of its resources. There should also be aggressive enlightenment campaign through the news media such as radio, television, and newspaper. Mangrove studies should be incorporated into the curriculum of high schools and universities. Students should be exposed to class and field trainings, to expose them to the practical ways of conserving mangrove forests.

10.8 Conclusion and Recommendation

Urbanization and oil and gas exploration are two activities that degrade the mangrove environment in the Niger Delta, which has implication on source of income and revenue. The Niger Delta people are mainly engaged in agricultural activities such as fishing and farming. Therefore, the pollution of land, water, and air affects these occupations and takes away their livelihood opportunities. It also affects their health and safety. Although urbanization is good, but it has a long-lasting effect on the environment if the principle of sustainable development is not practiced.

The Niger Delta has no policy on urban ecology; therefore, this paper recommends that it should be made a policy to improve the environmental health and safety of people living in rural and urban areas. More ecologists should be trained to specialize in urban ecology, and this topic should be included in curriculum of our institutions. Research grant can also be given to scientist to carry out experiments to determine the best approach to implement urban ecology. Another recommendation is that more trees should be planted within the cities to help purify the atmosphere from industrial pollution and exhaust from cars. In addition, unused land at the interface between urban and rural areas can be converted to agricultural projects. The land can be leased out to willing farmers to acquire and farm on it for a given number of years. This will increase the food production capacity of the people and the government with less reliance on wealth from crude oil production. Lastly, mangrove products can be used to manufacture drugs to be used to treat diseases. There is an ongoing research to test whether an extract of mangrove (*A. aureum*) found in the Niger Delta has antibacterial, antiviral, and antiparasitic qualities.

10.9 Future Perspective and Legal Policy Formulation

Since environmental factors influence the location of urban areas, variables such as climate, topography, waterways, and forests are important towards designing the outlook of human settlement within large cities. The Niger Delta is situated in coastal area with rich mangrove and rainforest. Cities around this natural reserve can be planned to create corridors for economic growth with the preservation of the environment as top priority. The rivers surrounding the cities can act as transport route to import and export raw materials for industries. It can also serve as major shipping route to export finished products abroad, which will boost local economy and thus, increase livelihood opportunities for local inhabitants. Urban areas sprawl outwards from upland to riverine areas, which is mainly a result of explosive population growth and increased land utilization. Increased population in the Niger Delta is a result of rural-urban migration for white collar and industrial jobs (Numbere 2020b). Increased population intensities impact on the environment as more persons take up space, use resources, and generate waste. The use of the IPAT model (Eq. 10.1) shows how population affects environmental quality.

$$I = P \times A \times T \tag{10.1}$$

where I = total impact; P = population; A = affluence; and T = technology.

Affluence magnifies environmental impact through greater per capita resource, which consumption leads to enhanced wealth and more land utilization. Technology enhances our ability to urbanize and explore for minerals. For instance, technology has made it possible for us to exploit more land and increase agricultural production which has further increased the ecological footprints in the Niger Delta. Some countries have taken some policy decisions to reduce human population through reduction in reproduction rate of its citizens, e.g., China. Africa has high fertility rate (4.7) as compared to Australia and South Pacific (2.5), Latin America and Caribbean (2.3), Asia (2.2), North America (2.0), and Europe (1.6) (Pop. Ref. Bureau 2010). Because of the African tradition and orthodox Christian religious beliefs that children are gift from God, it would be very difficult for government to regulate the reproductive rate of individuals and families. However, the policy solution that would work is enlightenment campaign for reduced family size and empowerment of heads of households that will have a trickling effect on the economy of people in the region. Birth control via family planning is another population-reducing mechanism. It is also believed that women empowerment in rural areas can help to reduce fertility rates; when young single girls have well-paying jobs, they won't be tempted into early marriages or out-of-wedlock pregnancies. Poverty is also another factor that increases population growth rate when jobless people engage in activities that lead to unwanted pregnancies. Poverty also leads to environmentally destructive behavior, but wealth can produce far more severe impact on the environment. Lack of livelihood opportunities in the rural areas has made a lot of people to use firewood for cooking because they cannot afford stove or gas cooker. The firewood is derived from red mangrove stem which is cut down incessantly, thereby putting much pressure on the environment. Loss of a single mangrove tree leads to the loss of hundreds of ecosystem services rendered by mangrove trees such as air purification, soil stabilization, etc. To reduce the use of firewood, alternative means of cooking such as low-cost solar cookers can be provided for rural dwellers.

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Challenges of Corporate Ecological Footprint Calculations in the SME Sector in Hungary: Case Study Evidence from Six Hungarian Small Enterprises

11

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Abstract

Scientific and social discourse examines primarily the environmental performance of large enterprise actors. Although these large enterprises usually operate on an international level, over half of the added value created in the European Union and thus over half of the environmental damage are generated by small- and medium-sized enterprises (SME). Nevertheless, while the tools and expertise required to measure environmental performance are available for large enterprises, the SME sector has only limited access to these tools.

As part of our research, we have developed an ecological footprint (EF) calculator applicable to the specificities of the SME sector, which has been tested on six Hungarian companies operating in different sectors and organisational frameworks. The test results indicate that the managerial information system of partnerships includes all the main inputs that are necessary to estimate a company's EF. However, in the case of sole proprietorships, most of the required data can only be acquired by estimation. Our EF calculations on analysed firms cannot be considered as representative data. But on the base of the case studies, we can suggest that our EF calculator for SMEs is suitable to take a more comprehensive survey on EF of Hungarian and international firms, in order to generate sectoral benchmarks. Ecological footprint among analysed enterprises ranged between 5102 and 263,589 global square metres. It is caused mainly by (1) the sector (e.g. constructions have generally larger footprints than office activities) and (2) the size, expressed in number of employees or value added. To increase transparency of the environmental performance of the SME sector, we recommend that the supplementary annex of partnerships includes the main input data necessary for the calculation of the EF in a comparable and consistent way, in natural units of measurement. With such information and our calculator, it would be possible to determine the average environmental impact of the individual sectors, which would provide an appropriate starting point for the environmental investments of enterprises.

Keywords

Corporate sustainability · Ecological footprint · Footprint calculator

Abbreviations

BFF	Best foot forward
CSR	Corporate social responsibility
EF	Ecological footprint
EPA	Environmental Protection Agency
EQF	Equivalence factors
GFN	Global Footprint Network
gha	Global hectare
GHG	Greenhouse gas
NEF	National Energy Foundation
SDGs	Sustainable Development Goals
SMEs	Small- and medium-sized enterprises
YF	Yield factor

11.1 Introduction

In recent years, several online tools have been developed by research institutions and consultancy firms to facilitate carbon (or ecological) footprint calculations of small- and medium-sized enterprises. Many of these calculators are available for free, they are easy to use, they do not require too many data, and their completion is not time-consuming. Their accuracy and reliability, however, raise a number of problems. Those who develop calculators have to face a double challenge. On the one hand, most small- and medium-sized enterprises (SMEs) do not have up-to-date databases which can provide detailed and extensive information beyond financial accounting data, including material and energy consumption, and there seems to be a general lack of professional competence regarding the application of such complex methodologies like EF (ecological footprint) calculations. On the other hand, the results can be highly inaccurate due to oversimplification of the calculators. An ideal calculator is easy to use and easy to complete, yet it provides an accurate carbon footprint calculation (Szigeti and Harangozó 2016). After we have reviewed the available carbon calculators, we came to the conclusion that EF calculators (similar to carbon footprint calculators) for SMEs are not yet available. This result is unexpected since the EF is a widely used and often cited indicator (Schaltegger et al. 2015; Szigeti and Borzán 2014) and there are EF calculators for large companies in the textile industry (Butnariu and Avasilcai 2014).

A major advantage of the EF indicator is that it is widely applicable—similar to the carbon footprint or indicators expressed in monetary terms. In the case of EF, figures can be accurately interpreted as 'too big'; furthermore, 'good' and 'bad' development can be clearly separated (Szigeti et al. 2016).

The aim of our research was to develop a methodology for measuring the non-financial performance of SMEs, including the measurement of their EF. In view of the specific needs and characteristics of these types of enterprises, we set out to create a calculator adapted to Hungarian conditions which provides reliable results, without the need for significant additional data input. The calculator we developed was tested on six companies operating in different sectors and organisational frameworks. Our results are based on the use of the calculator, the experiences learnt from the case studies and the conclusions drawn from thereof.

11.2 Ecological Footprint Scenario in the Corporate Sector Across the Globe and Hungary

A lot of enterprises have recognised that their present non-financial performance has significant implications to both their future financial and non-financial performance. Therefore, corporate strategies are getting aligned with sustainability issues (Wackernagel and Beyers 2019; Meena and Lal 2018)—for instance, the adaption of United Nations' SDGs, actions for decreasing the EF, etc. Some of these actions may contribute to—among other things—operational cost savings; therefore, in some cases, it can pay off as well.

Wackernagel and Beyers (2019) highlight the importance of EF calculations of enterprises. Their results—for example, GPT in Australia or Schneider Electric in France—show that significant savings can be achieved at low or no cost. We have no doubt that most enterprises could perform similar results all around the world and some of them may have already done so. Our experience shows that Hungarian enterprises, including SMEs, have promising initiatives, for example, retrofitting buildings, using smart devices in order to decrease electricity consumption, support cycling or public transit instead of using cars, etc., but they are not willing to disclose or communicate these measures.

The latest Hungarian Central Statistics Office data show that 99.1% of the total number of Hungarian enterprises is SMEs and 93.8% of all working enterprises fall into the category of micro-sized and 4.6% into the category of small-sized enterprises. Although the SME sector is economically significant, it fails to represent its real weight: two thirds of the total numbers of the Hungarian workforce are employed by them; however, their contribution to the total GDP is 43.7%. A critical issue is that only one third of the national investments are going to the SME sector (KSH 2018).

The EF calculation for SMEs is a niche market in Hungary—although some consultant and consultancy firms provide such services, they do not develop a generalised model, but the used methodology is fitted to the analysed company. Further problems are the following: (1) without a general methodology, the results are not comparable; and (2) industrial benchmarks cannot be provided on the basis of these figures. Therefore, the EF calculator developed, presented and tested in this study could fill a service gap and may form the basis of future research and recommendations for governmental measures.

11.3 Existing Eco-footprint Scenario in SME Sector in Hungary, Theoretical Framework

The EF shows the size of productive land a human community needs for sustaining itself and assimilating waste generated at a given level of technology.

EF has gained a prominent position in the sustainability debate since its introduction (Collins et al. 2017). The EF indicator is calculated by its developers on several levels from the beginning of the calculation. In addition to calculating the global EF for comparing the available biological capacity and the territorial demand of consumption, national, regional, municipal, enterprise, product and individual EF calculations are also made. The GFN calculates an EF indicator for the world and the countries and also has an individual EF calculator, but they do not deal with company-level calculations (Meena et al. 2020a, b, c).

Recognition of the EF differs significantly from one field of application to another: while the indicator is considered to be a very good one on a global scale (Stiglitz et al. 2009), its other applications are criticised from many sides (van den Bergh and Grazi 2014; Patterson et al. 2017). According to the concept of GFN, the EF indicator includes six land usage categories: cropland, grazing land, forest, fisheries, built-up land and energy land needed for carbon capture. All the consumption is measured by land usage, and then with the help of EQF, these are expressed in gha—globally comparable, standardised hectares with world average productivity. This conversion number serves as a tool to be able to compare, for example, cropland and forest area. In the case of a country, comparison should be made with the help of YF by measuring the differences between the various productive surface areas. For example, the productivity of cropland can be compared between Hungary and Greece (Lin et al. 2018).

Csutora and Harangozó (2019) have identified five different types of company EF that are applicable to organisational-level calculations: carbon footprint (carbon and GHGs), EF, water consumption footprint, environmental footprint and nitrogen footprint. According to the researchers, these footprint indices are distinct both on grounds of content and elaboration of methodology. Common elements are that they enable companies and other organisations to measure, manage and communicate environmental performance at organisational level. Since the footprints provide information about the direct as well as the indirect impacts, they play a vital role in monitoring sustainability performance of organisations. All five types of organisational EF focus on the environmental aspects of sustainability. It means that none of the reviewed indicators are capable of capturing the interconnections between environmental, social and economic performance. As a result, they are inadequate for the purpose of completing an overall/extensive sustainability evaluation. Therefore, in the broadening of the various types of footprint approaches, the integration of social and economic aspects would be a crucial task for the future. Another usable alternative indicator is the indicator of OECD Regional Well-Being, which is closer to measuring sustainability (Cseh et al. 2018).

Three fundamental questions arise in relation to corporate EF calculations: "Is it possible or would it make sense to calculate a separate corporate EF?", "Is it possible to avoid double accounting problems?" and "Is it possible to consider full product life-cycle?" (Lenzen et al. 2007).

The basic literature for enterprise applications was published in 2000 under the title *Sharing Nature's Interest: Ecological Footprints as an Indicator of Sustainability*. One of the three authors is Mathis Wackernagel, creator of the EF concept (Wackernagel and Rees 1996). The other authors are Nicky Chambers and Craig Simmons, the two founders of BFF. The book provides examples for various types of EF calculations, e.g. university, high school and corporate calculations, and product EF calculations (Chambers et al. 2000). So far, this book can be considered the starting point for designing sub-national calculations. The literature stream of sub-national or corporate EF calculation is growing, Wackernagel and Beyers (2019) provide a summary of major new results.

BFF, the leading European sustainability advisor, was a key player in corporate EF and carbon footprint calculations. BFF was founded in 1997 in the United Kingdom to help with sub-national-level calculations. They have helped many organisations and conducted over 300 footprint studies. One of the most significant of these was the study demonstrating the EF calculation of London, which received extensive press coverage. BFF joined the Anthesis Group in 2013, one of the leading sustainability advisory bodies in the United States and Asia (Szigeti and Borzán 2014). Most research on the applicability of EF calculations in corporate context was earlier conducted by John Barrett (Barrett and Scott 2001; Wiedmann and Barrett 2010).

According to Csutora and Harangozó (2019), the measurement of corporate EF has proved to be the most problematic, since this level provides the least amount of available examples, and in many cases the carbon footprint of energy usage is the major element in the EF. This raises the question of why not only use the carbon footprint as a corporate indicator.

Due to the limitations of footprint calculation, the method is primarily suitable for planning and documenting the company's own development, and it also helps in quantifying the results of environmental developments (Csutora and Harangozó 2019; Meena et al. 2018). The footprint as a 'common unit of measurement' helps in benchmarking, while the extent of improvement becomes quantifiable and the future impact of strategies assessable. A positive outcome of EF calculations may also be that consumption data is reviewed from other aspects as well, so database errors/inconsistencies that have not been revealed before can be detected. The EF can be a common unit of measurement for assessing eco-efficient investments and measures (Szigeti and Harangozó 2018).

On the contrary of abovementioned advantages of calculating EF for enterprises and free available online footprint calculators, there is no research on comparison of EF calculators for SMEs. All mentioned research is related to carbon footprint calculators. Results and recommendations (i.e. easy-to-use framework and need for reliable data) of former studies, however, were taken into consideration in the development process of our EF calculator for SMEs.

It is important to emphasise though that in the case of eco-efficient developments, a rebound effect is very common, i.e. in parallel with the reduction of specific pollution, paradoxically enough, due to an increase in consumption, the absolute volume of pollution increases (Szigeti and Tóth 2015).

11.4 Methodology

The basic hypothesis of our study was that an easy-to-use and reliable EF calculator could be created for the SME sector. The created calculator was tested as part of the case studies of six companies operating in various sectors.

The latest 2017 data show that 99.1% of the total number of Hungarian enterprises is SME and 93.8% of all working enterprises fall into the category of micro-sized and 4.6% into the category of small-sized enterprises. Although the SME sector is economically significant, it fails to represent its real weight: two thirds of the total numbers of the Hungarian workforce are employed by them, but their contribution to the total GDP is less than half (43.7%). A critical issue is that hardly one third (31%) of the national investments are related to the SME sector (KSH 2018).

There are two conflicting preconditions defined in the case of EF calculation methodologies to be drawn up/drawn up for SMEs.

1. In order to minimise the labour input, required data should be limited to those available or easily produced (e.g. public utility invoices, travel document statements, identification of used resources, etc.). Integration with existing (managerial) information systems does not only help reduce the need for extra work input, but experience shows that even large enterprises may make major errors in data sets that are not part of external or internal reporting (Szigeti and Harangozó 2018).
2. On the other hand, the calculator should be specific without excessive simplifications (Szigeti and Harangozó 2016). Although the different approaches and related specific EF may include data estimates in themselves, hard input data expressed in physical indicators (e.g. x kWh electricity or y litres of diesel, etc.) reduce the level of uncertainty to an acceptable level in our opinion. Based on the literature review on corporate EF calculations, the application of the developed combined methodology is suitable for overcoming issues caused by data gaps or deficiencies (Szigeti and Borzán 2014).

The calculator determines the EF of the examined companies in four steps.

1. In step 1, we calculate a simple company carbon footprint based on annual energy consumption (e.g. natural gas, electricity, diesel, etc.). For the calculation, we found two calculators using a wide range of databases, the structure of which met the expectations. One is the calculator of the EPA, while the other is that of the

NEF[1]. For our calculations, we applied the latter one because it is simple and easy to follow. Interestingly, there is no common 'EU' calculator at present, but the NEF calculator, basically relying on DEFRA database, offers UK companies a simple GHG and carbon footprint calculation option, but you may choose other countries too, and it offers the opportunity to use the EU energy mix as well. Online calculators provided by international organisations where the database used is available are useful tools since they were developed and tailored to the specific characteristics of SME sector. Two corrections were made to the calculator: (1) The units of measurement were changed to the metric system, and the GHG emission values were updated with the British government's GHG emission factors for the year 2018[2] (DEFRA 2018). Based on the EF methodology (Lin et al. 2018), instead of using GHG values, CO_2 values were used. This calculation is only a conservative estimate. (2) Rows that are likely to be relevant were also added to the calculator. The resulting carbon footprint value is converted to average yield land, i.e. gha, using the GFN footprint intensity of carbon factor. The conversion rates are taken from the latest GFN databases (Lin et al. 2018).

2. In step 2, the carbon footprint is supplemented with the diet footprint. The calculation is based on the estimate that the EF of the female diet is 0.475, while that of the male is 0.551 gha per year (Vetőné Mózner 2014). The population of the research was the total Hungarian adult population. It was a large sample query of 1012. The sample included Hungarian adults (aged 18 and over, permanent residency holders living in non-institutional households). The query was collected within the framework of a monthly data collection by TÁRKI[3] called 'Omnibusz' 2010. The survey respondents were contacted by an interviewer in person. The method of sampling was nationwide representative including 80 settlements. The survey was representative of residency, sex, age and education. The multistage sampling involved settlement selection first, followed by the implementation of a Leslie Kish random-walk sampling design on the selected settlements. It is assumed in the calculation that employees will have half of their meals at their workplace during the 255 working days of the year, resulting in a 0.17–0.19 gha per person EF. No other specification was made in the calculator, so the consumption of intellectual and physical or older and younger employees is considered the same.
3. In step 3, the result reached up to this point is modulated by the water consumption footprint based on data in scientific literature (Chambers et al. 2000), for which only the number of employees is considered. Based on the use of workplace toilet, washing hands, cleaning, etc., the footprint will amount to an

[1]The original calculator is accessible at http://www.carbon-calculator.org.uk/ downloaded: 2019.03.03.

[2]During the analyses we have considered Scope 3, i.e. well-to-wheel factors of the GHG Protocol in all cases.

[3]TÁRKI is a Social Research Institute in Hungary.

estimated 0.001 global hectares per year per employee. Greater water consumption will typically appear in energy consumption through hot water usage.

4. In step 4, the size of the built-up area in hectares is multiplied by the equivalence factor (EQF) and the YF, thus obtaining the infrastructure component of the EF (Lin et al. 2018).

From the second step onwards, the carbon footprint calculation framework can be left which proves that even the labour-intensive company adaptation has environmental impacts. Companies using little electricity but employing large number of people can have considerable EF.

In ecological calculations, the delimitation of the scope of activity is an important issue in all cases. This is particularly interesting in the case of SMEs, as their businesses activities are often confined to a smaller segment of the value chain. Although the calculator could be used to assess the EF of entire value chains, we have examined the EF of the added value of businesses in the case studies. In our opinion, this solution provides the most reliable results, as businesses have reliable information about their own impacts and can influence the processes. However, it is important to emphasise that large enterprises may outsource polluting, labour-intensive or low-reputation activities to SME in order to optimise their own activities and emissions, which may cause SMEs to be relatively more polluting. This phenomenon is present in the case of the national EF values. Highly developed countries can achieve GDP growth and decreasing EF parallel by shifting their negative impacts on other countries (Szigeti and Tóth 2015).

The size of the EF was compared to the economic activity of the enterprises. In our opinion, net turnover is not suitable for comparing the company's EF with economic performance for two reasons. On the one hand, the characteristics of certain sectors can lead to considerable differences between revenues (e.g. trade, manufacturing, consultancy, etc.). On the other hand, SMEs specialise in certain activities within the total value chain, and revenues do not necessarily reflect real performance because the revenues of companies participating in a value chain are influenced not only by their performance but also by other factors (e.g. organisation size, bargaining power, etc.). As a result, in the case of EF calculations of individual companies of a value chain, double accounting problems should be dealt with (Szigeti and Borzán 2014). An example for double accounting can be that in the case of semi-finished products, the impacts of transportation are accounted for by both the supplier and the contracting company. Accordingly, in the calculations, the added value of the company is considered, which we believe provides more accurate information for the approximation of economic performance than the net revenue of the company. Accordingly, we base our analysis on the added value of companies, which we defined based on the available accounting data, as the sum of personnel costs, amortisation and pre-tax profit.

Six case studies were conducted to test the calculator. The selection of companies was based on personal contacts; the results obtained are published anonymously. However, we strove to select companies to be able to explore the widest possible range of activities and forms of operation. The starting point for our studies was the semi-structured interview we conducted with six small enterprises. If the interviewed company could not provide sufficient information required for our calculations, the data were determined by an expert assessment in order to find the missing pieces of information.

11.5 Results

11.5.1 The Case Studies

Our EF calculator was tested with companies from six different industries. In the following, we will briefly describe the main characteristics of the businesses. For some detailed information and results of enterprises analysed, see Table 11.1.

The construction company is a limited liability company based in the west of Hungary. The primary activity of the company is general construction of industrial halls, but it also undertakes other construction works. The company employs 36 people directly and has an annual turnover amounting to HUF[4] 3 to 3.5 billion.

The company engaged in the production of grape-vine grafts is also a limited liability company based in West Hungary. Besides producing and growing grafts, the company also undertakes the planting of vineyards in Hungary and abroad. The company's annual net turnover is about HUF 350 million, and it employs 35 people. As a result of the specific characteristics of the construction industry, there might be considerable differences between EF from 1 year to the next depending on the projects the company is involved in. On the other hand, the interpretation of the EF of a particular year can also present challenges. So, in the case of the construction industry, the calculation of 'project footprint' showing the environmental impact spreading out to several years would be more relevant.

The hairdresser is in Győr, and there are two sole proprietors working in a rented retail space. The annual net turnover of the sole proprietors is around HUF 13 million. One of the challenges of the calculation is that there are only one electricity meter and one water meter in the retail space the two entrepreneurs rent so they cannot be separated.

The pharmacy is a parent company with three branch companies operating in Eastern Hungary as a limited partnership. The company employs a pharmacist and three employees, with an annual turnover of around HUF 125 million. Travelling between the premises makes a significant portion of their footprint, which is not an industry-specific but operation-specific characteristic.

The canteen operates as a sole proprietorship within a university campus in Budapest. The firm employs one person and has an estimated annual net turnover of HUF 6.5 million. In the case of this enterprise, a problem is the lack of information about their electricity consumption. Consumption can be estimated by their technical parameters.

[4] 1000 HUF = 3.08 (EUR, 2019.07.08).

Table 11.1 Reports on main analytical input data of analysed SMEs

Figures 2017	Measures	Carrier	Pharmacy	Construction	Grape-vine graft producer	Canteen	Hairdressers
Meals	Global square metres	1403	6637	67,432	62,587	1301	3318
Water consumption	Global square metres	20	40	360	350	10	20
Covered areas	Global square metres	201	680	10,280	10,541	109	92
Material consumption	Global square metres	0	0	0	42,205	0	515
Electricity consumption	Global square metres	1465	5520	4944	65,441	2501	6523
Heating (including water heating)	Global square metres	7025	3442	10,334	39,652	3960	6960
Transportation	Global square metres	4046	11,897	357,336	214,545	0	9833
EF	**Global square metres**	**14,160**	**28,215**	**450,685**	**435,322**	**7881**	**27,262**
Number of employees	Employees	2	4	36	35	1	2
Sales	Th. HUF	190,324	126,621	3,139,997	362,131	8504[a]	12,992[a]
Value added	Th. HUF	17,115	15,919	263,589	183,878	5102[a]	6496[a]

[a]Estimated values

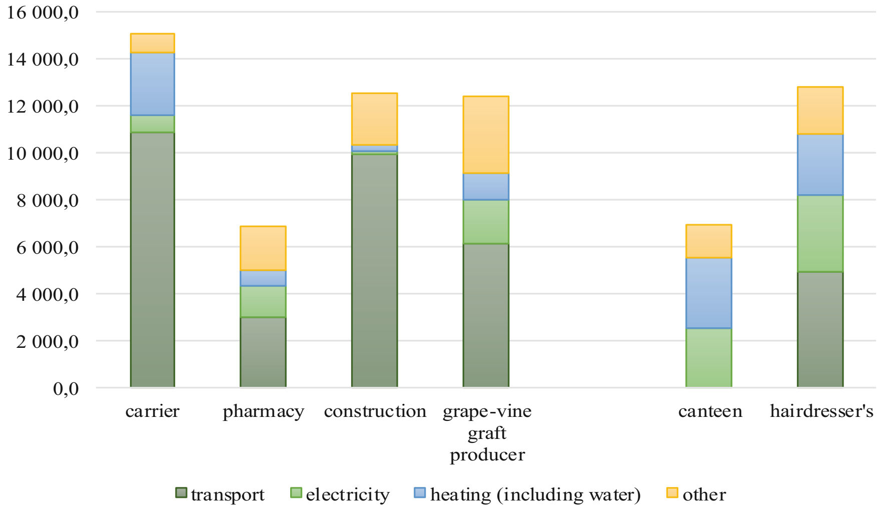

Fig. 11.1 Ecological footprint per capita of the firms analysed (global square metres per capita)

The carrier operates in Budapest as a limited liability company. The company offers complex logistics services between Western European countries, Hungary and Eastern Europe. It is important to emphasise that the company uses external service providers for transportation as it does not own any trucks. The company's annual turnover is around HUF 190 million and employs two people.

According to our experiences, the companies examined in the case studies implement solutions that enable ecologically more efficient operation (e.g. wood gasification boiler, low consumption motor vehicles, LED lighting, etc.) if they can primarily because of material and efficiency aspects.

These improvements—besides cost savings—also lead to a considerable decrease in the EF of the enterprise. In terms of improvement plans, environmental considerations are present *along with* economic efficiency. The decision process of environmental decisions was heavily influenced by the technical knowledge and attitudes of owner/manager (e.g. future use of electric car or solar panel). Our research results are in line with the results of two previous Hungarian studies:

- Information available regarding the environmentally efficient solutions are critical in the case of SME development decisions (Zilahy 2017).
- In the case of Hungarian SMEs, there is a well-definable group of leaders with modern corporate governance and CSR attitudes focusing on stakeholder needs (Benedek and Takácsné György 2016).

Based on the per capita EF of the examined enterprises, they can be divided into a more polluting and a less polluting group (Fig. 11.1). It is worth pointing out that the carrier's specific footprint is one of the lowest, since transportation is provided by external partners, so the pollution also occurs *outside the company's premises*. This

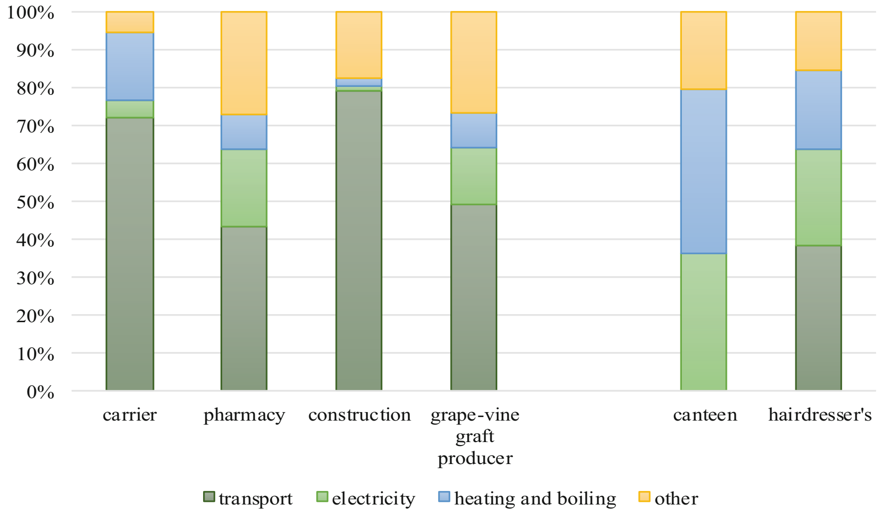

Fig. 11.2 Constitution of ecological footprint of firms analysed (%)

is exactly the opposite in the case of the hairdressers. The relatively large footprint is caused by their commuting by car, the usage of high-performance machinery and the low number of employees.

Experience shows that carbon footprint constitutes a significant part of the EF of enterprises. This observation is fully supported by the case studies—transportation, electricity, heating and hot water production resource usage represents at least 70% of the total footprint (Fig. 11.2). It is interesting to note that in the case of the canteen, transportation is climate-neutral, because the employee cycles to work.

We were faced with problems in the analysis of economic and ecological efficiency because the range of information available on the companies surveyed in case studies was varying. In the case of partnerships (the construction and transportation companies, the vineyard and the pharmacy), economic data based on published accounting reports were available for years back, so the calculation of added value was easily made. However, it should be added that the data needed for the calculation of the EF are not available in the reports; they require additional individual data collection, so a temporal analysis is not feasible in this case. Of the remaining two surveyed organisations, the hairdressers are sole proprietors, while the canteen operates as a unit of a larger enterprise. In their cases, there was no accounting data available, so economic data were based on estimates, which could inevitably have led to distortions.

Similar to the analysis carried out by Kocsis (2010), we compared the economic and ecological efficiency of the examined organisations (Fig. 11.3). If an enterprise produces high specific added value and low material intensity per unit, it is

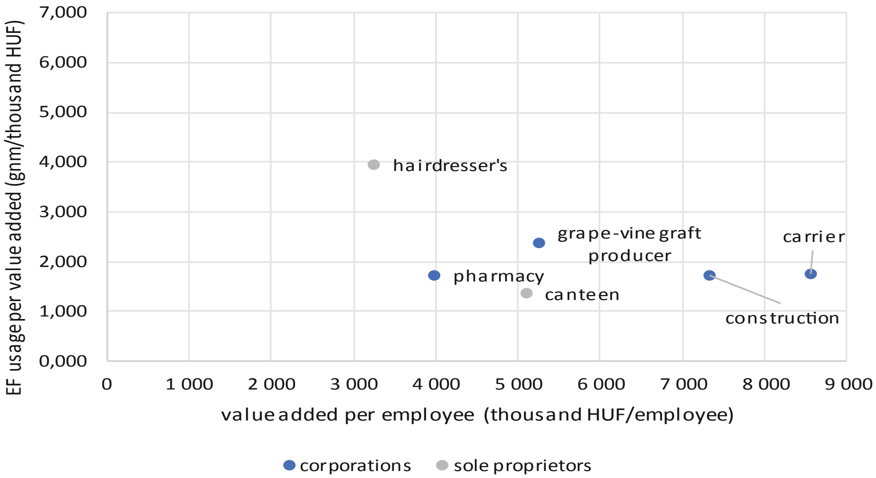

Fig. 11.3 Material intensity (gm2/thousand HUF) and economic efficiency (thousand HUF/employee) of analysed firms

considered favourable in the analysis. The reciprocal of ecological efficiency, material intensity, was defined as an EF per value added unit[5], while economic efficiency as added value per capita.

A slightly unexpected finding is that the hairdresser's has the least favourable indicators resulting from daily commuting causing high levels of GHG emissions. In terms of material intensity, the canteen, the pharmacy, the grape-vine graft producer and the construction company show similar values. There is a considerable sign of deviation in the economic performance. The relatively low financial performance of the canteen may result from the approximation method and seasonal sales and also the fact that it is a 'one-man enterprise'. The pharmacy is quite similar to the buffet, but here the cause of low financial performance is location (small, low income villages in the Eastern part of Hungary). In the case of the grape-vine graft producer and the construction company, there is a high specific added value. It is important to emphasise that the carrier has the best footprint value which is the result of outsourcing the actual carrier activity. There is no footprint value available to determine the sustainability of the business. In our opinion, the application of EF values that are considered to be sustainable at national, regional or global levels in the case of the enterprise sector is only suitable to produce rough estimates. This means that if an enterprise's footprint per employee is less than the value nationally considered sustainable, the enterprise can potentially be sustainable, but if not, it is certainly not sustainable.

[5]To show the order of magnitude, the measure of the ratio is global square metre/thousand HUF.

11.5.2 Discussion

The hypothesis of our research was that an EF calculator that would allow for a reliable calculation of the EF of SME with minimal additional data supply could be created. Based on the case studies, we can firmly say that the calculator we have come up with fulfils this condition. Since EF calculations show significant variation as a result of site-specific values and simplifications (Szigeti and Harangozó 2016), footprint comparisons can only be made for values calculated using the same calculator (and methodology). Accordingly, the calculator we have developed needs to be subjected to further cross-sector testing. Testing, followed by live operation, provides the opportunity to create a benchmark database that will enable us to determine the expected value of the EF of companies in each sector based on anonymous data provided the companies.

Another problem is that in the case studies the EF was calculated for 1 year. Experience shows that the EF of businesses is relatively stable, so dynamic comparisons can be made accurately with smaller corrections of the results. However, in the case of the construction company, the size of the footprint may vary considerably depending on the projects undertaken, so for the dynamic analysis, yearly footprint calculation is required. Our suggestion is also supported by the fact that the general recommendations related to the use of the EF indicator also prefer temporal comparison (Egedy et al. 2017; Kovács et al. 2017, Szigeti and Borzán 2014). We believe it possible that there may be several similar sectors; however, we do not have any substantiated results of the kind based on the case studies.

The methodology is also useful for enterprises because they can obtain a clearer picture about the area and they have the highest level of environmental impact. Even if they are not expert of the field, a higher level of environmental consciousness can be a positive attribute. Also, the reason why we believe enterprises should use EF calculators instead of carbon footprint calculators is that it makes it possible to determine the natural limit to company growth. It can lead to further economic analyses of optimal size comparable with issues of sustainability.

In the case of large enterprises, the data required for the calculation of the EF can be produced relatively quickly and almost completely from the existing accounting records and the statements of the internal information system. However, SMEs do not or hardly ever publish data required to calculate EF. The micro- and small enterprises surveyed in the case studies were approached on a personal basis. The data needed for the calculations were requested from the interviewed persons who collected and handed over the inside information as a favour. In the case of sole proprietors, even the accounts and internal statements were not available. We calculated the EF on estimates considering the used machinery and the type of activity, which estimates were based on data provided by the proprietors and industry averages. Consequently, the reliability of the results obtained is lower.

It is important to note that the cases we surveyed were relatively pure cases. In the case of smaller businesses or sole proprietorships, business and private spheres can overlap. The most common example is the private use of corporate assets (e.g. mobile phones, computers, cars, etc.). A good example is that hairdresser in the case study who washes towels and other tools at home, so the related energy and water consumption also takes place there. However, in the case of a shop in a mall, for example, we do not necessarily have an approximate statement of the amount of natural gas used for heating or hot water production or the use of electricity due to the rental relationship.

11.6 Research into the Ecological Footprint and the SME Sector

As we have already mentioned above, EF calculations could help enterprises to find measures and actions which decrease both their ecological impact and the operational costs. Case studies show that the EF can significantly decrease at low or to no cost (Wackernagel and Beyers 2019). We suggest, however, that some sectors need investments with higher costs or significant restructuring of business processes in order to achieve genuinely sustainable operations. EF calculations may support enterprises to identify the most efficient solutions. Accordingly, research and development processes should focus on two targets. Firstly, EF calculations must provide reliable results while they should suit to different size of businesses (e.g. sole proprietors, SMEs, large enterprises, etc.), to business models and to sectors as well. On the basis of the six case studies presented here and on the results of other tests, interview and experiences, we suggest that our calculator should fit SMEs across sectors; however, due to its extensive data input needs, it may not be suitable for sole proprietors. Since the ecological impact of the employees' private and professional life overlap, the EF calculation of their extended household may be a good compromise. Secondly, EF calculations should provide not *only* an EF figure but relevant measures and actions to reduce it as well.

11.7 Policy and Legal Framework in Relation to the Ecological Footprint and Corporate Sector

Financial reports of enterprises do not comprise EF or necessary data for calculation, such as consumption of resources in natural figures. Since such data is available on public utility and fuel invoices processed by bookkeepers, we suggest that SMEs should disclose some aggregated data. Non-financial reports, such as GRI reports, comprise such data, but generally only the larger enterprises make non-financial statements voluntarily, and their indicator set can be considered only à la carte.

Methodology of EF calculations is not regulated by governmental bodies or supranational organisations, but by a non-governmental organisation, the GFN. Guidelines of GFN can be considered as blueprint of EF calculations since it has the most extensive database and state-of-the-art methodology.

11.8 Conclusions

In the future, we plan to make the calculator available online first for further testing and then for live operation. Analysing the anonymous economic and EF data obtained from firms, the average ecological efficiency and specific added value of the various sectors can be established. This benchmark value can also be the starting point for potential ecological process rationalisation for the respondents. Another possible advantage of the database would be that it could provide a possibility for dynamic analysis after a few years.

In connection with the increasingly frequent occurrence of environmental and social data in corporate reporting, we recommend that the main input data for EF calculation should be displayed in natural units and in a manner comparable with the previous years' data in the supplementary annexes to the annual (accounting) reports of partnerships made up of at least five people. For avoiding excessive administrative burden for businesses, these data include key data such as the energy content of the natural gas used, the amount of electricity purchased or the annual mileage of each company vehicle.

There are two possible further research directions open to us. One is the further development of the created EF calculator according to the needs uncovered during testing. Another development option is the definition of (sectoral) benchmark data based on a larger database that can be analysed by statistical methods.

11.9 Future Roadmap for the Ecological Footprint in the Corporate Sector

On the basis of our research results, the authors suggest that it is possible to create a relatively easy-to-use and reliable EF calculator for SMEs. The next step of our research programme is to develop and test the online version of the calculator. Testing of the online calculator will be a crucial step since the online version must be robust enough to collect data from each sector and, in the future, from several countries as well. Since the reliability of the results is the most important issue, the calculator must be well documented and smart enough to mitigate input of false data (e.g. natural gas consumption of MJ instead of cubic metres). This online calculator could allow to calculate benchmark data in sectoral, regional and other aspects.

The largest limitation of the calculator is that it was adapted to Hungarian data. We suggest that the reliability of the results and their generalisability are a trade-off; therefore, if we intend to analyse SMEs outside of Hungary, we must provide unit data specific from the analysed countries. For example, there may be significant differences among the footprint of an electricity grid or local food consumption data for each country (Galli et al. 2017).

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Opportunities, Challenges, and Ecological Footprint of Sustaining Small Ruminant Production in the Changing Climate Scenario

12

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Abstract

The livestock sector has evolved enormously over time. The livestock sector not only supports a vast proportion of individuals across the globe; it also ensures food security. Erratically varying climatic conditions along with population growth are leading to serious competition for land and other natural resources. These factors will hamper global livestock production; amidst this chaos, the small ruminant industry is emerging as a sustainable source of farming. The small ruminant sector is known for its efficiency in producing quality products while using limited resources, its adaptability across various agro-ecological zones, its resilience to climate change, and its minimal eco-footprint. Small ruminants have a higher global average carbon footprint for milk production than cattle and buffalo (6.5 vs 2.8 and 3.4 CO_2eq. per kg of milk, respectively), while meat production from small ruminants has a lower carbon footprint than cattle and buffalo (23.8 vs 46.2 and 53.4 kg of CO_2eq./kg of carcass weight). The accuracy of genomic prediction for thermo-tolerance by GS was predicted to be between 0.42 and 0.61 using high-density single nucleotide polymorphism (SNP) genotypes. Despite this, small ruminant farming (sheep and goats) has not received its due recognition and is facing a threat due to climate change. Implementation of efficient ameliorative, adaptation, and mitigation strategies will have a positive impact on the sustainability of small ruminant production. In addition to this, it is of utmost importance to focus on improved breeding strategies, such as selection for adaptation and low methane emission traits, in addition to productivity traits. These breeding strategies will aid in the development of

climate-resilient small ruminant breeds, which can produce efficiently across various regions and at the same time have minimal impact on ecosystems.

Keywords

Adaptation · Breeding · Climate change · Eco-footprint · Goat · Heat stress · Sheep · Thermo-tolerance

Abbreviations

BAL	Balusha sheep
BAR	Bardhoka sheep
BCS	Body condition score
CP	Crude protein
DGAT1	*Diacylglycerol O-acyltransferase 1*
ESTR	*Estradiol receptor*
FAO	Food and Agriculture Organization
GDP	Gross domestic production
GHG	Greenhouse gases
GHR	*Growth hormone receptor*
GS	Genomic selection
GSH-Px	Glutathione peroxidase
IGF-1	*Insulin-like growth factor-1*
K^+	Potassium ion
K_2CO_3	Potassium carbonate
$KHCO_3$	Potassium bicarbonate
KOS	Kosova sheep
LEP	*Leptin*
MAS	Marker-assisted selection
N_2O	Nitrous oxide
Na^+	Sodium ion
$NaHCO_3$	Sodium bicarbonate
NDF	Neutral detergent fiber
NH_3	Ammonia
NRC	National Research Council
PLR	*Prolactin receptor*
Se	Selenium
SHA	Sharri sheep
SNP	Single nucleotide polymorphism
THI	Temperature-humidity index

12.1 Introduction

The rapidly increasing global human population has opened up wider market opportunities for livestock products. Though this demand would prove to be beneficial to the farmers, it is predicted that the livestock sector is under threat as a result of changing climate (Baumgard et al. 2012; Meena and Lal 2018). When compared to all other sectors, livestock sector has unique feature of both contributing to climate change and also being affected by climate change. Greenhouse gases (GHG), primarily enteric methane emitted by livestock, are a major cause of concern due to their negative implications on the environment (Pragna et al. 2018a). Heat stress, one of the prime outcomes of climate change, has severe implications for livestock production. Heat stress directly and/or indirectly deters livestock production. Sharp declines in growth rate, milk production, meat production, egg production, and meat and egg quality, lower feed conversion efficiency, and increased disease outbreaks are the evident impacts of climate change on livestock production (Sejian 2013).

Small ruminants play a crucial role by contributing towards development of sustainable livestock production (Sejian 2013). They provide a potential source of income and nutrition for small-scale farmers, especially in developing countries. In the current scenario with exponentially rising human population, there is increasing land competition between livestock, and livestock feed and fodder production, and human needs for housing and non-animal human food security (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). Goat and sheep production are a suitable solution for this situation. Rearing small ruminants requires relatively less initial investments when compared to large ruminants and other farm animals. Additionally both goat and sheep farming ensure greater economic returns to small farms due to their higher turn off of market animals (Pragna et al. 2018b). Both of these species pose excellent adaptability traits, which enables their farming across highly variable agro-ecological zones. Moreover, there is a relatively high disease resistance ability of these species, especially goats, making them better able to do well in challenging conditions. Another important benefit of small ruminant production especially in the developing countries is the absence of any religious taboo on their marketable products. Moreover, goat milk and meat are highly sought after by consumers due to the nutritional benefits of the milk and meat (Sejian 2013).

Sheep and goats are thought to be better adapted to climate change than other livestock; however, they still face challenges. Repeated incidences of droughts and floods have drastically altered the distribution of the small ruminant farming across the various agro-ecological zones (Sejian et al. 2018). Traditionally small-scale sheep and goat production has relied on their ability to seasonally move animals to secure adequate grazing. However the prevailing climatic variability has made this difficult. Additionally, frequent climate change-induced natural disasters are causing a decline in grazing resources (Shinde and Sejian 2013). Additionally unpredictable market demands due in part to climate change are adding to the challenges faced by the sheep and goat industries. The demand for mutton/chevon, skin, and wool has always been changing rapidly, and climate change is the major contributing factor to this rapid change. The volatility has led to a rapid change in the breed preferences among farmers as they try to meet changing markets and impacts of climate change. The rapid changes in market demands and incorporation of newer breeds into a region may result in a decline in production as the breed introduced may not be adapted to the region into which they are introduced (Shinde and Sejian 2013). The adverse impacts of changing climate on small ruminants can be reduced provided suitable ameliorative and mitigation measures are adopted. Broadly these strategies can be grouped into three approaches: management strategies to improve the micro-environment for optimum animal performance, genetic breeding approaches towards thermo-tolerant breed development, and nutritional interventions (Shinde and Sejian 2013). Recent molecular biotechnological advancements in genomic expression technologies (microarray, RNA seq) have the potential to identify candidate traits for thermo-tolerance (Moran et al. 2006). Incorporation of such genetic information may be effective in developing thermo-tolerant breeds. However, such strategies will only be effective if supported equally by all stakeholders especially government and nongovernmental organizations. It is therefore important to put forth effective policies and options which promote and propagate the uptake of technologies which would further improve the adaptive capacity of communities to climate change (Sejian 2013). Farmers should be encouraged to opt for sheep and goat farming and female empowerment. These two points should be the primary focus as they will lead to livestock improvement and communal development (Pragna et al. 2018a). Along with adaptability traits, inclusion of low methane emission traits in any breeding program is highly advisable. This not only would ensure sustainable small ruminant farming but also would improve the ecological footprint of this sector. This chapter will project to the readers the various opportunities and challenges associated with small ruminant farming. In addition, apart from targeting sustainability of the sector, the chapter also highlights its ecological implications.

12.2 Significance of Livestock in Developing Countries

Livestock production is considered to be the most widely adopted agricultural practices over the globe. Livestock production plays multiple roles in bringing viable community development around the world. This development is especially important in tropical countries where domesticated animals are mostly distributed. Livestock production has emerged as "the engine of agricultural growth" with its significant contribution to the total agricultural gross domestic production (GDP) in developing countries (Thornton 2010). Being an integral part of agriculture, livestock farming acts as an asset to safeguard the sustenance, income, employment, and livelihood of the poor and marginal farmers from developing states.

The human population has grown steadily and is anticipated to increase from 7 billion to 10.6 billion by the end of 2050; most of this growth will be in developing economies making them more vulnerable to food insecurity (UNPD 2008). As per the latest Food and Agriculture Organization (FAO) report (2019), many developing economies have witnessed instability in maintaining food security and eradicating poverty due to increased population growth. The recent decline in crop productivity associated with the repeated occurrence of extreme events most likely due to changing climates has further posed challenges to the nutritional demand of growing population. Indeed, malnutrition due to inadequate access to staple food results in short-term as well as long-term impacts on health and productivity of livestock as well as employment potential of rural economies. However, livestock has the potential to curtail the food insecurity. Currently, almost 33% of protein and 16% of energy in human diet are from livestock products (Martin 2001). As per the World Bank reports (2009), the demand for animal products is expected to increase further by 2050 especially in developing states.

Apart from bringing nutritional security, livestock contribute immensely to the economic stability of poor and marginal farmers (Meena et al. 2020a, b). It has been estimated that the majority of the poor people around the world live in developing countries where they depend on the livestock sector for their livelihood (Moyo and Swanepoel 2010). Poor landless farmers of developing countries find livestock production as a feasible way to ensure a secure livelihood. Further, farmers who practice crop cultivation rear livestock as an alternate source of income during scarcity periods. Indeed, livestock acts as a "living bank" for rural communities to minimize the impacts of natural calamities on their livelihood. Additionally, evidences from developing countries reveal that livestock play a significant role in bringing gender equity by providing employment opportunities for women.

Ecological intensification is referred to as knowledge-intensive process that helps in effective management of several ecological functions of nature and biodiversity to improve the performance of agricultural system to improve livelihood of farmers. Livestock contribute towards eco-intensification by eliminating the negative impacts of agricultural activity-oriented soil degradation through its manure-associated restoration and enhancement of soil microbes which got degraded as a result of extensive crop cultivation (Teague et al. 2013). Unlike developed countries, farmers in developing countries mostly rely on smallholder farms whose energy demands are satisfied by human and animal labor (Tabar et al. 2010). Substituting machineries with human and animals would decrease the emission of GHG, thereby reducing the carbon footprint from the sector. Through appropriate grazing patterns, livestock production contributes to several ecosystem services, including water infiltration, improving biodiversity, carbon sequestration, and ecosystem stability (DeRamus et al. 2003; Khan et al. 2020a, b).

12.3 Eco-footprint of Livestock Production in Developing World

The demand for meat doubled from 1980 to 2004 (FAO 2005), and meat production is expected to double further during the years 2000 to 2050 (Steinfeld et al. 2006). Ecological footprinting in livestock production takes into account the GHGs, fossil fuel use, reactive nitrogen loss, and blue water use (Rotz et al. 2019). The water footprint of a product constitutes of green, blue, and gray water (Mekonne and Hoekstra 2012). The blue water accounts for surface water and groundwater utilized for producing a product; the green water accounts for consumed rainwater, while the gray water represents freshwater, and it is mostly related to the standards set for water quality (Mekonne and Hoekstra 2012). Globally animal production requires 2422 Gm^3 of water per year (87.2% green, 6.2% blue, and 6.6% gray water). Beef cattle sector uses one third of 2422 Gm^3, while 19% is used for the dairy cattle sector. Water consumed by the animal, utilized for service and feed mixing, accounts only for 1.1%, 0.8%, and 0.03%, respectively, against the total water usage (Network 2017). Enteric methane emission and nitrous oxide emission contribute to 18% of anthropogenic GHG emission, while enteric methane alone amounts for 6.2 Gt of CO_2 equivalents (Moran and Wall 2011). The enteric methane emission footprint for livestock products includes direct enteric fermentation and manure management and should also include life cycle of livestock products starting from crop production, livestock feeding, transportation, and the processing procedures, along with packaging, distribution, and retail of the products, till it reaches the consumer (Liu 2015). Similar to methane emission, fossil fuels are used for feed production, transport, storage, processing, and distribution to individual farms. In addition, they are also required for the animal's environment like heating and cooling and also for waste collection and treatment. Fossil fuels are used for transport of animal products and their processing, refrigeration, storage, and transport till they reach consumer (Sainz 2003). In livestock systems fossil fuel consumption is highest in the production of eggs followed by dairy, beef, swine, poultry meat, and sheep (Sainz 2003). In southern Asia, for the period 2000 to 2014, mean NH_3 emission was 19.1 ± 3.5 Tg N $yr.^{-1}$ including both livestock and fertilizer application, while the ammonia emission from livestock excreta was 9.4 ± 3.5 Tg N $yr.^{-1}$ (Xu et al. 2018). Among livestock, cattle contribute the highest ammonia (NH_3) emission of 56.1% followed by buffalo 23.6% of the total livestock emission. Similarly for nitrous oxide (N_2O) emission, cattle were the highest contributor followed by buffalo and goats at 42.3%, 28.1%, and 15.5%, respectively, in India for the year 2003 (Aneja et al. 2012). Attainment of ecological footprints in the livestock production especially in the developing countries can only be achieved by increasing the livestock productivity and by using fewer animals.

12.4 Climate Change as a Constraint for Livestock Production

Climate change imparts multiple stressors on animals including heat, nutritional, and walking stress. Livestock production is affected by climate change both directly and indirectly. Direct effects are mainly through increased temperature, humidity, rainfall, and other such factors, which influence the performance of the animal. Scarcity of fodder, water availability, the carrying capacity of the rangelands, buffering ability of the ecosystems, and distribution of parasites and livestock diseases are the indirect means by which climate change affects animal production (Kumar et al. 2008).

The agro-ecological regions and the system of rearing determine the magnitude of environmental stress impacts in farm animals. The main production loss in livestock due to climate change is mediated through heat stress. The climatic extremes result in compromised productive performance in farm animals. This is mainly attributed to the adaptive mechanisms adopted by the animals to maintain homeothermy (Indu et al. 2014). Livestock production is affected by climate change mainly by changes in feed availability, crop production, and forage availability and sudden disease outbreaks which affect the health, growth, and production of animals (Sejian 2013). Growth parameters such body weight and body condition score (BCS) in livestock are also affected by heat stress (Pragna et al. 2018b; Indu and Pareek 2015). This effect of heat stress on growth performance is attributed to feed intake reduction (Pragna et al. 2018b).

High-production animals produce more metabolic heat and are therefore more affected by high heat loads. Milk production reduction is one of the primary adverse impacts of heat stress in livestock (Al-Dawood 2017). It has been established that 1% milk loss is expected for each unit increase in THI. Apart from affecting the milk yield, heat stress also affects the quality of milk produced (Salama et al. 2014).

Several meat variables are also significantly influenced by heat stress. Body weight, carcass weight, fat thickness, and dressing percentage also reduced in heat-exposed animals (Rana et al. 2014). The major carcass characteristics, primary cuts, edible offals, proximate analysis, and organoleptic variables were found to be affected following heat stress exposure (Archana et al. 2018).

Climate change has impacts on reproductive performance of both the sexes. Heat stress affects reproduction directly by effects of hyperthermia on the reproductive axis and indirectly by reduced feed intake which affects energy and nutrient status of the animals. In females, heat stress hampers the animal's fertility by reducing ovulation, estrous, conception rate, embryonic survival, and fetal development (Hansen 2009). As an outcome of heat stress, the secretion of the prime female reproductive hormones like follicle-stimulating hormone, luteinizing hormone, and progesterone is altered. This disturbs the dynamics of the estrous cycle, thereby resulting in impaired follicular and oocyte development (Niyas et al. 2015). The heat load also has a deleterious effect on the reproductive performance of male as it reduces the testosterone which leads to reduced libido, semen volume, and seminal pH, impaired sperm production and motility, and increasing sperm abnormalities (Niyas et al. 2015).

Heat stress associated with climate change results in depressed immunity in farm animals making them susceptible to diseases. Warm and humid conditions may also result in increased mortality and morbidity and also climate-sensitive infectious diseases.

Climatic change could influence livestock health through a number of factors like widening the range and increasing the abundance of disease-transmitting vectors and wildlife reservoirs enhancing survivability of pathogens in the environment, hampering the resistance of host to infectious agents and altered farming practices (Gale et al. 2009). Varying environmental conditions could also stimulate the spread of pathogenic vectors and parasites across different regions and/or emergence of newer pathogens within a region, in addition to increasing the prevalence of the already existing diseases. Such alarming situation would put the animal further under extreme stress ultimately leading to reduced productivity and increased mortality

Table 12.1 Impact of climate change on livestock production

<table>
<tr><th colspan="2">Effects of climate change</th><th>Impact on livestock performance</th><th>References</th></tr>
<tr><td colspan="2">Direct effect</td><td rowspan="9">Production
• Reduction in growth
• Performance
• Decreased milk yield and composition
• Reduction in meat quality and carcass characteristic
Reproduction
Male
• Reduced libido
• Impaired spermatogenesis and motility
• Reduced quantity and quality of semen
Female
• Impaired follicle and oocyte development
• Reduced ovulation, estrous, conception rate, embryo quality, and development of fetus</td><td rowspan="9">Gale et al. (2009), Hansen (2009), Indu et al. (2014), Rana et al. (2014), Sejian (2013), Salama et al. (2014), Indu and Pareek (2015), Niyas et al. (2015), Al-Dawood (2017), Archana et al. (2018), Pragna et al. (2018b)</td></tr>
<tr><td>High temperature</td><td rowspan="2">Heat stress</td></tr>
<tr><td>High humidity</td></tr>
<tr><td>High/low rainfall</td><td>Flood/ drought</td></tr>
<tr><td colspan="2">Indirect effect</td></tr>
<tr><td>Fodder scarcity</td><td rowspan="2">Nutritional stress</td></tr>
<tr><td>Water scarcity</td></tr>
<tr><td>Reduced rangeland/ pasture</td><td>Nutritional stress, walking stress</td></tr>
<tr><td>Low immunity</td><td>Disease outbreak, parasitic infestation</td></tr>
</table>

(Rust and Rust 2013). Apart from vector-borne diseases, soil temperature and humidity have a strong influence on development of intestinal nematodes. Both the direct and the indirect climate change effects on small ruminants are described in Table 12.1.

12.5 Importance of Small Ruminants for Small and Marginal Farmers

Small ruminant production caters for the needs of farmers during times of insufficient income particularly in tropical regions. Sheep and goats assure that the livelihood of the landless, smallholders, and marginal farmers within rural communities is safeguarded against the collapse of crops, thus contributing towards food security and poverty reduction (Sejian et al. 2019). Sheep and goat production is favored by rural populations due to the animals' short gestation periods, high fecundity, and production that is highly sought after (e.g., no religious taboos), and importantly it provides an employment opportunity in rural areas (Monterio et al. 2017). Sheep and goats are considered to be primary economic resources for smallholders apart from the cultural importance of having the animals and in addition provide some gender equity as women are topically the proprietors of small ruminants while the men are contributing towards the dairy animals at villages (Abdulrahman et al. 2017). Hence, small ruminants are vital components in the livestock production systems of rural economy and offer an alternative employment to increase the income of small farmers (Wodajo et al. 2020). Further, sheep and goats have a significant role in the contribution of high-quality animal proteins in addition to ensuring food security (Sejian et al. 2019).

Small ruminants act as an integral part of livestock production systems due to their unique biological characteristics like short gestation period, relatively higher prolificacy, rapid growth rate, remarkably higher feed conversion efficiency, and better disease resistance ability along with ensured marketability in comparison with other farm animals (Adams and Ohene-Yankyera 2014; Sejian et al. 2019). Sheep and goat can thrive well in a variety of agro-ecological zones (Pragna et al. 2018b; Sejian et al. 2019). Further, morphologically sheep and goat can adapt to varied environment due to their capacity to withstand droughts and water scarcity.

The increasing demand for small ruminants' meat along with minimal capital investment and low recurring cost, rapid returns, and less risk make sheep and goat farming a profitable and sustainable enterprise for rural households (Adams and Ohene-Yankyera 2014; Mohini et al. 2018). Hence, small ruminant livestock production systems have exceptional potential to be proposed as the "future animal" for rural and urban prosperity under the changing climate scenario.

12.6 Role of Small Ruminants in Reducing Eco-footprint and Combating Climate Change

The small ruminants are considered to be an important sector worldwide, and they account approximately 56% of the world's domestic ruminant population (FAO 2016). Predominant sheep and goat population are distributed in arid tropical environment (FAO 2016). This sector plays an important part in the development of the ecosystem, conserving the biodiversity and also supplying niche marketable products (Marino et al. 2016).

Small ruminants are mainly distributed in tropics due to their wider adaptive potential (Silanikove 2000). Small ruminants especially sheep have the ability to graze on wider range of pastures such as wasteland in developing countries to pasturelands in Australia (Monteiro et al. 2018). Small ruminants also act as an important source of GHG (FAO 2016). Opio et al. (2013) reported that milk production of small ruminants has a higher global average carbon footprint when compared with cattle and buffalo milk production (6.5 vs 2.8 and 3.4 CO_2eq. per kg of milk, respectively). The carbon footprint of meat production is low in sheep and goat as compared to large ruminants (23.8 vs 46.2 and 53.4 kg of CO_2eq./kg of carcass weight). These differences are mainly due to: (i) higher productivity of dairy cows; (ii) higher fecundity, greater prolificacy, reproduction cycles and short cycles for the meat production in sheep and goat than the beef cattle production. Therefore, small ruminant farming can offer an efficient and sustainable option for meat production in addition to favoring carbon balance of the production system (Marino et al. 2016).

There is a global pressure on livestock production system due to their role in climate change and emission of GHGs. Small ruminants are very hardy and cope with harsh environments by means of various key adaptive mechanisms, viz., behavioral, morphological, physiological, and genetic adaptations (Sejian et al. 2012a; Seixas et al. 2017). Small ruminants play a significant role in combating climate change by their utilization of low-quality and low-quantity feed resources (high digestive efficiency) which are not used by other ruminants, morphologically smaller body size, low metabolic requirements and ability to reduce metabolism, ability to adjust to different environments, superior heat balance capacity and tolerant capacity to water shortage, and capacity to emit less methane.

Therefore, small ruminants are advantageous for future adaptation of livestock to climate change and to protecting earth ecosystem. However, information on the productive potentials of several agro-ecological zone-specific indigenous breeds is scant warranting detailed studies on the adaptation capabilities of indigenous breeds of small ruminants across various agro- ecological zones.

12.7 Challenges Associated with Small Ruminant Production

Various factors that affect the small ruminant animal production efficiency and productivity are (i) lack of feed and fodder availability; (ii) shrinking of available grazing land; (iii) ineffective financial support; (iv) poor infrastructure; (v) lack of organized market for small ruminant products; (vi) nonavailability of high-yielding breeding stock; (vii) lack of national breeding policy; (viii) unorganized and unhygienic slaughterhouses; (ix) poor initiatives on conservation of indigenous goat breeds; (x) climate change; (xi) lack of modern techniques for improving the reproductive efficiency; (xii) lack of veterinary care; and (xiii) high kid mortality (Mohini et al. 2018). Under the South Kivi and eastern DR Congo region, the challenges faced by the small ruminant animal production include animal diseases, 78%, followed by 60% of lack of feed, animal housing space, transportation, and veterinary care and products (Maass et al. 2012). Similarly, in the Sudano-Sahelian zone of Mali in West Africa, the challenges faced by the small ruminant farmers include the feed scarcity, water scarcity leading to surge in animal diseases, lack of housing, absence of stock routes, herders and farmers' conflict, and poor productive and reproductive performing animals (Umutoni et al. 2015). Major constraints faced in arid and semiarid regions include feed and fodder scarcity and lack of good-quality breeding stock especially in the existing small ruminant production system (Kumar and Roy 2013). Similarly small ruminant farming also faces several challenges in developing countries like India wherein limited awareness among the farmers about the productive potential of small ruminants; absence of/limited active rearing organizations; pressure due to fodder unavailability; inefficient veterinary health services; lack of breeding programs focusing on genetic improvement; cumbersome credit and insurance claim procedures; inefficient marketing mechanisms; and poor interdisciplinary coordination are listed among the prime

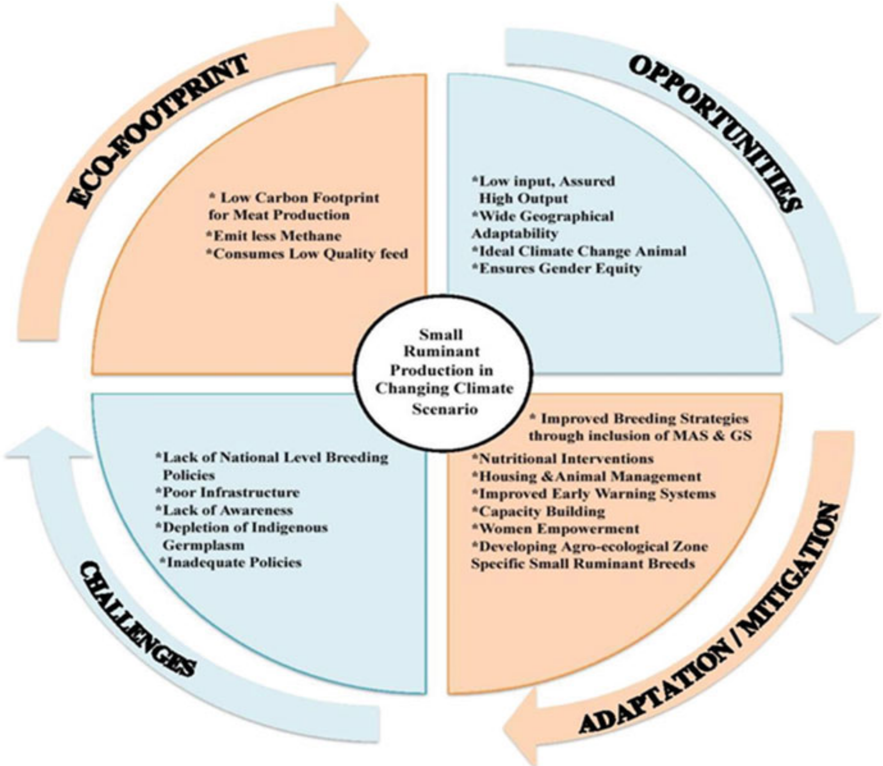

Fig. 12.1 Opportunities and challenges associated with eco-intensified small ruminant production strategies (Conceptualized from Opio et al. 2013; Mohini et al. 2018; Richkowsky et al. 2008; Sejian et al. 2019)

challenges (CALPI 2005). Figure 12.1 describes the various opportunities and challenges associated with eco-intensified small ruminant production strategies.

Hurdles faced by small farmers in the Latin American countries are adaptation of new technology, vulnerability during drought periods, disease conditions, low investing capacity, and limited access to market (Rodríguez et al. 2016). Challenges in Mexico include the limited availability of veterinary health, extension, and diagnostic facilities against the endemic diseases like *Brucella melitensis* and *Chlamydia* spp. Intensive feeding in commercial industries which has increased the cost of feeding and inability to produce high amount of goat milk yield during high-demand season are the common issues with Mexican small ruminant farmers. However, in Brazil the availability of poor-quality forages during dry season and the lack of planning, organizing capacity, selection traits, sustainability, and market trends are the other challenges faced by the small ruminant farmers (Rodríguez et al. 2016). In Bolivia, lack of proper infrastructure in goat rearing poses a major challenge in the arid and semi-arid zones. On the contrary, Peruvian goat production has suffered setbacks due to cultural prejudice, lack of scientific technology, socio-economic conflicts, and bureaucratic politics (Perevolotsky 1991).

12.8 Heat Stress Amelioration Strategies in Small Ruminants

12.8.1 Breeding Strategies

Ideally small ruminant farming should be able to maintain a balance between its production, profitability, and sustainability. This could be achieved on merging several aspects like selective breeding, nutrition, health, management, and market demands. Several factors have to be looked at while considering the breeding objectives, economic values of the trait being one among them. Tagging economic values to targeted breeding traits can ensure if the selective breeding is proportional to the economic returns. Though this is not a new concept, studies in this aspect are comparatively limited. The relative economic values for milk yield and daily gain were estimated as 84.96:15.04, 84.42:15.58, 83.45:16.55, and 82.36:17.64 for Bardhoka (BAR), Balusha (BAL), Sharri (SHA), and Kosova (KOS) sheep breeds, respectively, reared in Kosovo, Croatia (Bytyqi et al. 2015). Similarly, economic values for production and functional traits were derived for Kenya dual purpose goats. These values were calculated based on their production system and also production circumstances (Bett et al. 2007). Conducting such studies would not only give an estimate for the economic value of the concerned trait but would also give an insight into its value under different production systems. Positive economic values for the traits under different rearing and production system are indicative of a positive effect on the profitability of the system by a unit increase in the genetic merit of the trait. Therefore, it is essential to consider this variable while breeding for thermo-tolerance.

The tropical regions, especially Asia and Africa, are the major centers for sheep and goat production. Despite being subjected to extreme climatic conditions, which is predominant in these regions, the native sheep and goat breeds have excellent adaptability, tolerate heat stress, and also survive well on low-quality feed. Therefore, ensuring sustainable use of these indigenous livestock diversity could lead to improved productive performance of these animals. Among all the strategies to target to strengthen sustainability of indigenous livestock breeds, improved breeding programs are the most potential approach (Richkowsky et al. 2008). The preliminary initiative to be taken for this is to promote the use of indigenous livestock among the farmers; reconsider breeding programs; screen these native small ruminants to identify potential adaptive traits and candidate biomarkers; and finally incorporate them into the breeding programs through advanced breeding strategies like marker-assisted selection (MAS) and genomic selection (GS).

Developing elite thermo-tolerant breeds having the ability to survive across different agro-ecological zones is the need of the hour. It is the genotypic traits that give a better overview of the impact of heat stress on small ruminant production and also on their adaptability. Advances in the field of biotechnology with techniques like next-generation sequencing, metagenomics, and proteomics have paved a quicker pathway to identify such biomarkers (Sejian et al. 2019). Researchers across the globe have reported a number of potential candidate genes associated with heat stress response and adaptation in sheep and goats. Genes influencing growth (*insulin-like growth factor-1* (*IGF-1*), *growth hormone*; *growth hormone receptor* (*GHR*)), milk production (*diacylglycerol O-acyltransferase 1* (*DGAT1*); *prolactin receptor* (*PLR*)), meat production (*leptin* (*LEP*); *myostatin*), reproduction (*luteinizing hormone receptor*; *estradiol receptor* (*ESTR*)), and adaptability have been identified in small ruminants (Tao et al. 2013; Iso-Touru et al. 2016; Archana et al. 2018; Sejian et al. 2019). Incorporation of such genetic information into advanced breeding programs can aid to develop climate-resilient livestock population.

The MAS and GS have been proven to have higher selection gains when compared to the conventional breeding strategies. However both MAS and GS were adopted predominantly in the temperate livestock industry with the main focus on large ruminants, pigs, and poultry. The accuracy of genomic prediction for thermo-tolerance by GS was predicted to be between 0.42 and 0.61 using high-density single nucleotide polymorphism (SNP) genotypes. This value is much higher than that of pedigree-only selection which was 0.16. Adopting these advanced breeding programs in small ruminant breeding would be an ideal long-term strategy to reduce the adverse effects of heat stress and develop climate-resilient breeds of sheep and goats. Another important criterion to look at while designing a breeding program is the development of agro-ecological zone-specific sheep and goat breeds. Developing and maintaining such small ruminant diversity can boost the livelihood of marginal small-scale farmers. Additionally, such improvements could also help other regions having similar agro-ecological zones sustain small ruminant production during the varying climatic conditions.

12.8.2 Nutritional Interventions

Nutritional intervention is an important heat stress mitigation strategy to alleviate heat stress to improve productivity in sheep and goat. The adjustment in the ration balancing is highly significant in minimizing the adverse impacts of heat stress in sheep and goat (Sarangi 2018). The modification includes feeding of animals at cool hours with appropriate feeding intervals and grazing time and altering the dietary composition of major macro- and micronutrients along with supplementation of vitamins and feed additives (Conte et al. 2018). Feeding during the cooler periods of the day restores the normal feed intake which may also be helpful in reduction of metabolic and climatic heat load. Further, the enhancement of frequent feeding intervals reduces the diurnal variations in rumen fermentation variables in addition to maintaining effective feed utilization (Soto-Navarro et al. 2000; Sejian et al. 2015a). The encouragement of grazing before sunrise and during the night hours when the environmental temperature is at minimum in case of grazing animals may help to reduce the heat stress effect. Further, heat stress alters the nutrient requirements and signifies the need for modification of ration balancing and diets modified for low metabolic heat production to sustain the normal feed intake and performance.

12.8.2.1 Dietary Fiber

The digestives and metabolic processes are the additional sources of heat production in animals, and supplementation of high fiber content in the feed may enhance heat production (Conte et al. 2018). The modification in the dietary fiber content is highly essential to reduce the high heat increment during rumen fermentation processes. The low fiber content of feed during heat stress is necessary in view of heat increment which is correlated with more acetate metabolism than propionate (Atrian and Shahryar 2012). Sheep and goats are highly capable of converting poor-quality feed into products than large ruminants. Feeding of corn grain-based or wheat forage treated with 3% sodium hydroxide decreased the physiological responses in sheep during heat stress exposure resulting in declined fermentation rate and minimal heat production (Osei-Amponsah et al. 2019).

The feed intake is improved in heat-stressed animals when the neutral detergent fiber (NDF) level of roughage ranged between 27 and 35% in the ration, and this also reduced the respiration rate and rectal temperature during heat stress (Miron et al. 2008). In a report it was established that the reduction of dietary roughage NDF from 18–12% on dry matter basis significantly reduced the rectal temperature (Adin et al. 2009). Further, supply of sufficient high-quality fiber forage in diet could retain normal rumen activities in heat-stressed animals. In addition, highly fermentable carbohydrates may be used during heat stress conditions to restore feed intake, and the benefit of high-grain diets must be counterbalanced for the possible threat of rumen acidosis. However, it is highly essential to maintain adequate level of 18% acid detergent fiber and 28% NDF on dry matter basis of the feed to ensure optimal rumen function (West et al. 2003).

12.8.2.2 Dietary Fat

Energy is the limiting nutrient which has to be increased in the ration along with concentrate to reduce forage content to meet the higher demand for maintenance as well as to produce less metabolic heat (Conte et al. 2018). Reduced roughage to concentrate ratio enhances the feed utilization efficiency in heat-stressed animals. The supplementation of fat increases the net energy intake during hot environmental conditions resulting in less heat generated through metabolic processes than fiber- and starch-based diets (Gupta and Mondal 2019). The addition of fat in the diets must be restricted up to the level of 5% without any negative effect on ruminal microbes (Palmquist and Jenkins 1980). Further, the source of supplementation must be of protected fat to obtain optimum performance because the rumen-protected fats in the diet lower the metabolic heat production and enhance digestive efficiency during heat stress (Conte et al. 2018). Supplementing 4% fat in the feed of dairy goats during summer has enhanced milk production efficiency and yield and at the same time reduced rectal temperature (Gupta and Mondal 2019).

12.8.2.3 Crude Protein

The reduced feed intake during heat stress exposure results in negative nitrogen balance in animals. The quality of protein source is highly important during heat stress conditions, and crude protein (CP) content of 16% with low degradability is optimum because highly degradable CP enhances the endogenous heat production in ruminants (Huber et al. 1994; Conte et al. 2018). Further, feed rich in undegradable protein along with calcium soaps of fatty acids and monopropylene glycol improves the performance of animals with lower plasma urea (Calamari et al. 2013). The dietary essential amino acids are important during heat stress for the restoration of protein-producing machineries or processes such as transcription and translation to sustain the productive performances of animals. Addition of lysine and methionine in the diet of lactating goats during heat stress increases the synthesis of milk protein and enhances the antioxidant capacity (Lin et al. 2009). The supplementation of lipoic acid enhances the thermo-tolerance by promoting insulin and antioxidant status of heat-stressed animals (Rhoads et al. 2013). The feeding of rumen-protected glutamine, arginine, tryptophan, and citrulline intensifies the immune status in ruminants subjected to heat stress (Conte et al. 2018).

12.8.2.4 Water

One of the best methods to reduce heat stress is provision of fresh, cool, and clean drinking water ad libitum. During heat stress the water requirements of small ruminants increase; therefore, it is necessary to ensure that the animals have continuous access to fresh drinking water both on the farm and at pasture (Da Silva 2010). Water is very essential to maintain the physiological functions such as tonicity of tissue, lubrication, thermoregulation, nutrient transport, and excretion. Water metabolism is highly associated with the thermoregulatory mechanisms of the ruminants in the regulation of homoeothermic status (Ben Salem 2010). Water acts as a heat carrier medium in the elimination of excessive heat load from the core body via evaporative heat loss mechanisms during heat stress. The requirements for water are controlled by dry matter intake, environmental temperature and dehydration, urine, feces, and milk (Al-Dawood 2017). The water requirement increases during heat stress for thermoregulation due to higher demand for heat dissipation which results in increased water intake (Berman 2006). Small ruminants encounter less water during different environmental conditions (Ben Salem 2010). In general, sheep and goats are very much capable to tolerate drought especially goats which are superior in water conservation because of their browsing nature (Silanikove and Koluman 2015). However, goats drink double the quantity of their water requirement during exposure to heat stress to assist both cutaneous and evaporative heat loss mechanisms (Hamzaoui et al. 2013; Caulfield et al. 2014). The total water evaporation is threefold higher as compared to water intake during hot environmental conditions in goats (Hamzaoui et al. 2013). However, the insensible water loss increases by twofold when the environmental temperature is 35 °C than at 18 °C (Shafie et al. 1994). Sheep drink 2 kg water/kg dry matter intake up to ambient temperature of 15 °C, and at 20 °C the water requirement increases by threefold (Al-Dawood 2017). Further, water consumption of sheep varies from 9 to 11% of the total body weight during winter, and it increases up to 25% in summer (Ismail et al. 1995). Therefore, providing fresh, clean, and cool drinking water ad libitum may ensure optimum performance (Samara et al. 2016).

12.8.2.5 Vitamins and Minerals

The reduction in feed intake as a consequence of heat stress during hot environmental conditions may influence the requirement of vitamins and minerals that are highly associated with health status and immunity (Conte et al. 2018). Therefore, it is essential to supplement vitamins and minerals to reduce the negative impact of heat stress in small ruminants. Supplementation of vitamins A and E along with trace minerals such as selenium (Se), copper, and zinc above National Research Council (NRC) recommendation improves the immunity and health status of ruminants during heat stress conditions (Khorsandi et al. 2016). The higher level of dietary vitamin E and Se reduces the respiration rate and rectal temperature during hot environmental condition and restores the normal feed intake in sheep (Osei-Amponsah et al. 2019). The ameliorative effect of vitamin E and Se is attributed to their capacity to overcome reactive oxygen species by decreasing the production of prostaglandins and cytokines which are compromised to activate systemic responses and feed intake (Mavangira and Sordillo 2018). Further, vitamin E is the primary lipid-soluble antioxidant in the cellular membranes which inhibits lipid peroxidation, and Se is an integral part of glutathione peroxidase (GSH-Px) that disintegrates hydrogen peroxide and lipid peroxide production (Chauhan et al. 2014; Osei-Amponsah et al. 2019). Further, Osei-Amponsah et al. (2019) suggested that the addition of betaine at the rate of 2 g per day alleviated the heat stress responses in sheep. The inclusion of protected niacin in feed which is a subcutaneous vasodilator alleviates heat stress by enhancing the evaporative heat loss and also minimizes the impact at cellular level (Lundqvist et al. 2008). The cation requirements increase especially Na^+ and K^+ during heat stress in animals due to their higher rate of excretion up to 80% and 18%, respectively (Goetsch 2019). Supplementation of $NaHCO_3$ and K_2CO_3 and $KHCO_3$ as a source of Na^+ and K^+ increases the feed intake and improves the production performances in ruminants (Sanchez et al. 1994). In addition, micronutrient chromium supplementation may reduce the negative impacts of heat stress through the enhanced action of insulin on glucose, lipid, and protein metabolism (Mirzaei et al. 2011).

12.8.2.6 Feed Additives

In general, the feed additives enhance the feed intake in animals where fungal cultures and plant extracts may have beneficial effects in rumen metabolism and thermoregulation of body temperature during heat stress (Conte et al. 2018). Supplementation of yeast enhances the nutrient digestibility and feed efficiency with maintenance of optimal rumen pH and improved the feed intake and production performances (Gupta and Mondal 2019). Shwartz et al. (2009) reported that inclusion of exogenous enzymes and yeast culture in the feed restored the rectal temperature during heat stress by facilitating thermoregulatory functions. The supplementation of plant extract daidzein to the heat-stressed ruminants counteracts the impacts of heat stress by promoting antioxidant system with increased level of glutathione peroxidase (Pan et al. 2014). Further, addition of *Ascophyllum nodosum* in the feed enhanced the production level with decreased rectal temperature during heat stress (Pompeu et al. 2011). Ellamie et al. (2020) proved that the supplementation of 4% of dietary *Sargassum latifolium* has enhanced the antioxidant defense system and regulation of thermo-respiratory and inflammatory responses during heat stress in Barki sheep. Soni et al. (2018) suggested that the supplementation of *Tinospora cordifolia* stem powder decreased the respiration rate and the adverse impact of heat stress in goat during hot environmental condition. The feeding of seaweed *Gracilaria birdiae* alleviates the heat stress and reduces the respiration rate and rectal temperature by enhancing the antioxidant capacity in heat-stressed goats (de Lima et al. 2019).

12.8.3 Management Strategies

The extreme heat exposure in animals adversely disturbs the function of the animals' biological system that leads to reduced dry matter intake, altered energy metabolism (glucose, protein, and fat) and mineral and water metabolism, and changes in hormone, enzyme, and metabolite secretions and function, ultimately affecting the productive and reproductive potential of the animals. During dry hot summer, heat exchange by radiation is the predominant mechanism to dissipate body heat. Alteration of microenvironment of an animal through proper housing can help to protect the animals from direct solar radiation and maintain their optimal performance (Renaudeau et al. 2012). Therefore, various managemental strategies like provision of shelter/shades and evaporative cooling (fans, sprinklers, etc.), adjustment in feeding and grazing, and providing clean water should be applied to alleviate negative impact of heat stress exposure in farm animals (Morrison 1983; AI-Dawood 2017).

12.8.3.1 Housing

The site of animal's house and housing design is fundamental to plan for heat stress amelioration in small ruminants. Housing site should be the first criteria to be considered as it plays a vital role on heat dissipation which can ensure long-term protection benefits (Da Silva 2010: Sejian et al. 2015b). Fully enclosed shelters would hinder the natural ventilation and hence should be strictly restricted in hot climatic areas. Therefore, partially enclosed shelters are most preferable (Sejian et al., 2015b). Also, while designing animal house, simple and basic rules related to structure and functions of house should be adopted to reduce the impact of heat stress (Renaudeau et al. 2012).

12.8.3.2 Shade

Modifying the surrounding environment of an animal is a fast method to ameliorate heat stress. However environmental alterations are expensive and economically not feasible for farmers (Dunshea et al. 2013). Shades are the most simple, easiest, and cost-effective method to reduce the impact of heat stress due to direct solar radiation which help the animals cool themselves enhancing their productive and reproductive performance (Sejian et al. 2012a). However, shade does not change air temperature or relative humidity. It is most applicable under extensive rearing system in tropical and subtropical regions. These shading structures used could be either natural or artificial. Trees are natural source of shades that provide an effective shelter to the animals to protect them from the effects of solar radiation combined with beneficial cooling as absorption of heat and evaporation of moisture from the leaves. Moreover, tree plantations are beneficial to animals, humans, and environment (Da Silva 2010; Renaudeau et al. 2012; Sejian et al. 2012b).

There is a limitation in the use of natural shades under grazing conditions, and this necessitates use of artificial shades to ameliorate thermal stress in animals (Silanikove et al. 2010). Well-designed shade structure could decrease total heat load by 30–50% (Blackshaw and Blackshaw 1994; Collier et al. 2006). During hot and humid summer season, animals could easily access to shade, and provision of shade is an efficient tool to alleviate heat load, and it enhances animal comfort and helps to maintain weight gain and milk production and reproductive efficiency (Berger et al. 2004). Provision of artificial shade to dairy cows was found to increase milk production and reproduction in addition to reducing the rectal temperature and respiration rate in shaded dairy cows (Collier et al. 2006). Providing shades during extreme weather condition can ameliorate heat stress and reduce mortality in livestock (Bubsy and Loy 1996; Gaughan et al. 2010). Shade at feeders increases the feed intake and feeding time and reduces feed waste in goats (Alvarez et al. 2013). Feed intake and growth performance increased in shaded feedlot cattle during hot summer months (Blackshaw and Blackshaw 1994; Mitlöhner et al. 2001).

12.8.3.3 Cooling

The cooling systems minimize the heat stress in livestock. There are several methods available to cool the air temperature below ambient temperature for optimum production. Air conditioning is too costly in livestock farming system. Evaporative cooling systems are more economical, and they can be achieved by two approaches: (i) directly by cooling the animals where moisture evaporates from the skin surface of the animal and (ii) indirectly by cooling surrounding environment of the animal using cooling pads and fans inside the shed (Sejian et al. 2012b). Evaporative cooling system includes mist, fog, cooling pad, and sprinkling. Evaporative cooling is more effective when sprinkling combined with fan that facilitates evaporation of moisture from skin and hair coat. Spraying is the more effective and economically viable method for alleviating heat stress in small ruminants. The respiration rate, panting score, and rectal and skin temperature of the sprayed goats are within normal range during the hot summer condition (Darcan et al. 2007). These authors also observed that feed intake and physical activity of sprayed goats were higher compared to that of control group. Thus, spraying method effectively reduces the effect of heat stress and improves animal welfare. Spraying combined with forced ventilation further improves the benefit of spray cooling system. Darcan and Güney (2008) reported that spraying combined with forced ventilation was found to be an effective management tool to minimize heat stress effects in goats during summer months of hot and humid Mediterranean climate. These authors observed that spraying and forced ventilation (1 h/day) of heat-stressed goats resulted in higher feed (18%) and water (7%) intake resulting in increased milk production (21%). Apart from this, increasing the air movement along with active evaporative cooling is more effective to ameliorate heat stress. East and Central European countries practice fan and fogger cooling system in the free stalls and feeding area as a protective measure against heat stress (Broucek et al. 2020).

Air movement plays a significant role in reducing heat stress, and it can be natural or forced (mechanical). It facilitates both convective and evaporative heat losses. Open-sided construction might increase natural air movement and provide comfort during hot summer condition. If natural ventilation is not sufficient, additional fans can be installed to increase air movement, thus enhancing animal heat losses. Installing shade plus fans and sprinklers could also enable additional benefit. Fans however have better efficiency in confined structures wherein they help in the movement of warm air from the animal via convection and thereby cooling it. However, sprinklers facilitate heat losses from animal body via conduction. Thus adopting a combination of both, fans and sprinklers, can have additive effect by merging conduction and evaporative cooling (Nickerson 2014).

12.8.3.4 Feeding Management

Reduction in feed intake has been observed in animals during summer hot condition. Therefore, adjustments in feed composition, feeding time, feed quantity, and grazing hours are vital to achieve the optimal production during hot condition in small ruminants. During summer, the feeding behavior changes both in sheep and goat, and increased consumption was recorded when fed in early morning and late evening hours (West 1999). Thus in order to maintain the normal feed intake during heat stress, animals should be fed preferably during the early morning or late evening which have the cooler hours. Such feeding practices also prevent increment of metabolic heat within the animals. Fiber to concentrate ratio significantly affects the nutrient digestibility in ruminants (Islam et al. 2000). Feeding low fiber rations during heat stress condition is the better choice to avoid metabolic heat load. To compensate for reduced dry matter intake and induce better nutrient utilization, high-energy-density diets are preferred (West 1999).

12.8.3.5 Animal Handling

Handling of animals during hotter part of the day will increase the stress level of exposed animals in addition to increasing their body temperature. Therefore, handling should be avoided during hot and humid weather condition. If it is necessary, handling protocols (vaccination, deworming, castration, transportation, milking and other herd health programs, etc.) must be carried out during cool hours of the day (Morrison 1983). Table 12.2 describes the various amelioration strategies to reverse heat stress effects in small ruminants.

Table 12.2 Heat stress amelioration strategies in small ruminants

Amelioration strategies	Outcome	References
Breeding strategies		
Selective breeding of indigenous breeds	Thermo-tolerant breeds of sheep and goat	Richkowsky et al. (2008), Tao et al. (2013), Iso-Touru et al. (2016), Archana et al. (2018), Sejian et al. (2019)
Marker-assisted selection (MAS)		
Genomic selection (GS).		
Nutritional interventions		
Low dietary fiber	Reduced metabolic heat production	Atrian and Shahryar (2012), Osei-Amponsah et al. (2019)
Dietary fat (<5%)	Enhanced milk production and digestive efficiency	Palmquist and Jenkins (1980), Conte et al. (2018), Gupta and Mondal (2019)
Crude protein	Enhanced antioxidant, immune and insulin function	Lin et al. (2009), Rhoads et al. (2013), Conte et al. (2018)
Water	Maintain essential physiological functions including thermal balance	Da Silva (2010), Ben Salem (2010), Hamzaoui et al. (2013), Samara et al. (2016), Al-Dawood (2017)
Vitamins and minerals	Improved antioxidant, immune, metabolic, and health status	Mirzaei et al. (2011), Chauhan et al. (2014), Khorsandi et al. (2016), Mavangira and Sordillo (2018), Osei-Amponsah et al. (2019)
Feed additives	Improved feed intake, nutrient digestibility, maintaining rumen pH, thermal balance, enhanced antioxidant status	Shwartz et al. (2009), Pan et al. (2014), Conte et al. (2018), Soni et al. (2018), Gupta and Mondal (2019)
Management strategies		
Housing	Protection from solar radiation	Da Silva (2010), Sejian et al. (2015b)
Shade	Protection from solar radiation, enhanced feed intake, animal comfort and productive performance	Berger et al. (2004), Collier et al. (2006), Silanikove et al. (2010), Sejian et al. (2012a, b), Alvarez et al. (2013), Dunshea et al. (2013)
Cooling	Improved feed intake, better animal comfort, enhanced growth performance and milk production	Darcan et al. (2007), Darcan and Güney (2008), Sejian et al. (2012b), Nickerson (2014), Broucek et al. (2020)
Feeding management	Prevent metabolic heat increment, better nutrient utilization	West (1999), Islam et al. (2000)

12.9 Adaptation Strategies to Sustain Small Ruminant Production

Being aware of the adverse impact of climate change on livestock production, it is necessary to initiate suitable ameliorative and mitigation strategies to reduce the damage. The livestock production in the developing countries, most of which are in the tropical zones, is most hit due to climatic variations than the developed countries. Despite having diverse small ruminant populations which are hardy and well adapted to harsh environments, the tropical regions fail to sustain production as they lack the basic adaptation strategies to tackle the situation. The developed countries focus and emphasize on developing and implementing the adaptive technologies to prevent a calamity and also prepare them for it. One of the prime technological interventions required to prepare the farmers against harsh climate is the early warning system (Sejian et al. 2015b). Such systems having high accuracy are not available in the developing part of the world resulting in more intensified devastating effects of climate extremes on small ruminant production. Moreover, most of such modeling approaches are not specific for each region within a country. This is essential as the predictions made in one region may not work effectively in another. Additionally it is also necessary to have proper information to disseminate those technologies as they do not reach the end user, the livestock farmers. Informing the farmers about the varying climatic conditions and providing them with a relatively accurate climate prediction well in advance can give them sufficient time to initiate adaptive methodologies. This information should also be disseminated to the local veterinarians and other stakeholders who can also provide their knowledge and inputs.

Secondly, as mentioned in the earlier sections, promoting indigenous goat and sheep breeds adapted well to the local environment is the most potent and effective adaptive strategy. The sheep and goat farmers should be made aware of the excellent adaptive traits exhibited by these animals. Promoting indigenous livestock population, well adapted to each agro-ecological zone, and forming breeding strategies to improve their production would be the ideal approach to ensure long-term amelioration against heat stress (Sejian 2013). Additionally, validating the performance of adapted indigenous sheep and goat in multiple locations may yield rich dividends Studies conducted by Pragna et al. (2018b) have identified Salem Black goat (breed from the South Indian state of Tamil Nadu) to be performing better in Karnataka (South-Indian state) than its native, Osmanabadi breed. Thus it is of prime importance to promote such breed development programs.

Another adverse impact of climate change is on the fodder production and water availability. This not only leads to huge losses to agricultural farmers but also hampers livestock production as most of the production losses in livestock during heat stress are due to such indirect effects. Therefore effectively implementing fodder and water management strategies can resolve multiple issues. Unlike earlier times, it may not be suggestive to follow the uniform farming practice of cultivating a single crop. Farmers should be encouraged to opt mixed cropping and preferably grow zone-specific vegetable based on the soil type and input availability. At the same time, livestock farmers should also follow stringent grazing practices to avoid overgrazing and follow rotational grazing. Due to the increasing human encroachment, there is a conflict for land occupation, and farmers often intrude into either barren or swamp lands for agricultural purposes. Studies have proved that though such practices could provide a temporary relief from the fodder scarcity, eventually they were non-profitable. Hence proper surveillance and advice have to be taken from the experts before adopting any such innovative approaches. Apart from this, the indigenous knowledge of the farmers may also be considered.

Water management is a vital entity both from livestock and agricultural production point of view and also for human survival. Time immemorially several water management strategies have been suggested and practiced by our ancestors. However most of these are not practiced currently. Moreover in such approaches, the needs of the poor farmers are often neglected, and they face huge crisis. Improving water availability and implementing effective integrated water management strategies should be the priority of any climate change adaptive strategy. Conserving the existing water resources and reviving the drying lakes and ponds can resolve a major proportion of this problem. Such approaches will undoubtedly need a cooperative involvement of the stakeholders at various levels.

Women are considered to be very effective in managing livestock production; however, they have either not given an opportunity or not given due credits for their contribution. Often women are looked down and tagged to be suited for managing household chores, but they are more responsible and possess excellent management skills. They have outstanding decision-making skills which can be effectively diverted towards livestock rearing and production. Women also have an exceptional leadership quality and convincing ability to bring about a change. In fact they are also said to play a more effective role in ecosystem management services and food security than men. Increasing participatory research into the roles of women in small ruminant sector and also encouraging the involvement of many more would aid to boost the production (Sejian et al. 2017). This can also help in reducing the gender gap in addition to giving them more confidence to take livestock as one of their primary activities. This could be achieved by creating special livestock insurance and subsidy schemes special for women livestock owners.

The success of any adaptation strategy ultimately depends on how effectively it is transferred and implemented by the end user, the livestock owners. This would require active participation by the government and nongovernment agencies to support the development of adaptive strategies and also various policies. There is also a need to create awareness among the livestock keepers about the impact of climate change on small ruminant production and also urge them to implement the adaptive strategies. Conducting trainings to enlighten farmers on the heat stress ameliorative measures, organizing workshops on heat stress mitigation, forming committees to represent the issues of the farmers to higher authorities, and also mitigating the climate change-induced adversities through technological and knowledge dissemination approach from the experts to farmers are a few possible capacity-building strategies (Sejian 2013). Another important point to be looked at is farmer's requirements and problems as addressing that would directly boost production. It is also necessary to look at the indigenous methodologies adopted by the poor and marginal-scale farmers to tackle heat stress. Bringing the farmers in decision-making loop and implementing participatory approach would enable the development of a holistic approach for mitigating the adverse heat stress impacts.

12.10 Research and Development Priorities Associated with Small Ruminants Towards Reducing Eco-footprint and Sustainable Livestock Production

As the scientific community battles in its efforts to identify robust animals which could withstand the climate change-associated adversities, research and development priorities need to be in place for the future to sustain small ruminant production. The primary focus of such approach must be to ensure active participation of all the stakeholders including the poor and marginal farmers. While sustaining the productive potential of small ruminants deserves significance, equally important is to minimize the impact of such efforts on the ecosystem. One possible way to realize this is to find solution through genetic approach involving modification of the existing breeding programs to cater the need of the hour for the small ruminant sector. Intensified research efforts must be in place to identify potential biomarkers governing their production, adaptation, and low methane emission. Such an attempt could not only help in developing climate-resilient small ruminant breeds but also would realize the vision of producing animals which can produce very less methane per unit of feed consumed. This could effectively minimize the sectors' impact on the ecosystem by reducing their carbon footprint. Several advantages associated with the small ruminant sectors in the face of changing climate than the large ruminants make them the future animals to invest. Therefore, setting up of research and development priorities oriented towards creating such robust animals specific to different agro-ecological zones may help to ensure the livelihood securities of poor and marginal farmers across the globe.

12.11 Policies and Legal Framework

Small ruminant farming could be a vital source of income for a major proportion of marginal small-scale farmers in the near future provided their potentials are propagated and adopted effectively. The first move for this would be to put forth a sound breeding policy taking into account the production, adaptation, and low methane emission trait. The government also needs to take initiatives to conserve its valuable indigenous germplasm which also has been overlooked. For all these goals to reach an effective stage, the end users, the farmers, should be first educated and informed about the importance of adopting sheep and goat farming. Awareness should be created among the farmers about the negative influence of heat stress on sheep and goat production, and the potential role of small ruminants should also be highlighted. Apart from creating such awareness, the policy planning should also include provisions for financial assistance to such farmers. Sustainable livestock farming especially sheep and goat farming via utilization of thermo-tolerant breeds would be the ideal strategy to combat the changing climatic scenario, and this should be enforced through a multidisciplinary approach. Therefore along with the government agencies, nongovernmental organizations, private firms, local cooperatives, and self-help groups should also play an active role to improve small ruminant production. A comprehensive approach should be initiated in unison by all the stakeholders beginning from appropriate data recording to development and distribution of agro-ecological specific thermo-tolerant sheep and goat breeds up to adoption of advanced technologies and providing financial support to the farmers. Further legal frameworks should also be considered to strengthen the existing infrastructure and skilled manpower engaged in the small ruminant sector. Taking all these comprehensive measures could aid in sustaining sheep and goat farming.

12.12 Conclusion

Sustaining livestock production in the changing climatic condition is one of the top priorities for the farming community in the global change scenario. As the projections of climate change are quite alarming for the future, it becomes a formidable challenge for the scientific fraternity to find solution for the problem. Therefore, assessing the current situation and planning for the future climate projections must go simultaneously to help the farming communities to prepare themselves for the battle ahead in sustaining livestock production. Small ruminants are undoubtedly identified to be the most climate-resilient species in the agricultural sector. This is particularly very significant in the developing part of the world wherein animal agriculture is one of the primary livelihood options and the prevailing tropical environmental conditions are not congenial for sustaining their production. In addition, most of the farmers in these geographical regions are resource poor, and they look towards the policies from the government for their survival. Small ruminants can definitely offer huge relief to such farming communities due to their higher thermo-tolerance, drought tolerance, ability to survive on limited pastures, and disease resistance potential. With these huge advantages over other farm animals, small ruminants are tipped to be the go-to species for future in the changing climate scenario. It is apparent that apart from setting up of research and development priorities, the government also must ensure that appropriate policies do exist to safeguard the interests of poor and marginal farmers. The sector also has the potential to generate minimal eco-footprint for the products generated from the small ruminants. Enough investments with multi-stakeholder approach can help the farming communities to equip themselves to cope with the adversities associated with climate change by sustaining the small ruminant production in addition to reducing their impact on the ecosystem.

12.13 Future Thrust Area

The future thrust area for sustaining small ruminant production during exposure to adverse environments includes (i) development of more reliable heat indices; (ii) development of new breeding programs involving traits pertaining to production, adaptation, and low methane emission; (iii) understanding the applications of nutrigenomics, metagenomics, and transcriptomics in small ruminant production; (iv) analyzing the epigenetic pathways of adaptation in small ruminants; and (v) climate-smart small ruminant production.

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Determining the Perspective of Turkish Students Ecological Footprint Awareness Based Upon a Survey

13

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Contents

Abstract

In the near future, the more of energy demand probably will be met by low or zero carbon. Therefore, the size of each person's footprint decreasing is important, due to contribute in meeting this potential demand. Turkey as a developed country with a high level of reliance on imported energy supplies is in the center of attentions for utilizing new energy resources as it is blessed with considerable

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potentials of renewable and sustainable energy. Hence, the purpose of this study is to explore how Turkish consumers perceive the ecological footprints and how they behave in the case of their lives. The data gathered by 375 higher education students that are belonging in both Y and Z generation with a formal ecological footprint quiz. The perspectives on each footprint cover all of the footprints such as carbon, food, good and services, and housing.

Keywords

Carbon Footprint · Ecological Footprint · Students · Turkish Consumer

Abbreviations

CLUM	Consumption Land-Use Matrix
EF	Ecological Footprint
GFP	Global Footprint Network Report
GHG	Greenhouse Gases
OECD	Organization for Economic Co-operation and Development
UN	United Nations
WHO	World Health Organization

13.1 Introduction

Wuhan (China) Municipal Health Commission stated a cluster of cases of pneumonia in their city, and then a novel coronavirus was eventually determined. Began first in China, deeply concerned both by the alarming levels of spread and severity and by the alarming levels of inaction, World Health Organization (WHO) announced that COVID-19 can be characterized as a pandemic in 11 March 2020 (www.who.int) (WHO 2020). After this date, the human beings realized that nothing would be the same again as it was before in their world. As it is seen that for the last decade, however we are being aware of the danger, but it is difficult to implement lots of cautions all over the world at the parallel time. Governments are implementing the strict lockdown orders to slow the spread of the Covid-19 virus disease all over the world. Human beings realized that there is one world. "*There is no planet B,*" this slogan has been used in United Nations conference on climate change in Paris. In this conference, most participants have referred to the consumption and waste which cause numerous damages to the environment (Hennig 2015). Nowadays the term of ecological footprint has been accepted as one of the most popular environmental performance indicators (Ulucak and Apergis 2018).

In this chapter, ecological footprint concept and its sense in the literature will be discussed then there is a statistical result report of perceptions of students in an emerging economics, Turkey**.** Ecological footprint of consumption in Turkey is more than 50% from global bio-capacity per capita (www.footprintnetwork.org). Turkey is one of the emerging economies countries that have major amount of younger population. According to recent research made by higher education institution in (2018), number of university students enrolled for 2017–2018 academic years approximately eight million (www.yok.gov.tr). In recent days, the daily life activities of students have gained importance in socialization. Thus, one student's behavior can easily affect the behavior of another student.

13.2 Conceptual Framework

13.2.1 Overview of Ecological Footprints

Ecological footprint (EF) can be defined as a measurement of human demand on the Earth's natural resources and is widely used for increasing awareness of environmental impacts, education tools, and resource management tool (See et al. 2016). The concept had gained the first-time attention in United Nation (UN) World Summit on sustainable development, at South Africa in 2002 (Raj et al. 2012; Meena and Lal 2018). Until that time, the concept has not been quite popular among people and societies. Especially, with the beginning of the new century, environmental issues have started to be paid more attention (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). Thus, many educational communities, businesses, and other public institutions have looked for best way to integrate environmental issues into their curriculum and business plan (Haque and Roper 2005).

Ecological footprint analysis was developed by William Rees et al. to observe that all electricity, land and water usage for resource production over a given period of time is used (Rees et al. 1996). Ecological footprint is associated with the area of productive land, energy, and water sources for a population to survive their life over the 1 year (Venetoulis 2001; Südaş and Özeltürkay 2015; Meena et al. 2018). For example, two people consume approximately 100 pounds of corn and 100 pounds of wheat in a year; this requires about half an acre of ecologically productive land. Each person's footprint would be half this amount. Nevertheless, the measurement of ecological footprint is not quite easy, it includes more complicated calculations. Such as, the footprint is divided into four consumption categories: food, carbon, housing, goods and services. Each category has own questions to measure and understand the ecological footprint of population in a various community. Thus, an ecological footprint is one of the best indicators that observe the balance of the demand on resources and the ability of the supply of these resources (Da Cruz and Marques 2014; Meena et al. 2020a, b). Furthermore, ecological footprint and sustainability have a significant relationship in terms of improving environmental standards (Goel et al. 2011). Therefore, in recent years, there has been an increasing interest in ecological issues not only in economic environment but also in academic area. Thus, ecological footprint has been applied at various scales: university, individual, regional, and world level.

Over the last half century, the impacts of both global warming and manufacturing industry on the environment have been felt most strongly and seriously in the world.

Using cleaner types of energy and fuels will have co-benefits for the country's economic growth and environmental sustainability (Yousefi-Sahzabi et al. 2017). The contribution of the Kyoto Protocol especially among the developed countries especially has huge effect in the process. Kyoto Protocol (the United Nations Framework Convention on Climate Change) was adopted in 1997 and developed countries classified their prospects for decreasing of greenhouse gases (GHGs) over the first commitment in the period of 2008–2012 (Olsson and Olsson 2012). The most proactive countries' mindfulness was appeared to lead their companies, consumers, and at all stakeholders during the production and consumption process. Indeed, the most proactive companies should be engaged with both internal (employees) and external stakeholders (customers, communities, governments as a regulator, and suppliers) to decrease their carbon emissions (Bocken and Allwood 2012).

13.2.2 Ecological Footprint Analysis in Developed and Developing World

Humanity is currently faced up two essential challenges. One of them is economic development and the other one is preserving the earth's environment. Especially for both developed and developing countries, the major concern is called as the environment, as a result of accumulation of GHGs in the atmosphere resulting in a raise in mean global temperatures (Uddin et al. 2017). The related studies that gather the data from developed and developing countries mostly use the secondary data. Table 13.1 has shown the related studies:

Wackernagel et al. (1999) evaluating the use of natural capital with the ecological footprint in Sweden. They improved the method of footprint and bio-capacity calculations. Lenzen and Murray (2001) examined a modified ecological footprint method and its application to Australia. Another study made by Chang and Xiong (2005) investigated the ecological footprint based on RS and GIS in arid land. Ghita et al. (2018) published a paper in which they identified and forecasted patterns of environmental footprint behavior in European countries. In the previous studies, it is realized that especially European Union member and/or candidate member countries EF and different indicators relations were measured.

13.2.3 People Perception Based Awareness Regarding Ecological Footprint

According to study of Wackernagel et al. (2002) and Rockström et al. (2009), it shows that human demands on our planets' systems are rising significantly. This acceleration has caused the ecological deficit, in other words "ecological overshoot." In global, ecological problems have occurred significantly due to advanced technological development, rapid population growth, and industrialization since 1980s (Borucke et al. 2013). Following this, one question emerged among academicians

Table 13.1 Some related studies in developed and developing countries

Author (s)	Country (ies)
Wackernagel et al. (1999)	Sweden
Lenzen and Murray (2001)	Australia
Pereria and Ortega (2012)	Brazil
Galioğlu (2015)	Turkey
Aşıcı and Acar (2016)	116 countries
Uddin et al. (2017)	Australia, Austria, Belgium, Brazil, Canada, China, Cyprus, Denmark, France, Germany, India, Indonesia, Italy, Japan, Mexico, Nigeria, Philippines, South Korea, Sri Lanka, Sweden, Switzerland, Thailand, Tunisia, Turkey, UK, USA, Vietnam
Ulucak and Bilgili (2018)	High, Middle- and Low-Income Countries
Ghita et al. (2018)	European Union member countries
Danish et al. (2019)	Pakistan
Sharif et al. (2020)	Turkey
Kassouri and Altıntaş (2020)	13 MENA countries (the Middle East and North Africa) Algeria, Bahrain, Egypt, Iran, Israel, Jordan, Libya, Morocco, Qatar, Saudi Arabia, Tunisia, Turkey, and United Arab Emirates

and policy makers; "*how the ecological footprint can be reduced through lower population, lower consumption and more efficient technologies*" (Wackernagel and Rees 1997). After the increasing of awareness of ecological issues by humanity, a considerable amount of literature has been published on ecological footprint. Many studies (Moffatt 2000; Wackernagel et al. 2006; Kitzes et al. 2008; Farber 2012; Hoekstra and Widemann 2014; Toth and Szigeti 2016; Galli et al. 2017; Global Footprint Network 2018) have indicated that humans are consuming natural resources much faster than the earth can regenerate. Increasing in awareness of students in environmental degradation has become one of the crucial topics. To be able to change the lifestyle and increase awareness towards friendlier environment, there is a large volume of published studies investigating the role of sustainability and ecological footprint (Thompson Jr and Gasteiger 1985; Benton Jr 1994; Moffatt 2000; Gayford 2004; Gottlieb et al. 2012; Ozawa-Meida et al. 2013; Aroonsrimorakot et al. 2013; Martin and Carter 2015; Schoolman et al. 2016). Overall, these studies indicate that education on environmental issue should be improved and the effect of individual actions on environmental quality has been emphasized (Tuncer 2008). However, in higher education, there is a limited number of studies which examine student's behavior, on the context of ecological footprint analysis (Keleş et al. 2008; Özeltürkay and Südaş 2015; Südaş and Özeltürkay 2015; Li et al. 2015; Eren et al. 2016). Turkey's ecological footprint consumption was 2.7 gha in 2007 and this score was equal to the world average value and this score is

Table 13.2 Survey based related studies on ecological footprint

Author (s)	Country (ies) (sample)
Rashid et al. (2018)	Pakistan (residents)
Akıllı et al. (2008)	Turkey (academicans)
Keleş et al. (2008)	Turkey (teachers)
Raj et al. (2012)	India (Students)
Südaş and Özeltürkay (2015)	Turkey (students)
Özeltürkay and Südaş (2015)	Turkey (students)
Li et al. (2015)	China (Students)
Eren et al. (2016)	Turkey (Students)
Medina and Toledo-Bruno (2016)	Philippine (students)
Lambert and Cushing (2017)	USA (students, faculty, and staff)
Sahin et al. (2018)	(Turkey (teachers)

lower than the average of Mediterranean countries. Therefore, this study's aim is to determining the perspectives of ecological footprint of Turkish university students.

The study of the Raj et al. (2012) pointed out the ecological footprint score of university students in India. Another study conducted by Bagliani et al. (2008) examined the environmental conditions of the area of Siena by the context of ecological footprint analysis. Gottlieb et al. (2012) demonstrated that ecological footprint is an appropriate tool for encouraging ecological behaviors in students. In 2016, Medina and Toledo-Bruno investigated gender differences in the resource consumption among university students, by the context of ecological footprint analysis. One study by Lambert and Cushing (2017) researched the understanding ecological footprint reduction in university students. Another recent study by Şahin et al. (2018) examined the determination of ecological footprint awareness of preschool teacher candidates. Südaş and Özeltürkay (2015) analyzed the thoughts of ecological footprint of university students. In reviewing the literature, we can easily realize that there has been an increasing amount of literature on ecological footprint applied to various populations. Previous researches have indicated the biggest purpose of measurement of ecological footprint in various areas to improve lifestyle and sustainability with reducing the impact to environment (Table 13.2).

13.2.4 The World's and Turkey's Ecological Footprint

The data prepared by Global Footprint Network Report (GFP) (2018) indicates that humanity has been in ecological overshoot since the 1970s. At the global level, human has started to use more ecological resources and services than ever before by the effect of urbanization, gross domestic product, and energy consumption (Jorgenson 2003; Li et al. 2010). World's ecological deficit has increased steadily since 1970s. In 2018, the global ecological footprint is 1.7 earths. The result implicated the Earth's need to 1 year and 6 months to regenerate what we use in a

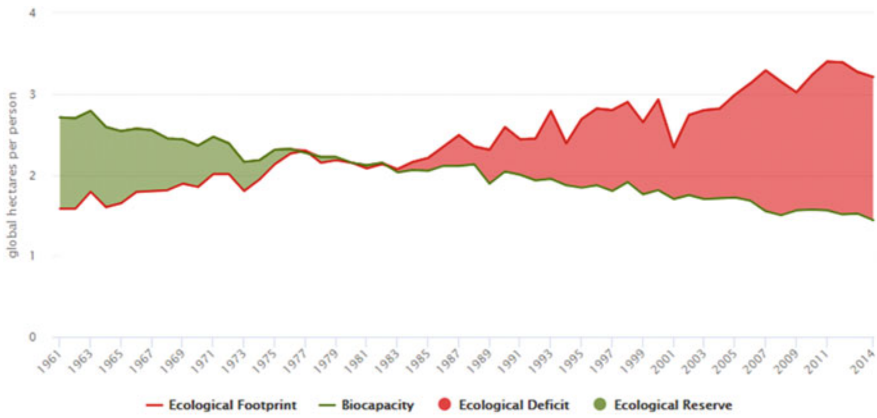

Fig. 13.1 Turkey's ecological footprint and bio-capacity from 1961 to 2014

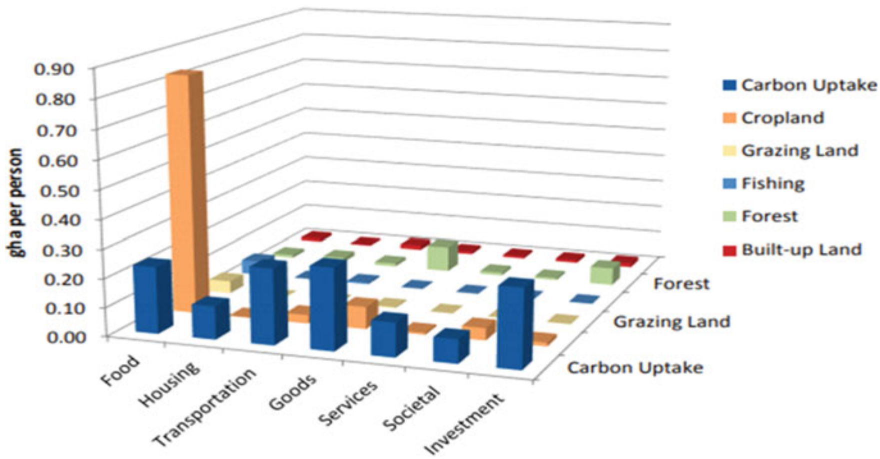

Fig. 13.2 Turkey's ecological footprint components. (GFP 2018)

year. Recent research made by See et al. (2016) stated that two planets will not be sufficient to meet the demand on resources by 2030.

In world ranking, ecological footprint per person of Turkey is in the 82rd place among 188 countries (GFP 2018). It can be seen at Fig. 13.1, total ecological footprint in Turkey began to increase for the first time in 1980s, and this ecological deficit continued to exceed the following years. During the past 10 years (2005–2014), world's ecological footprint per capita average was 1 gha. However, Turkey's ecological footprint average was about 1.5 gha with this period (GFP 2018). This situation indicated that people who are living in Turkey is higher than world average in terms of ecological debt. In Fig. 13.2, Turkey's ecological footprint components are shown.

In Fig. 13.1, Turkey's ecological footprint and bio-capacity rates are shown. According to data from Global Footprint Network (GFP), Turkey's ecological footprint has doubled between 1961 and 2014, respectively, 1.58 and 3.21.

Turkey's ecological footprint has been analyzed by six different categories of land types: carbon, cropland, grazing land, fishing, forest, and built-up areas. Carbon and cropland footprints are the largest land types of Turkey's total ecological footprint, respectively, 46 and 35%. These are followed by forest land with 11%, grazing land with 3%, fishing grounds with 2%, and built-up land with 3%. In addition to analyzing Turkey's ecological footprint by land type, a consumption land-use matrix (CLUM) has been developed to analyze the contribution of different consumption activities (GFP 2018). This matrix is associated with how much our footprint decreases when we make changes in our lifestyle in terms of consumption patterns. In other words, this indicator helps us to understanding the relationship between our daily activities and usage of natural resources. According to Turkey's ecological footprint report made by Global footprint shows that people are living in Turkey biggest consumption category is food with 52%, followed by goods, transportation, services and housing.

There have been some trigger factors (population & income level) that increase the level of ecological footprint in Turkey (Südaş and Özeltürkay 2015). Turkey has high income inequality; it causes the huge gap among the people in terms of income level (OECD 2016). When people have a higher income, they cause the much more ecological footprint. Another important factor is rapid population growth of Turkey. According to statistics of GFP, Turkey's population was about 30 million in 1965, but today, it has almost reached 80 million. During the past 50 years, population of Turkey almost reached the tripled. As stated by Dietz et al. (2007), "*population growth will substantially increase the human footprint on the planet*."

13.3 Methodology

To meet the research aim, it is measuring the awareness and normal habits of Turkish young consumer's ecological patterns in their daily lives. Three hundred and seventy-five Turkish students who are educated in business oriented higher education of one of a foundation university in Turkey with the tool of "*Ecological Footprint Quiz*", placed on www.myfootprint.org site. Students are chosen as a sample for this study, the previous research with higher education students (Frank and Meyer 2007; Vicente-Molina et al. 2013; Wang et al. 2013; Xiong et al. 2013; Hartikainen et al. 2014) accepted education is the key to knowledge and having more sustainable world. The hard copy questionnaire was used and the survey form contains four parts including carbon, food, goods and services, and housing related questions. The questionnaire comprised from 31 questions and took approximately 10–15 min averagely to complete the survey. Descriptive studies are aligned in the following tables in result part. Three hundred and seventy-five questionnaires were accepted as valid to analyze.

13.4 Results

Results are represented under this title and began with the demographics of the profile. Nearly 53% of the participants are male, and all of the participants are from Z generation (1995 and above) & university students. Approximately, 25% of the respondents indicate that they visit websites related to environmental protection. Four footprint categories and their related are aligned in the following tables. Table 13.3 indicates the carbon footprint estimations including "size of home," "transportation types," "energy saving habits," "energy sources," and "location of home" criteria.

Table 13.3 Carbon footprint perspectives of the respondents

Size of home	n	%	Transportation type	*n*	%
50–100 square meters or less	8	2.1	Highway	366	83.8
101–150 square meters	77	20.5	Railway	29	6.6
151–200 square meters	179	47.7	Airway	42	9.6
201–250 square meters	71	18.9	**Total**	437	100
250 square meters or larger	39	10.4	*Energy saving habits (a)*	*n*	%
Missing value	1	0.3	Compact fluorescent bulbs	222	25.0
Total	374	99.7	Energy efficient appliances	207	23.3
Energy sources	*n*	%	Extra insulation	60	6.8
Electricity	274	54.3	Insulating blinds	30	3.4
Natural gas	195	38.6	Solar panels	132	14.9
Heating oil	4	0.8	Storm doors and windows	175	19.7
Wood or biomass	32	6.3	Water saving fixtures	62	7.0
Total	505	100	Total	888	100
Location of home	*n*	%	*Energy saving habits (b)*	*n*	%
Inner city	256	68.3	Turn off lights when leaving rooms	341	27
Older suburb	35	9.3	Use power strips to turn off stand-by lights	88	7
Newer suburb	62	16.5	Turn off computers and monitors when not in use	241	19.1
Rural	14	3.7	Dry clothes outside whenever possible	255	20.2
Missing value	8	2.1	Keep thermostat relatively low in winter	39	3.1
Total	375	100	Unplug small appliances when not in use	238	18.8
			Minimal use of power equipment when landscaping	63	5.0
			Total	1265	100

Table 13.4 Food footprint profile of the respondents

Diet	*N*	%	Food supplier	*n*	%
Vegan	5	1.3	Farmers markets	43	11.5
Vegetarian	8	2.1	Natural foods markets	25	6.7
Omnivore	293	78.1	Supermarkets	213	56.8
Carnivore	30	8.0	Convenience stores	86	22.9
Top of the food chain	38	10.1	Fast foods	6	1.6
Missing	1	0.3	Missing	2	0.5
Total	375	100.0	Total	375	100.0
Certified organic products	*N*	%	*Meal frequency*	*n*	%
Most of the time	91	24.3	One large meal	62	16.5
Sometimes	236	62.9	Two large meals	217	57.9
Almost never	46	12.3	Three large meals	91	24.3
Missing	2	0.5	Missing	5	1.3
Total	375	100.0	Total	375	100.0
Own garden	*N*	%			
Yes	106	28.3			
No	256	68.3			
Missing	13	3.5			
Total	375	100.0			

Table 13.3 shows the results of the question related to carbon footprint estimation. As it is seen respondents mostly live in “151–200 square meters” home. Most of the houses are located in inner city and electricity is the most preferred energy source among respondents. Highway is the most common transportation type. The main energy saving habits among respondents are compact fluorescent bulbs and turn off lights.

Table 13.4 indicates the results related to food footprint estimation of the respondents. They mostly prefer “omnivore” diet type and the most preferred food suppliers are supermarkets. About 58% of respondents stated that they normally eat two large meals per day. Respondents sometimes consume “organic certificate products.” Some respondents (28.3%) do have their own garden.

The results of the questions related to housing footprint estimation. Almost 55% of respondents live in a small and large apartment. Most of the respondents (67.2) not sure use the recycled products. As seen in Table 13.5, almost half of the respondents do not use second hand products for their home furnitures. Low flow shower and run clothes and dish washers are most preferred water saving features among respondents. It can be seen from the data in Table 13.5, respondents sometimes use non-toxic cleaning products.

According to Table 13.6, respondents generally live within their means. Forty-six percent of respondents replace some items before they need to. Almost half of the respondents fill one or two garbage bins per week. About 46% of the respondents sometimes purchase items labeled as natural, organic, or fiber, during buy clothing or paper products. Most of the respondents (88%) don’t member of any organization.

Table 13.5 Housing footprint estimation

Describes home	*N*	%	Recycled materials	*n*	%
Farm	12	3.2	Yes	56	14.9
Single family house	75	20.0	No	62	16.5
A house	83	22.1	Not sure	252	67.2
A small apartment	102	27.2	Missing	5	1.3
A large apartment	102	27.2	Total	375	100
Missing	1	0.3	*Second hand*	*n*	%
Total	375	100	Almost none	211	56.3
Water saving features (a)	*N*	%	A few	98	26.1
Low flow toilets	91	24.2	A fair amount	55	14.7
Low flow shower heads and faucets	123	32.7	Almost all	7	1.9
Instant water heaters on sinks	119	31.6	Missing	4	1.1
Rainwater catchment system	15	4.0	Total	375	100.0
Grey water recycling system	16	4.3	*Cleaning products*	*n*	%
Drought tolerant landscaping	12	3.2	Almost never	107	28.5
Total	**376**	**100**	Sometimes	211	56.3
Water saving features (b)	*n*	%	Most of the time	46	12.3
Garbage disposal	13	1.8%	Missing	11	2.9
Toilet flushing	110	15.3%	Total	375	100.0
Run clothes and dish washers	237	32.9%			
Wash cars rarely	56	7.8%			
Fix leaks regularly	203	28.2%			
Avoid hosing down decks	102	14.1%			

13.5 Extension Activities Promoting Awareness and Perception Development in Relation to Ecological Footprint

According to the report created by Berke and et al (2017) stated that Paris agreement which was coming into effect in 2016, the international community adopted the global increase in temperature of 1.5–2 °C target band reached the limit of what might be the cost of failure to Turkey. Production in Turkey, according to the reference scenario shows that national income and employment will be declined and food prices will be increased whether the precautions are not taken.

The Republic of Turkey has led to providing new facilities for the young generation, in Turkey, to succeed in the troubles and problems of climate change, biodiversity losses, limited natural resources, global health topics, and other related issues. Ministry of Youth and health announced that each university should add at least one selective course related to be a voluntary. The year of 2019 is accepted as a "voluntary year" in Turkey. The official document was sent from YOK (Turkish Higher Education Institution) to all universities. In the following year (2020–2021), universities would add at least one lecture that supports the voluntary behavior of the young population at Turkish universities. The web page of "*sende gonul ver-* be

Table 13.6 Goods and services footprint estimation

Spending and saving habits	*N*	%	New things to replace old ones	*N*	%
Spend all of my income	69	18.4	Need to replace them	167	44.5
Live within my means	211	56.3	Replace before I need to	172	45.9
Frugal spender	88	23.5	Frequently replace	28	7.5
Missing	7	1.9	Missing	8	2.1
Total	375	100.0	Total	375	100.0
Garbage bins	*N*	%	*Labeled as natural, organic, and fiber*	*N*	%
Less than one	48	12.8	Almost never	177	47.2
One or two	168	44.8	Sometimes	172	45.9
More than two	149	39.7	Almost always	16	4.3
Missing	10	2.7	Missing	10	2.7
Total	375	100.0	Total	375	100.0
Member of organization	*N*	%			
Yes	39	10.4			
No	330	88.0			
Missing	6	1.6			
Total	375	100.0			

lover" provides a lot of opportunities for Turkish young generation improving their degree of voluntariness. The ministry supports that higher education has a vital role to have a better and livable world.

13.6 Legal and Policy Framework for Imparting Education towards Perception and Awareness Generation in Relation to Ecofootprint

Identifying minimum educational qualifications for potential job opportunities, increasing the lessons of environmental awareness and ecological footprint at a better and deeper level will lead the more responsible people in the world. This will facilitate successful people–public–private partnership thereby decreasing the negative impact of any factors on environmental quality, by restricting import of polluting technologies and defining public property rights in a stricter manner. For policy formulation, OECD countries should formulate policies to attract investments, in energy efficient and clean technologies (Zafar et al. 2020b).

In global context, the Turkey is one of the largest countries which has largest ecological deficit compare to other developing countries such as Brazil, Argentina, and Russia (GFP 2018). Natural balance of the global ecosystem is decayed day by day, it causes to insufficient to meet humans' needs effectively (Akten and Akyol 2018).

Increasing the public awareness is related to sustainable structure to push major policies and regulations of governments in this field. Therefore, higher education community should support young researchers to do some studies for clarifying the needs and for the crisis times of the industry for a paradigm shift. When the foundations for enhancing a more sustainable future is laid in the educational context, the conceivable problems in the industry can be more easily resolved. Depend on the previous studies, the awareness of sustainability is better than before. The curriculum of the education system does not contain much lectures, facilities, etc. all except a few universities in Turkey. According to this study, Topak et al. (2019) stated that the curriculum of architectural and civil engineering departments should be reevaluated and adjusted to scale up the education for sustainable construction for Turkey.

The previous studies (Ardoina and Estelle 2017; Zafar et al. 2020a; Toomey et al. 2017; Monroe and Krasny 2016) stated that environmental consciousness can be adapted easily to the people by increasing or supporting their education. Hereby, environmental education contains approaches, tools, methods, and programs that develop and support environmentally related attitudes, values, awareness, knowledge, and skills that prepare people to take informed action on behalf of the environment (Ardoina et al. 2017).

13.7 Conclusion

Human capital is one of the major elements of economic development. Education, skilled labor, knowledge, and innovation are important drivers that affect human development. However, education is the only source that equips us to perceive the reality of things. Technology adaptation and implementation costs are significantly reduced with the help of human development. Meanwhile education has a crucial role to upgrade the level of development for ensuring a more sustainable time (Zafar et al. 2020b).

University education should become a change agent for society having the large periods of time spent in education by millions of young people, as well as adults in terms of supporting sustainable development principles. Education can easily affect many spheres of life as being one of the major drivers of development and contributes to inequality reduction (Leal Filho et al. 2018; Collins et al. 2018). The majority of today's students have an important role and also, they will carry out legal, social, technological, and other innovations on the behalf of the whole environment. However, according to the report of Association for the Advancement of Sustainability in Higher Education there is still a long list of actions to be taken in higher education context for a paradigm shift towards more sustainable industries, which could be rationalized with collaborative summits between higher education community, state agencies, sustainability NGOs, and students in Turkey (Topak et al. 2019).

13.8 Further Research

As it is shown in the previous parts the education has a very important role to make students be aware of all the challenges that they will meet in the future. The humankind is consuming the natural resources so fast. The university students would be the leader of the companies, and they would be conscious parents, whether they have the right knowledge on the right time. Even they recognize this importance in a better way, they might be controlling all resources depend in a proper and legal way. Each ecological footprint dimensions should carefully discuss and teach to the leaders of future in a proper way. Therefore, in the further research, the researcher can focus on related issues and examine the perspectives of the remaining part and compare with cross cultural studies.

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Energy and Climate Footprint Towards the Environmental Sustainability

14

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Abstract

Agriculture has a share of 5% energy use globally. Most of the source is not from the renewable sources leading huge amount of GHG (greenhouse gases) emission. As per the Paris agreement on the use of climate change the major emphasis should be given for reducing GHG emission. Therefore, the process of agriculture needs a modification. It was observed that the various forms of ecological footprint are very important for environmental sustainability of agroecosystem. Energy footprint estimation is a key issue in the era of energy crisis. Improved technology and processes has improved the lifestyle of common man and as a consequence of that the energy consumption has given at tremendous rise. The non-renewable energy sources are declining at a fast rate and therefore, emphasizing switching over to renewable alternatives. Moreover, the energy demand and footprint is increasing day by day. In the agroecosystem with improved agrotechnology and mechanization of the agriculture practices the energy requirement is gradually increasing day by day. It is leading to release of huge amount of GHG emission from the agroecosystem leading to increase in energy subsidy in agriculture sector. Energy footprint estimation in cropping system is therefore most needed aspect at the present time. Further emission of huge amount of GHG from the agroecosystem is creating the problem of climate change and global warming. Therefore, the climate footprint of the earth ecosystem is also reflecting changing pattern. It is also hampering the agricultural productivity and production. Proper management of agriculture through organic farming, crop rotation and other indigenous technologies under changing climate has become the biggest challenge on the earth surface. The concept of energy footprint is associated with the level of GHG emission that is taking place from various sectors of agroecosystem. Addressing environmental sustainability in the field of agriculture requires sustainable and integrated management of resources along with emission reduction of GHGs. This would help to reduce the energy footprint of the agroecosystem and subsequently help in combating climate change. The pattern of climate footprint needs to be conserved in order to avoid the hazards of the changing climate that is challenging the issue of environmental sustainability. Therefore, analysing climate and energy footprint is a key issue from agroecosystem point of view in order to attain environmental sustainability of the agriculture sector.

Keywords

Agroecosystem · Climate footprint · Energy footprint · Sustainability

Abbreviations

AFOLU	Agriculture Forestry and Other Land Use
C	Carbon
CF	Carbon Footprint

CFP	Carbon Footprint Potential
CH_4	Methane
CO_2	Carbon Dioxide
EU	European Union
GGE	Global Greenhouse Emission
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
N	Nitrogen
N_2O	Nitrous Oxide
WF	Water Footprint

14.1 Introduction

Latest report given by IPCC (Intergovernmental Panel on Climate Change) reveals the role of humans in aggravating the issue of climate change across the world. For the last 40 years combustion of fossil fuel and industrial activity have contributed more than two-third of GHG (greenhouse gas) concentration into the atmosphere (IPCC 2014). On the other hand, AFOLU (Agriculture, Forestry and Other Land Use) sector has contributed 25% GHG emissions by anthropogenic activity. As a matter of fact, there is gradual rise of energy and associated climate footprint during last few decades. Now various governments across various nations across the globe are trying to reduce the energy emission footprint and climate footprint by reducing GHG emission and switching over to renewable source of energy (Meena and Lal 2018). European Commission has set a target of increasing 20% of renewable source of energy in the overall energy consumption pattern followed by 10% in the transportation sector by 2020 (European Commission Directive 2009; Meena et al. 2018). As per the reports, more than 10% of the energy supply came from renewable sources in 2008 where major share comes from the bioenergy sector (Moomow et al. 2011). In the bioenergy sector, biomass tends to has significant contribution in energy production and use (Allen et al. 2014; Meena et al. 2020a, b). Biomass energy in the form of fuelwood, crop residues and energy crop has taken a significant share across various nations in the globe. Food crops can be used sometimes as energy crops having higher yield followed by lesser agro-inputs (Cherubini et al. 2009). A very interesting fact is that energy generation from energy crops is highly beneficial due to equality of CO_2 (carbon dioxide) capture followed by its release. It was observed that GHG emission takes place at various segments of the production process and thus proper agricultural management would help to reduce GHG emission from the concerned sector (Blengini et al. 2011).

The concept of C (carbon) footprint reveals the requirement of formulation of guidelines and standards for specific assessment of GHG emission. C footprint potential is the technique for calculating the potential GHG emission through life cycle analysis expressed as CO_{2eq}. Various tools are used to assess the GHG emission from agricultural products (Colomb et al. 2013). The calculators for CFP (carbon footprint potential) have been divided into three sections which include calculating tools, standard procedures and modeling approach (Denef et al. 2012). Various methods are available which are used to measuring CFP with latest advancement in the form of web based system for calculation of GHG emission during energy crop plantation in cultivation process (Colomb et al. 2013). CFP calculation has been used under diverse cultivation system associated with crop management at the farm level.

The concept of CFP calculators were used by the farming community, agricultural workers and researchers to identify and quantify the GHG emission at local level (Hillier et al. 2009). Overall the CFP calculation while suggesting mitigatory strategies should include the local ecological condition, prevailing agricultural practices and technologies along with various forms of crop management (Brankatschk and Finkbeiner 2015).

Modification or alteration of crop rotation pattern tends to reduce the GHG emission to a considerable extent (Nemecek et al. 2015). However, C footprint potential calculation for crop cultivation practices considers a single growth period for a single crop (Brankatschk and Finkbeiner 2015). As the agroecosystems are complex in nature and therefore, short span analysis does not reveal the clear picture. Most of the calculation ignores several factors such as the cropping pattern, crop interactions between existing and previous crops, time duration of farming activities which may influence the CF (carbon footprint) calculation (Brankatschk and Finkbeiner 2015). The challenges associated with CFP calculation are that it does not include the time schedule of the cultivation practices present in the agricultural production.

It was observed that in agriculture field direct source of GHG is the crop residues as well as different forms of synthetic and organic fertilizer. As per AFOLU of IPCC direct emission should be considered in the form of CO_2 and indirect emission in the form of ammoniacal nitrogen for calculating anthropogenic GHG emission (IPCC 2006). Emission of CO_2 takes place through liming and urea application. Application of mineral and organic fertilizer adds nitrous oxide (N_2O) into the atmosphere from the agroecosystem through nitrogen volatilization along with leaching and agricultural runoff from fertilizer application. Nature and type of fertilizer applied under field condition determine the fate of GHG emission (Bouwman et al. 2002). Application of digestate in the form of organic fertilizer as an alternative for mineral fertilizer tends to reduce GHG emission. However, it was observed that application of digestate leads to higher diesel consumption followed by increase in GHG emission (Gissén et al. 2014).

Further the process of denitrification and nitrification GHG emission takes place from the crop residues. Therefore, such emissions should be included for carbon footprint calculation. It was also revealed that, CH_4 (methane), $CO_{2,}$ and N_2O emission along with other air pollutants are released into the atmosphere due to fossil fuel combustion practices (IPCC 2006). The fuel amount depends upon various cultivation activities as well as on crop management practices (Sorensen et al. 2014). Changes in land use pattern may alter the soil organic carbon stock leading to emission of CO_2. Selection of suitable crop species has got a significant influence over GHG emission. Therefore, type of energy crop used is significant for calculating energy footprint of agroecosystem.

14.2 Energy Footprint of Agroecosystem and Agriculture Sector

The term energy can be simply defined as the capacity to do work. There is a mutual dependency between economy, environment, and energy (Pimentel et al. 1994). Agriculture is intricately interrelated with the energy sector. Agriculture activities are using energy supplies the energy in the form of bioenergy (Alam et al. 2005). During the present era there is continuous growth in science and technology. This growth is also prevalent in the agriculture sector in which the output of agroecosystem is dependent upon the use of energy. Amount of energy consumption is dependent upon amount of agricultural activity, agricultural lands as well as level mechanization involved in the agricultural process. The input output ratio of energy is dependent upon the cropping pattern, soil type, agricultural activity, yield and productivity operations (Ozpinar and Ozpinar 2011). Gradual technological growth has increased more use of energy during cultivation of crop. As a consequence the efficiency of energy use by the agroecosystem is reflecting a declining trend (Mandal et al. 2002). With gradual increase in energy consumption by the agroecosystem it is adversely affecting the environment in the form of depletion of resources followed by contribution to global warming and climate change (Ghorbani et al. 2011; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, 2019b). Changing climatic pattern and perturbances is reducing the yield to a significant level (Lobell and Gourdji 2012).

Under the conventional system of agriculture tillage is the most important factor as it drives the productivity through effective crop management (Busari et al. 2015). Tillage helps to improve the mechanical structure of soil and thus helps to enhance the crop productivity (Parihar et al. 2016). Such an approach emphasizes more fuel and energy consumption leading to higher emissions of CO_2. In comparison to conventional system, zero tillage system of agriculture lesser fuel requirement takes place leading to lesser emission of CO_2. It is a good aspect as it is a common fact that CO_2 leads to global warming followed by climate change (Hobbs et al. 2008). The yield potential is also higher under rainfed condition in comparison to conventional tillage system (Farooq et al. 2011).

Global consumption of energy for agroecosystem stands to be 5% of the total (IPCC 2014). Higher inputs in the form of agrochemicals application, fuel use, use of farm machineries promote higher energy consumption leading to higher emission of GHGs (Li et al. 2016). In order to analyse the production of agroecosystem from energy analysis perspective all the inputs and outputs of the system need to be converted into energy units (Michos et al. 2017). The situation of energy crisis began from 1970 onwards with limited availability of conventional energy resources (Hulsbergen et al. 2001). Scarcity of proper availability of energy resources requires a proper approach for proper estimation of energy and its consumption in agroecosystem (Kizilaslan 2009). As per the reports of FAO (2019) up to 3% fossil fuel consumption were reflected from the agriculture, forestry and allied sector in the European Union (EU) (Eurostat 2014). If we trace the energy inputs in an agroecosystem, use of fossil fuel, electricity consumption for operation of farm machinery are the principle sources of energy inputs (Michos et al. 2018).

As per the reports the cultivation practices are accompanied by 12% global GHG emission which is estimated to be up to 6.1 GtCO_2-eq annually till 2005. In comparison other GHGs such as the CH_4 and N_2O are emitted as 3.3 GtCO_2-eq/year and 2.8 GtCO24 -eq/year, respectively till 2005. In the cultivation sector the anthropogenic emission till 2005 has been evaluated which reveals more than half contribution of N_2O and CH_4. There is a huge amount of exchange of methane between the land and atmospheric system under agroecosystem but the overall flux seems to be remaining balanced. Globally, agricultural CH_4 and N_2O emissions have increased up to 17% within a span 15 years which is equivalent to 60 Mt. CO_2 -eq/year. Non-Annex-I countries reflected more than 30% increment in GHG emissions till 2005 which has a major contribution to agricultural sector.

Annex-I countries has reflected up to 12% decrease in GHG emission. Therefore, reduction in emission of GHG in the agriculture sector can be done through management of pastureland and improved agronomic practices and restoration of soil quality. Further, under rice cultivation proper water management, land use, agroforestry practices and organic farming practices needs to be done. Technological development may act significantly in mitigating the effect of climate change followed by reduction in GHG emission (Khan et al. 2020a, b).

Modeling approach on long-term basis reveals that non-CO_2 crop and livestock management may have significant contribution across worldwide up to 1520 Mt. CO_2-eq on annual basis till 2030. However, such modeling approach does not include the process of soil C management. The continuous emissions of various GHGs such as CO_2, N_2O and CH_4, etc. either from fuels or from various agroecosystem practices are estimated by a standard methods adopted from IPCC (2006). Also, IPCC has also developed some coefficients for calculating fertilizers and soils (IPCC 2014). Similarly, the ratio of total utilizable volume of water (m^3/year) to the total production quantity (kg/year) is used for calculating water footprints (WF) of varying crops in any agroecosystem (Mekonnen and Hoekstra 2014; ISO 2014). Thus, the calculation of both CF and WF reflects the status of energy footprints that could help producers to minimize their greenhouse gases in economically efficient way. However, the CF of various agroecosystem based food items in the world is depicted in Fig. 14.1 (Chapagain and James 2011). It reflects that livestock based food items contributed in higher CF as compared to vegetables and fruits, respectively. That is why ruminant's animals produce more GHG (especially CH_4) due to faulty manure management in agroecosystem. This hypothesis creates one question in our mind "Is animals based food products contributes in higher CF than fruits and vegetables?" Similarly, water footprints of various food items in the world are also depicted in Fig. 14.2 (Hoekstra and Chapagain 2008; Hoekstra 2013).

As per the prediction the mitigation potential from the agriculture sector stands to be up to 6000 Mt. CO_2-eq annually till 2030. Further, it is assumed that sequestration

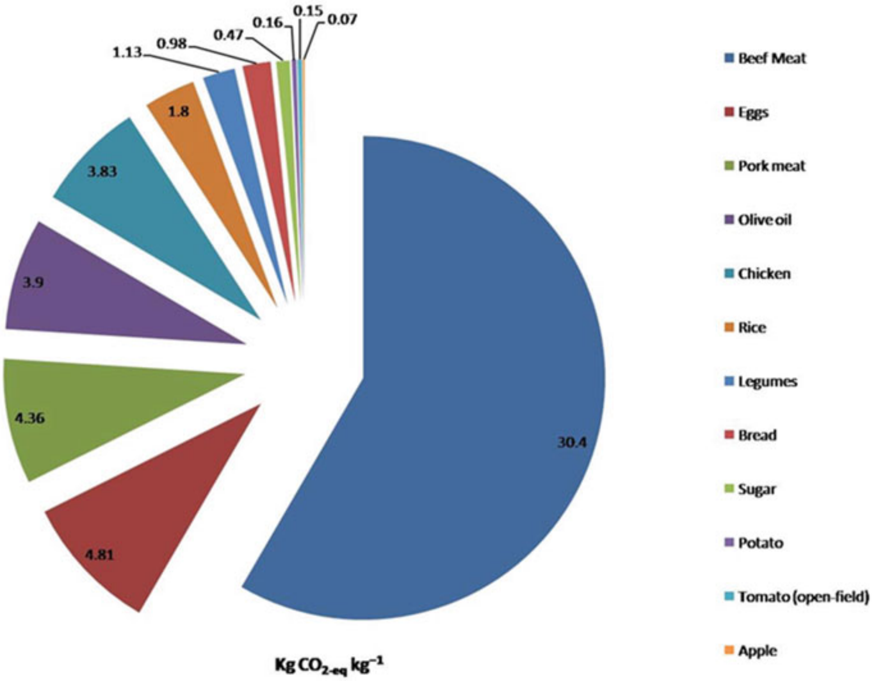

Fig. 14.1 Carbon footprints of food items in the world (Adopted Chapagain and James 2011)

of C in the soil ecosystem has the mitigation potential about 90%. Further, other non-CO_2 gases such as CH_4, N_2O reflects mitigation up to level of 9% and 2%, respectively. However, there are some challenges and uncertainty in terms of future mitigation measures along with effectiveness of adopted measure for reduction of GHG emission. The level of mitigation is influenced by changing climatic pattern, prevailing socio-economic condition. Economic regulation is an also important factor in terms of abatement of GHG emission. For example, higher C price tend to change the land use pattern and allow feed based mechanism for mitigating climate change. Mitigation strategies and policies needs to be evaluated for cultivation practices, land use and crop management.

GHG emission reduction can be achieved by switching off from use of fossil fuels towards organic supplements in the form agriculture by products in the form of feed stocks which can be used as energy source. As per the reports the climate change mitigation potential from the agriculture sector tends to be up to 1260 Mt. CO_2-eq till 2030. Further, additional mitigation of CO_2 till 2030 can be achieved through climate smart agriculture practices followed by mitigation potential evaluation in the infrastructure and transportation sector. It was predicted that future GHG emission rates may show an increasing trend in due course of time due to population explosion and changes in consumption pattern. Greater food production to fulfil the needs of the growing population may lead to higher emission of CH_4 and N_2O due to

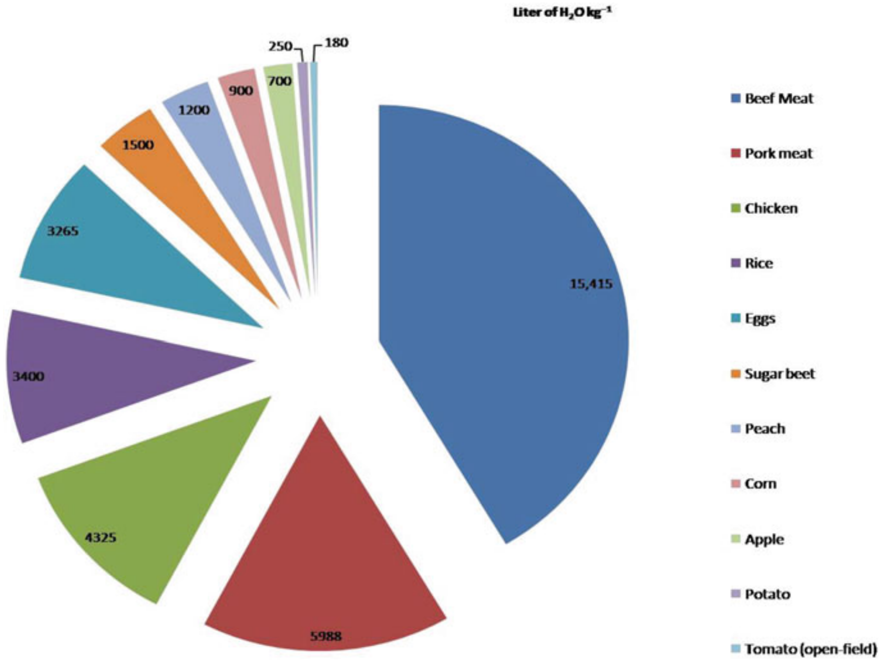

Fig. 14.2 Water footprints of food items in the world (Hoekstra and Chapagain 2008; Hoekstra 2013)

higher presence of livestock population and greater use of nitrogen (N) fertilizers. To inhibit the further increase of GHG emission till 2030 strategies should be formulated for mitigation purpose in the livestock system and application of N fertilizers. Soil C loss would be a significant aspect in relation to climate change.

It is a proved fact that agriculture sector potentially contribute significant level of CO_2 and other GHGs (Paustian et al. 2004). Therefore, the energy footprint for this particular land use seems to be higher from its various component parts. One of the common pathways of CO_2 release is the microbial decomposition of the biomass residue, combustion of plant litter and excess presence of soil organic matter (Janzen 2004). Further, CH_4 is produced during organic matter decomposition under lack of oxygen which is a common process known as fermentation adopted by livestock population. In addition CH_4 is further emitted from organic manures and very prevalent paddy fields (Mosier et al. 1998). N_2O is produced through microbial intervention in the form of N from manures and soils. It is enhanced in the presence of excess N which is present in the soil under moist conditions (Oenema et al. 2005). Therefore, there are diverse source within the agroecosystem for emission of GHGs. As a consequence energy footprint is significantly higher in agriculture than the other forms of land use. Still there is high possibility of mitigation of GHG emission through eco-friendly practices and appropriate scientific explorations.

14.2.1 Analysis of Energy in Agroecosystem

Energy analysis is a process or methodology to convert all the inputs and outputs of agroecosystem into units of energy. Under this process the total amount of energy that flows into and out of the agroecosystem is evaluated and measured (Michos et al. 2018). It is a very important aspect for agroecosystem perspective in order to improve the environmental performance of agroecosystem (Chen et al. 2006). In the crisis of ever increasing population, the agricultural production needs to be improved taking into account of efficient use of energy (Michos et al. 2017). Such methodology reflects ecosystem resilience and energy use efficiency of agroecosystem (Ozkan et al. 2007). The evaluation process varies depending upon the site conditions, time of production followed by materials used (Hulsbergen et al. 2001). This would help to reduce the inputs in agriculture production leading to improvement in the productivity (Kehagias et al. 2015). However, this may impact the economy of the agriculture output and therefore it is the urgent need for formulation of strategies to have a harmony between economy and energy use efficiency for effective management of agroecosystem production (Unakitan and Aydin 2018).

14.3 Climate Footprint in Agroecosystem

Concept of climate footprint has emerged from carbon footprinting that evaluates the whole set of GHG gases to be regulated as per Kyoto Protocol. Climate footprint is much more comprehensive in order to assess the role of human beings towards climate change but is a tedious and more labour intensive methodology. The term climate footprint is usually defined as the sum total of all GHG emission that takes place from a population, activity or system. It is usually calculated in the form of CO_2eq. using global warming potential for 100 years.

In the agriculture sector the use of energy is directly associated with global greenhouse emission (GGE). GHGs tend to absorb and release radiation in the form of heat and increased temperature in the atmosphere. The major GHGs are CH_4, CO_2 and N_2O. It was reported that the agriculture activity contributes 22% of GGE emission having deleterious impact on climate. On the other hand cultivation of crops contributes 20% of CO_2 emission annually (IPCC 2014). In the EU, GGE approximates up to 470.6 Mt. of CO-eq from the agriculture activities which is one tenth of the total emission of GGE (Eurostat 2014). As per the Paris agreement the emission of GGE should be reduced through reduction in the fossil fuel consumption along with the other sustainable cultivation practices (Bryngelsson et al. 2016). The climate footprint of agricultural produce can be estimated through life cycle analysis of product (Weidema et al. 2008).

14.4 Measuring Energy Footprint Through Life Cycle Assessment Approach

Life cycle assessment (LCA) is an integrated approach to quantify the used energy in any agriculture and farming land use system which calculate both carbon and WF throughout the whole life cycle of plants at farm levels (Michos et al. 2018). Recently, a study has been conducted on LCA application to see environmental benefits through production of jam by fruits based agroforestry system in the region of Peruvian Amazon (Recanati et al. 2018). However, the methodology of LCA is useful to understand the environmental impacts due to prevailing agricultural productions. In this consideration, a research in agriculture system would be modified to explore energy footprints which help in better understanding of environmental impacts. Further, an accepted and valid standardizations are emerged which can be adopted for next part of research for energy footprint in agroecosystem (Roy et al. 2009).

In this context, a flowchart is developed that shows modified LCA methodology to assess energy uses and footprints in agricultural land use systems. In stage 1, quantifying used energy in different agricultural and farming land use system. Exploration and identification of low energy input based species and farming system are also considered under the aims and scope. Calculating energy input-output mechanisms of the prevailing agricultural system are comes under inventory analysis of stage 2. Similarly, stage 3 indicates the impact evaluation that quantifying crops yield effects due to practicing farming system in the regions. Comprises, evaluation and discussion of the findings are comes under stage 4. The last stage 4 indicates the applications of planning for crop replacement, reducing energy inputs and exploring environmental impacts are considered for applications (Fig. 14.3) (Taxidis et al. 2015; Platis et al. 2019).

14.5 Pattern of Energy and Climate Footprint of Agroecosystem

Within a span of 15 years (1990–2005), the CH_4 and N_2O emission reflected a rise of 17%. It appeared that ruminant fermentation; soil emissions followed by biomass burning are the principle sources approximating 88% of the GHGs emission (US-EPA 2006a).

14.5.1 Future Global Pattern of Energy and Climate Footprint

As per future prediction emission of N_2O may rise up to 60% till 2030 due to overuse of chemical fertilizer along with manure production (FAO 2003). Mosier and Kroeze (2000) have mentioned a 50% rise in N_2O emission in comparison to the level attained in 1990. With the rising population the demand of food would gradually increase and therefore the emission of GHGs would further increase as per the

Fig. 14.3 Modified life cycle assessment methodology to assess energy uses and footprints in agricultural land use systems (Modified Taxidis et al. 2015; Platis et al. 2019)

demand. Therefore, proper management and eco-friendly technologies in the agriculture sector may help to reduce the emission for per unit of food produced.

As per the reports of FAO (2003) the animal husbandry practices would lead a 60% rise of CH_4 emission till 2030. This could be managed through alteration in the feeding of ruminants and proper method adapted for manure production. According to USEPA (2006a) the total contribution of CH_4 from manure decomposition and bacterial fermentation process would rise up to 21% within a span of 15 years (2005–2020). Further, FAO (2003) estimates a rise of paddy production up to 4.5% and accordingly CH_4 emission would rise. The situation could be handled through proper irrigation practice with lesser rise production along with improved rice cultivars that emit less CH_4 may serve the purpose to some extend (Wang et al. 1997).

For non-CO_2 GHG emission, USEPA (2006a) predicts an increase up to 13% of emission for the last two decades (2000–2020). Similar rate of increase would contribute GHG emission of about 8300 $MtCO_2$–eq up to 2030. Keeping the deforestation rate constant and promoting conservation tillage may cause a reduction of GHG emission to lesser amount across the globe (FAO 2001).

14.5.2 Regional Pattern of Climate and Energy Footprint

In the Middle East, Africa and Sub-Saharan regions have reflected a rise up to 95% of GHG emission within a span of 30% (1990–2020) (US-EPA 2006a). Further work on this aspect reveals that in Sub-Saharan African region the per capita food production has been kept constant or lower down for emission reduction (Scholes and Biggs 2004). This may be low input agriculture or lack of fertility of soil which have reflected such trends (Sanchez 2002).

It is seen that the economy of urban area is gradually increasing with improved lifestyle and infrastructure. Therefore, the diet composition of urban population is shifting towards the livestock products and as a consequence the demand increases. This has secondary consequences of agricultural intensification in South and Central part of Africa with significant rise in GHG emission. Similarly, the GHG emission also increases in Eastern part of Asia from the livestock population. Data of FAOSTAT (2006) reveals the increase of dairy production up to 12th time within a span of 43 years (1961–2004). However, the consumption pattern reflects lesser consumption but the gradual rise of emission would continue for a long span of time. In the South Asian countries the gradual rise of emission is associated with expansion in N fertilizer use for more production to feed the growing population. As an export quantity agricultural products are the base for the Latin America and Caribbean countries who reflected significant changes in land use and its management through forest conversion in to crop land, resulting in to higher GHG emission.

Some regions of Latin American countries have reflected adoption of no-till agricultural practices which approximates 30 Mha areas annually. On the other hand the developed nations such as parts of Europe reflect a steady rising economy through increase in agricultural production. In Russia, the agricultural expansion may take place up to 14%. It was observed that implementation of intensive system of crop management would give 2.5 times higher yields with increased use of N fertilizers. From 1990 onwards the use of N fertilizers showed a declining trend and thus the emission of N_2O decreased. With gradual rise in economy the increased application of N fertilizer took place at an unprecedented rate up to pre-1990 levels. US-EPA (2006a) reported a 32% increase in N_2O with an average rate of 3.5 $MtCO_{2eq}$ annually for North America and OECD regions. There is a continuous increase in GHG emission from the agricultural sector as reflected from Pacific region of OECD. In most cases the major contributions come from the manure as non-CO_2 emissions and N_2O from soil. In the region of Oceania there is continuous rise for last 45 years leading to five-fold increase in GHG emission from New Zealand from 1990 onwards. Similar contribution of manure towards GHG

Table 14.1 The trend of domestics energy consumptions in India (Ramachandra 2019)

Energy consumption trends (100%)	Total commercial source	58%	Coke	47%
			Coal	29%
			LPG	10%
			Charcoal	11%
			Petrol	1%
			Diesel	1%
			Kerosene	1%
			Electricity	0.09%
	Total non-commercial source	42%	Fire wood	62%
			Crop residues & others	37%
			Dung cake & Biogas	1%

emission was also reflected from North American region. In Western Europe the reduction in energy footprint based upon agroecosystem took place through emission reduction by managing inputs along with efficient N use, livestock management by proper feed arrangement laid to reduction in CH_4 emission (Paustian et al. 2004; Clemens and Ahlgrimm 2001). However, the result varies from region to region. Agroecosystems tend to hold C as a large reserve in the form of organic matter. It was observed through scientific observation that 50 PgC stored in the soil are released to some extend which can be conserved through suitable management approach (Lal 2004a).

It is seen that methods promoting photosynthetic build up of C and subsequent release through respiration and other abiotic processes tend to increase C reserve and thus converting soil as a large C sink. Researches in this particular aspect have revealed that success in the process lies with the local conditions (Lal 2004a). Contribution of C from vegetal part into the soil can be done by applying agroforestry systems in the agricultural (Albrecht and Kandji 2003). Bioconversion of crop residues in the form of ethanol may help to avoid the GHG emission (Cannell 2003). GHG emission should be avoided or reduced through sustainable agricultural practices (Foley et al. 2005).

Domestic energy consumptions trends are depicted in Table 14.1 which is divisible into commercial and non-commercial sources that shared 58.0 and 42.0%, respectively. Coke contributed 47% of energy consumption followed by coal, LPG and charcoal that shared 29.0, 10.0 and 11.0%, respectively, whereas petrol, diesel and kerosene shared 1% as compared to least contribution (0.09%) by electricity under commercial sources. Similarly, firewood showed highest (62.0%) sources of energy consumption followed by crop residues (37.0%), whereas least (1.0%) contribution from dung cake and biogas, respectively under non-commercial sources for energy consumption in domestic purposes (Ramachandra 2019).

14.6 Renewable Energy Footprint

Throughout the world there is a continuous swift of energy use pattern as most of the countries are switching over from non-renewable to renewable sources of energy. For example, in United States (US) the use of renewable energy tends to increase up to 35% to be used as electricity. Such events are taking place due to the mega event of climate change. With gradual improved in the living standards through science and technology the energy demand has raised both in developed and developing nation. Further, the dependency on fossil fuels as energy source has lead to release of huge amount of GHGs in the atmosphere giving rise to the mega event of climate change and global warming. Therefore, legal policy framework has been developed to implement more use of renewable source of energy. Among these policies reduction in energy footprint has been aimed through reduced GHG emission (Snape III 2010).

The renewable energy resource would help in mitigating the event of climate change followed by reduction in emission of GHG. As per the reports US would be requiring more than 65 million acres of land to fulfil the growing demands of electricity and fuel. In order to address the issue of mitigation of climate change use of renewable source of energy such as the biofuels is a suitable alternative. However, the issue of land use stands to be greater in amount for renewable energy in comparison to non-renewable source of energy in the form of fossil fuels. On the other hand the fossil fuel such as the coal extraction leads to environmental degradation in the form of deforestation and biodiversity loss followed by emission of CO_2 through coal burning for energy production. Therefore, the non-renewable energy sector reflects two way damages to the whole ecosystem. From this perspective, the renewable energy "footprint" is the most significant approach to regulate the climate change and footprint (US global change research program 2009).

Policy formulation regarding shifting towards renewable source of energy accounts the various sources followed by the individual land footprint of each of the renewable sources. Depending upon the land required for renewable energy harvesting would determine the investment on specific energy resources. However, the major benefit towards switching over to renewable sector would lead to reduction in CO_2 emission. Further the environmental consequences that take place through rise in ambient CO_2 concentration can be curbed through such approaches. As per the research reports it was found that wind energy may reduce CO_2 emissions up to 99% instead of coal and 98% instead of gas. Apparently it is seen that the land investment for renewable energy sources is more than the fossil fuel sources but the net benefit in terms of combating climate change and GHG emission reduction surpasses the increased value of land footprint.

14.6.1 Renewable Energy Footprint to Mitigate Climate Change

Renewable energy sources are becoming a good strategy that helps in reducing energy and footprints and maintain overall environmental sustainability. In this context, some agroecosystem based feedstock's were used to analyzed for energy values by estimation of feedstock's and biodiesel yield values which is depicted in Table 14.2 (Salim et al. 2019). From this table, the value of feedstock's (kg ha^{-1}) and biodiesel yield (kg per kg BDF) are considered highest under Palm (*Arecaceae*) in the region of Indonesia where least value of biodiesel yield (kg per kg BDF) considered under poultry fat in worldwide, respectively. Thus, these agriculture based feed stocks are considered alternate source of energy consumption rather than fossil fuel consumption which causes unstoppable emission of GHGs into the atmosphere resulting into climate change and global warming phenomenon.

14.7 Reducing Energy and Climate Footprint in Agroecosystem

In the modern times maintaining agricultural production is the key issue to feed the ever increasing human population. Climatic change significantly reduces the productivity of agroecosystem (Schuman et al. 2001; Derner et al. 2006). Therefore, it is the urgent need to reduce the climate footprint through emission reduction in the agriculture practices. Specific policies and strategies need to be formulated to increase the carbon storage in the crop ecosystem and subsequent reduction in CO_2 emission. For example, adjusting the livestock strength the emission of non-CO_2 gases can be regulated. By increasing the C storage the productivity of the crop ecosystem can be increased. Use of organic amendments in the form of compost, manure, plant litter promotes significant storage of C in soil (Schnabel et al. 2001; Conant et al. 2001). However, application of nitrogen fertilizer creates the opportunity of N_2O emission leading to air pollution (Conant et al. 2005). Proper irrigation in grasslands leads to gain in soil C (Conant et al. 2001).

Table 14.2 Energy analysis of biodiesel yield from different feedstock's biomass in the world

Feedstock's in different regions	Value of feedstock's yield (Kg ha^{-1})	Value of biodiesel yield (kg per kg BDF)	References
Palm (*Arecaceae*) in the region of Indonesia	82697.00	6.38	Siregar et al. (2015)
Jatropha (*Jatropha curcas*) in the region of Indonesia	9703.00	4.50	Siregar et al. (2015)
Soybean (*Glycine max*) in the region of U.S.	4676.00	5.50	Chen et al. (2017)
Cotton seed (Gossypium species) in the region of Brazil	3846.00	10.0	Lima et al. (2018)
Poultry fat in worldwide	–	1.16	Jørgensen et al. (2012)

Proper management of nutrient application can mediate emission reduction (Dalal et al. 2003). Further during fertilizer management, proper care should be taken in terms of animal residue management as they add nutrients into the soil (Oenema et al. 2005). Biomass burning contributes significantly towards climate change. For instance, burning of crop residue, stubble mulches after harvesting is an important contributor of CH_4 and N_2O. Further such activities generate hydrocarbon compounds and nitrogen species which undergo photochemical reactions to produce ozone molecule which is itself a powerful GHG. Further, during burning of the biomass it results into formation of smoke aerosols which alters the climatic condition of the atmosphere (Andreae et al. 2005; Venkataraman et al. 2005). Burning activity causes reduction in the albedo value leading to warming of the earth surface (Beringer et al. 2003). Therefore, reduction in the burning activity may increase the vegetal cover resulting into C sink in biomass and soil (Scholes and van der Merwe 1996). The tree species becomes saturated in terms of C sink up to 50 years but tend to avoid non CO_2 gases.

Further, fire suppression techniques may be adopted for mitigating the emission of GHG. It can be achieved through proper management of vegetation by reducing the use as fuel. Strategies can also be oriented in biomass burning at the time of low emission of N_2O and CH_4 (Korontzi et al. 2003). However, the natural burning process cannot be ignored under climatic influence (Van Wilgen et al. 2004).

Reduction in CO_2 emission can be achieved through cultivation of species of grasses that tend to accumulate more C in roots and that ultimately would lead to soil C and further increase in their value. Savannah grassland biome has reflected higher accumulation of C (Conant et al. 2001). As a consequence nations have adopted integrated farming practices involving grass species, livestock and crop cultivation. Concept of zero tillage has also been adopted under integrated system (Machado and Freitas 2004).

Emission reduction of CO_2 from crop ecosystem can further achieved through incorporation of legume into the pastureland which add to the soil C pool (Soussana et al. 2004; Jhariya et al. 2018a, b). Due to this, the productivity of the ecosystem increases through biologically added N by replacing synthetic fertilizer (Diekow et al. 2005). Practices oriented towards reducing GHG emission from livestock population of grazing lands through proper livestock management can be achieved (Derner et al. 2006). C storage in croplands can be increased through increasing productivity and through increasing nutrient deficiency which results into higher return of litter followed by soil C storage (Conant et al. 2001). Care should be taken that addition of N fertilizer stimulates the N_2O emissions (Conant et al. 2005). Irrigation activity in grassland ecosystem tends to promote soil C increase (Schlesinger 1999). Use of strategies to increase nutrient use by plants can reduce the emission of N_2O (Dalal et al. 2003). This strategy is little bit problematic for grassland ecosystem due to nutrient input from the grazing livestock in the form of defecations as well as unequal distribution nutrients in the crop ecosystem (Oenema et al. 2005).

Biomass burning at the onsite level significantly contributes towards climate change. It gives off CH_4 and N_2O along with hydrocarbon compounds and other nitrogenous emissions. They undergo secondary chemical reactions leading to formation of trophospheric ozone which is considered to be a powerful GHG. Further, biomass burning leads formation of aerosols smoky in nature resulting into warming of the atmosphere or cooling effect (Andreae et al. 2005; Venkataraman et al. 2005). It also reduces the albedo value of the land surface resulting into warming (Beringer et al. 2003). Further, combustion of wood and grassland area can have negative effect as the grassland as savannah occupies 1/8th surface area of the world (Scholes and van der Merwe 1996).

Agroecosystem is an integrated unit from which GHG emission takes place from various sectors. Further, the energy footprint seems to be higher which leads to mega event of climate change, global warming and other forms of environmental pollution. Therefore, the climate footprint also increases which shows deleterious impact over agricultural productivity crop yield, livestock production and other associated products on long-term basis. It was observed that increasing C storage within agro-products may store up to 83 MtC annually during the last four decades. This leads to a tentative removal of CO_2 in the range of 3–7 Mt. CO_2 from the atmosphere which is very minor amount from mitigation perspective. As per the reports non-CO_2 GHGs emission from the farming practices at the global level may reach up to 6116 Mt. $CO_{2\text{-eq}}$ annually till 2005 tends to contribute up to 12% of GHGs emission from anthropogenic sources (US-EPA 2006a).

Further, for non-CO_2 contribution of GHGs agriculture tends to contribute 47% along with 58% from the anthropogenic source. It was observed that N_2O from soil and CH_4 from ruminants contributed 38% and 32%, respectively, as non-CO_2 emission till 2005 (US-EPA 2006a). The other potential sources include the burning of the biomass, paddy cultivation and activity such as composting, etc. It is seen that CO_2 emission from agricultural sector is not evaluated due to incorporation in the process of land use change and forestry practices. According to IPCC (2001) the CO_2 inflow and outflow between agroecosystem and atmosphere varies significantly. According to the estimates given by US-EPA (2006b) net emission of CO_2 from agricultural soil tends to be in minute quantity (1%) when compared to the anthropogenic sources. The non-Annex-I countries have contributed 74% of GHG emission from the agricultural sector till 2005. In these countries N_2O appeared to be the main output as GHGs from the agricultural sector. In case of Caribbean and Latin American countries the fermentation process seems to be the dominant source of GHG emission (US-EPA 2006a). This is dependent upon the large number of livestock population present in the area which represents up to 1/4th of the world population of livestocks (FAO 2003).

GHG emissions from rice production along with biomass burning were found to contribute more than 90% of the emission of the globe. It was observed that CH_4 emission takes place from paddy cultivation in various parts of Asian sub-continents where it is the staple food crops. Further, biomass burning taking place in Africa and Latin American countries contributes up to 74% of the emission. Further, manure should be properly managed in order to reduce the emission from both developing and developed countries (US-EPA 2006a). However, the inflow and outflow balance in agroecosystem in relation to CO_2 emission is unpredictable and may vary case to case basis. As per the reports of US-EPA (2006b) some nations reported net emission while others reported net removal of CO_2.

Considering the energy and climate footprint of agroecosystem it is very important to mitigate them in order to address the issue of climate change and global warming. Moreover, sectors specific approach is required in order to reduce the GHG emission and thus the energy and climate footprint. Firstly, the management of cropland needs to be done properly in order to reduce net GHG emission. In this approach agronomic practices that lead to higher yield along with higher C storage in the soil need to be implemented (Follett 2001). Typical examples include crop rotation, cultivation of perennial crops, lesser of fallow land, etc. would serve the purpose (Freibauer et al. 2004). In general addition of N fertilizer is deleterious in nature but under nutrient deficient conditions adding nutrients may promote C storage in soil. However, proper care should be taken about the N_2O emission from N fertilizer and CO_2 from synthetic fertilizers (Gregorich et al. 2005).

Nature based cropping system could be highly fruitful in reducing agrochemical inputs along with GHG emission (Paustian et al. 2004). Crop rotation in terms of plantation of leguminous crops may be a fruitful strategy for N_2O emission reduction (Rochette and Janzen 2005). Another approach includes provision of vegetative cover between successive crops or rows of plantation may also prove fruitful for reducing emission which builds up soil C and helps to mobilize the unused N in the soil (Freibauer et al. 2004).

It was observed that the synthetic fertilizer applied as nutrient source is not properly utilized by the crops (Galloway 2003). The excess N leads to emission of N_2O (McSwiney and Robertson 2005). Increasing the efficiency for proper N utilization may lead to lesser GHG emission. Volatilization of N and its subsequent release if properly managed becomes very effective for reduction of N_2O emission. Various methods have been attempted by several workers to increase the N use efficiency of crops. In this context, precision farming, use of slow release fertilizer, inhibition of nitrification are found to be fruitful to reduce N loss. Therefore, N becomes more accessible to plant roots and thus fulfils the plant requirement and emission reduction takes place (Monteny et al. 2006).

In the process of tillage management, shifting towards no-tillage or reduce tillage may prove to be fruitful in reducing GHG emission. This has now being widely adopted by various countries across the globe (Cerri et al. 2004). Further, higher tillage or maximum tillage leads to disintegration of soil particles leading to higher rate of decomposition and erosion which contributes significantly towards C loss (Madari et al. 2005). The application of no-tillage may give good results but the results are controversial both in terms of C gain or reducing N_2O emission (Helgason et al. 2005). The results vary in terms of N_2O emission on area-to-area basis along with prevailing climatic conditions. Cropping system based on retaining crop residues increases soil C storage and becomes the base materials for formation of soil organic matter. Therefore, burning of stable mulches needs to be avoided (Cerri et al. 2004).

Irrigation is a crucial factor in agriculture sector as it regulates the production and yields. It was observed that irrigation of agroecosystem at higher level tend to increase the emission of CO_2. On the other hand the use of fuels may also lead to emission of GHG, hydrocarbons and other air pollutant into the atmosphere. However, proper irrigation may increase the yield as well as C storage from the biomass of the crops (Lal 2004a). Further, proper drainage under humid climate increases the soil C and productivity along with reduced N_2O emission (Monteny et al. 2006). Cultivation practices such a wetland rice system may be used for reducing CH_4 emission (Khalil and Shearer 2006). This is due to the fact that varieties of rice offer important mitigatory approach of CH_4 emission reduction (Akiyama et al. 2005). Under off season for paddy cultivation CH_4 emission is reduced through sustainable water management in the form of sprinkler or drip irrigation and avoiding water logging (Xu et al. 2003). The two fold process of increasing soil organic C in one hand and proper composting of the organic residues can help to reduce CH_4 emission as well as paddy productivity (Pan et al. 2006).

Conversion of crop land into land cover changes in the form of wind breaks, shelter belts could be fruitful to promote C storage. It was observed that the conversion of cropland to grassland helps to accumulate sufficient soil C (Lal 2004b).

Pasture land management is another important aspect in order to reduce GHG emission. Research studies reveal that grazing time and intensity influences the rate of C storage in soil (Conant et al. 2005). Increasing the deficiency of nutrients increases the litter deposition and further decomposition to add to soil C pool (Conant et al. 2001). Irrigation in grassland may increase soil C storage (Conant et al. 2001).

14.8 Role of Agroecosystem Towards Reducing Climate Change and Environmental

14.8.1 Sustainability in the Context Climate and Energy Footprint

Agrotechnology is an important aspect from the perspective of climate change. Under this process the ability of the green plant to absorb CO_2 and its further sequestration to soil in the form of biomass can be exploited for a C neutral environment (IPCC 2018).The level of C sequestration may increase on the basis of time span. However, research data reveals that agriculture practices are the significant contributor of GHGs through anthropogenic means (IPCC 2018). Agricultural area expansion through deforestation and grassland destruction are the potential anthropogenic activity increasing the C footprint of the agriculture production. Other potential process includes emission of methane from paddy fields, release of N_2O from degradation of unused N fertilizer and ruminant fermentation process. Reports of IPCC reveal that more than 30% of GHG emission results from cultivation practice and altered land use. In the food processing steps, if transportation and consumption of a product is considered then the emission of GHGs goes up to 40%. Therefore, agriculture is the main issue that needs to be addressed in order to mitigate the climate change through GHG emission reduction.

It was observed that the values of climate footprint vary significantly depending upon the cultivation process. As a consequence farming at small scale depending on indigenous inputs is much more eco-friendly than the industrialized fertilizer based intensive cultivation practice. Further, small-scale production for domestic consumption is far more fruitful in comparison marketing based agriculture production in terms of mitigating climate change. Soil management on the basis of climatic condition could be a good option to reduce both the energy and climate footprint and address environmental sustainability of the agroecosystem.

The cultivable land should be kept under vegetal cover and we should move towards zero tillage agriculture practice. This would help in buildup of soil C pool and hence fertility of soil. Some strategies such decomposition of stubble mulches within the soil, implementation of agroforestry systems may help to regain the sustainability of the agroecosystem. For emission reduction and associated reduction of climate and energy foot print concept such as organic farming, biofertilizer technology, use of biopesticides instead of energy intensive synthetic fertilizer and other agrochemical use can be implemented in order to reduce the energy input and output from the agroecosystem. The energy crisis situation has led to the pathway of renewable energy resources along with efficient use of energies. In order to achieve that regenerative practices in agriculture, waste reduction, sequestering more C in the soil followed by emission reduction from the agro-based food products are required. Shifting towards renewable forms of energy can mitigate up to 55% of GHGs emissions.

Circular economy can be effectively utilized for emission reduction up to 49% of GHGs and may thus reduce half of the emission till 2050. Emissions from the AFOLU shared 24% of overall GHGs emission. Production of food is an important component of AFLOU which harbours diverse form of activities and therefore approximates up to 8.4 billion tonnes CO_2e to be emitted till 2050. It is seen that 60% of emission is associated with the food production system. As for instance production of beef leads to release of more methane than release of CH_4 from paddy cultivation. High tillage operation leads to release of soil C in to atmosphere, use of nitrogenous fertilizer for crop production leads to release of N_2O. The amount of food wasted in the life cycle of a product has a significant contribution in emission. Circular economy approach would be highly fruitful in reducing C emission by acting as an integrated unit in the form of sequestering C in soil, reducing C emission, degrading the waste followed by natural system regeneration. According to one estimate if the organic matter level in soil is increased up to 3% it may reduce 1 trillion tonnes CO_2eq of C emission. Practices such as the composting can do well good in this aspect. Further the composting process leads to release of CO_2 which has a lesser global warming potential than CH_4. Further use of compost may also reduce the use of synthetic chemical fertilizer which may reduce the emission of N_2O. This would lead to reduce the climate and energy footprint considerably.

Regenerative agriculture is the process that aims towards adopting eco-friendly technology, maintaining soil health and crop biodiversity. Improving C sequestration for a particular area on the basis of soil, topography, prevailing land use practices such as integration of tree crops within the pasture land, cropping perennial crops which add more C to the soil and other modes of eco-friendly agrotechnologies would serve the purpose. Controlled grazing can do world good in reducing emission. Strategies include rotation of feed stock, rotation of livestock population, maintain the density of the livestock population may provide an annual emission reduction of about 1.4 billion tonnes $CO_{2eq.}$ till 2050. Using the concept of regenerative cropland concept by adopting zero tillage activity, intercropping practices, use of organic amendments may lead to higher C sequestration in the soil may benefit up to 2.5 billion tonnes CO_{2eq}.

14.9 Conclusion

Agroecosystem is a key component which needs to monitor in terms of its energy and climate footprint. Addressing sustainability on the issue of footprint is the biggest challenge of the present century. Both the climate and energy footprint address the issue of GHGs emission from various sectors of agriculture. It is crucial from combating climate change perspective. The livestock population and its associated grazing land as a major component of agroecosystem have proven to be the significant source in GHG emission. Both the sectors of crop production and livestock management involving the agroecosystem has reflected significant energy use, emission of GHG leading to gradual increase in the energy and climate footprint value. Research and development techniques have highlighted various methods and techniques to be implemented at the farm level in order to reduce the emission of GHG from its various spheres. This would help to reduce the energy and climate footprint of the agroecosystem and would help to achieve the environmental sustainability of the agroecosystem.

14.10 Research and Development and Future Perspectives towards Energy and Climate Footprint for Environmental Sustainability

Research and development activities are required for reducing climate and energy footprint in order to move towards a greener future for agroecosystem. Adoption of zero emission machineries and farm equipment, optimization of the feed material of the livestock population for lesser fermented emission of GHG (Sass 2003; Harmsen 2019), expansion of anaerobic manuring, improve livestock production efficiencies (FAOSTAT 2019), reduced application of N fertilizer in the developing world, optimum fertilizer application in paddy cultivation (Bell et al. 2010), proper processing of feed grain for lesser fermentation and lesser release of CH_4 (Forsgren et al. 2019), nitrification process inhibition on pasture land (Munoz and Llanos 2012) could provide significant result in emission reduction.

Conversion of fuel based equipment to zero emission through manual methods would be highly fruitful in terms of energy saving and emission reduction. Policies regarding proper development of zero emission equipment would help to reduce the emission. Therefore, research and development activities need to be aimed in the aforesaid direction (Munoz and Llanos 2012). Scientific research should be focused on breeding programmes of animal husbandry towards reducing ruminant fermentation process. Researches reveal that 20% of CH_4 emission from the livestock comes from the germline (Bell et al. 2010). From US perspective genetically modified products may reduce the methane load up to 11 kgs per cow. Fertilizer amendments in the form of ammonium sulphate and gypsum can reduces the activity of methanogenic bacteria present in paddy field followed by CH_4 emission reduction.

Another important research area towards reducing emission reduction is through proper monitoring and evaluation of livestock health which may aid towards emission reduction through optimum fermentation and proper manure management. Animal feed optimization through higher fat diet is another important aspect of reducing the fermentation process. Fat tend to reduce the fermentation of organic matter and improve its further digestibility along with inhibiting methanogenic bacteria to perform their activity in the rumen of the ruminant animals. The dry matter percentage of fat is increased up to 3% in the cattle feed. As a consequence of that CH_4 emission reduces up to 4% (IRP and UNEP 2018). Reports have further revealed that cattle feed material such as propionate precursors reduce the cattle fermentation without affecting the growth of the animals. It also mentioned that 13% reduction in fermentation rate along with 2.5% productivity increase has led to 15% reduction in CO_2 emission (Ellen MacArthur Foundation 2017).

Improved management of the flooding during paddy cultivation through alternate wetting and drying method has shown to reduce emission reduction to considerable level. Capture of CH_4 through anaerobic digestion to reduce GHG emission can be done through the system of hog manure approach. Different types of anaerobic digestors are available for production of biogas which can be used for electricity generation and thus they reduce the GHG emission. Processes such as mechanical flaking improve the grain digestion. This reduces the particle size for greater level of microbial decomposition and thus it can reduce the potential GHG emission. Research studies have shown that such approaches may reduce enteric fermentation up to 15% followed by improved productivity up to 5%. Transplantation of rice seedlings for sowing purpose may be modified through direct dry seeding method. Under this method the field needs not to be flooded for a month thus inhibiting the methanogens for producing and emitting CH_4. Such approaches can reduce emission of CH_4 up to 45% on per hectare basis. Increasing the production efficiency of livestock population through hormones, and other forms of biomolecular applications in the form of various growth promoting substances that is alternative to antibiotics may reduce the GHG emission lead to 15% CO_2 emission reduction (Material Economics 2018).

Use of substances that inhibit nitrification process in pasture land tend to reduce N_2O emission (Favier et al. 2018). Zero or low tillage activity tends to conserve soil organic matter which reduces the fuel consumption by the farm machinery up to 75% followed by reduction in the denitrification process and N_2O emission up to 18% (UNEP and IEA 2017). Researches at field level has further revealed that use of slow release fertilizer tend to reduce 20% of N_2O emission. Such fertilizers fulfil the demand of nutrients required by the crop plants when they require it for growth and development process. In this way they reduce lesser nitrogen loss into the environment (Ellen MacArthur Foundation 2017).

Use of new innovative technologies may also prove good for emission reduction and reducing the footprints of agroecosystem. Simultaneously it would also address the issue of environmental sustainability from future perspective. One such method is the precision agriculture which applies the fertilizer as per the requirement of the crop on per unit area basis through geographical information system and remote sensing based tools. Such approaches tend to reduce the use of excess chemical fertilizer which tends to emission reduction (Zhang et al. 2013). Use of CH_4 inhibitors in the feed material has led to 30% reduction in the enteric fermentation. Therefore, future researches should be aimed towards screening of cattle breeds that produces less CH_4 after their feeding (Hristov et al. 2015). Future research and various forms of advance technologies (such as gene editing) could play significant part in emission reduction and thus reducing the climate and energy footprint. Improved farming strategies in the form of conversion of anaerobic system of paddy cultivation to anaerobic system may lead to reduction in CH_4 emission.

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Ecofootprint of Charcoal Production and Its Economic Contribution Towards Rural Livelihoods in Sub-Saharan Africa

15

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Abstract

Charcoal is used in up to 80% of urban households and in small- to medium-scale commercial entities across sub-Saharan Africa (SSA). These provide a ready market which contributes to household income generation, poverty reduction, national development, employment, and development of especially the rural economy. The demand for charcoal as an energy source is mainly driven by urbanization and population growth and also varies with the level of income among other factors. Meanwhile, charcoal production in SSA is mostly by producers in rural areas who are usually scattered and work independently of one another. Their production operations are temporary, and they shift whenever the wood resources dwindle. Charcoal energy footprint has become vital, and calculating the impacts of charcoal production is important in shrinking the ecofootprint. Contribution to rural livelihoods and national economies is significant but grossly undervalued due to the nature of the sector. In 2008, charcoal production and trade contributed US$8 billion and employed seven million people across the region. This was projected that it would be worth US$12 billion by 2030 and employing eight million people. It has an oligopolistic structure whose major players in the value chain are producers, wholesalers, transporters, and retailers. The transporters/wholesalers get as much as four times the income of the producers and more than 10 times that of retailers. The stable urban demand, easy access to forest resources, and low investment cost ensure that 60% of rural household income is from charcoal production and trade in most of the SSA. Production technologies are quite a challenge as they are of low efficiency (10%), thereby putting immense pressure on the natural forests that provide the feedstock. This, in turn, increases the energy footprint due to the reduced carbon sequestration capacity of the SSA woodlands. Hypothetically, production is projected to increase by 73% in 2030 with the fastest growth being in the Central African sub-region of SSA driven by, among other things, an increase in the human population. However, despite its contribution to rural livelihoods, policymakers give the charcoal sector a low priority and nearly zero consideration in planning and the implementation of national or regional energy action plans. Besides, existing policies, if any, are rarely implemented, and are usually governed by a weak regulatory framework. As such, the charcoal sector remains largely informal and less appreciated at both national and regional levels in the SSA.

Keywords

Charcoal footprint · Charcoal production · Livelihood · Natural resources · Sub-Saharan Africa

Abbreviations

CA	Central Africa
CBNRM	Community-based natural resource management
DRC	Democratic Republic of Congo
EA	East Africa
EF	Ecological footprint
GDP	Gross domestic product
GFN	Global footprint network
gha	Global hectares
GHGs	Greenhouse gases
IEA	International Energy Agency
km	Kilometre
SA	Southern Africa
SSA	Sub-Saharan Africa
WA	West Africa

15.1 Introduction

Charcoal has occupied a large proportion of the household energy budget in many parts of the developing economies, especially the sub-Saharan Africa (SSA) from time immemorial. As such, its production has tripled globally from 1964 (17.3 million tons) to 53.1 million tons in 2014 (Rodrigues and Junior 2019). Between 2010 and 2016, charcoal production in Africa grew by 12.6% (Alfaro and Brieland 2018). An estimate of 93% households in rural areas and a further 58% of peri-urban and urban areas in SSA depend on wood fuel for meeting their daily energy requirements (Schure et al. 2013). In particular, charcoal is used as a primary energy source by about 80% of urban households (Zulu and Richardson 2013; Branch and Martiniello 2018) and in small- to medium-scale commercial entities like bakeries, tea, and tobacco processing (van Dam 2017) across the SSA region. It is the preferred biomass fuel among urban households because of its affordability, cleanness, and ability to burn evenly when cooking compared to firewood (Iiyama et al. 2015; Vollmer et al. 2017).

Charcoal production in SSA contributes to household income generation, poverty reduction in urban and rural areas through employment creation, and development of rural economies (Angelsen and Wunder 2003; Kiruki et al. 2019). According to Cuvilas et al. (2010) about three million people (approximately 15% of the population) are involved in and benefit from the charcoal trade in Mozambique. This constitutes an estimated value of approximately 2.2% of Mozambique's gross domestic product (GDP) (Van der Plas et al. 2012). In Malawi, charcoal trade indirectly employs 120,000–140,000 people with a contribution of approximately 3.5% of GDP (Zulu 2010) as much as the sum of the total contribution of tobacco and sugar sectors (Kambewa et al. 2007), while in Liberia, 90% of the urban population depends on charcoal with a contribution to GDP ranging from 6 to

11% for the 2005–2013 period (Alfaro and Brieland 2018). In Uganda, charcoal trade provides income to thousands of households and is considered one of the highest earning economic livelihood ventures for rural households (Mwampamba et al. 2013; WWF 2015). Charcoal production has the potential to contribute towards improved rural economies and financial stability among rural communities, particularly during crop-failure seasons. Although charcoal contributes greatly to both rural and national economies, information on its contribution at regional level is missing. This chapter, therefore, highlights the contribution of charcoal production and trade to economies across SSA. Additionally, the chapter also deals with policy and legal aspects related to charcoal production.

15.2 Concept of Energy Footprint and Its Valuation

The Global Footprint Network (GFN) describes energy footprint as the sum of areas utilized to provide non-feed energy, for example, land used for hydropower generation, cultivated land used to provide fuel crops, and land gazetted for forest wood fuel generation (Global Footprint Network 2009). Okoko et al. (2017) describe carbon footprints as amounts of greenhouse gas (GHG) emissions about a given activity and linked to climate change and its impacts. Among the GHGs, carbon dioxide contributes the most to carbon footprint at 87% with methane, nitrous oxide, and other GHGs contributing the rest (Johnson 2009). In 2016, global warming, an important factor of energy footprint was ranked as the most significant global threat to the environment, society, and the economy (World Economic Forum 2016; Meena et al. 2020a, b). The link between the energy footprint, energy supply and consumption, and subsequent carbon emission from sources such as charcoal remains unclear yet its important to understand how the energy footprint impacts charcoal consumption.

In SSA, wood-based energy sources remain high and critical in meeting rural and urban energy demands, because of affordability and availability (Okoko et al. 2017). As such, the land is affected, impacting the energy production significantly as many millions of acres of forested areas may be consumed to meet the demand for charcoal energy posing a threat to conservation and reducing the energy footprint as more land is needed to meet energy demands (Outka 2014).

However, the increasing feedstock scarcity associated with deforestation, exacerbated by the negative socio-economic and environmental outcomes of inefficient production, can reduce the energy footprint, highlighting the importance of alternative energy use (Meena and Lal 2018). In addition, an integrated approach aimed at reducing energy poverty can reduce people's carbon footprint. Climate change impacts arising from GHG emissions have been linked to energy consumption and are threatening the livelihood of vulnerable communities, thus the need to reduce the carbon footprint of energy use including the use of biomass fuels (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b).

15.2.1 Methods of Calculating the Energy Footprint of Charcoal Production

15.2.1.1 Calculating Charcoal Energy Footprint Using Carbon Sequestration

Globally, consumption of energy increased from 4661 Mt. in 1973 to 9425 Mt. in 2014 (International Energy Agency 2016). Charcoal energy and GHG emissions are of concern as GHGs have adverse environmental impacts such as climate change (Saidur et al. 2009). As mitigation, the use of improved kilns and energy-saving technologies has increased significantly to reduce GHG emissions.

Energy and carbon footprint have been used for communicating the causes of climate change (Mulrow et al. 2019). However, the use of charcoal energy footprint in assessing carbon and reduction of greenhouse gas emissions through the charcoal production value chain is relatively new. Energy footprint calculators take a variety of methods, but all seek to measure the energy emissions that result from a given activity.

Charcoal energy footprint has become vital as interest grows in calculating the impacts of charcoal production on the environment at individual household and national level (Mulrow et al. 2019). Here, we adopted calculation of charcoal energy footprint, from the energy footprint (EF_{energy}) calculation formulas (Fu et al. 2014), using the carbon sequestration method (Liu 2009) as the basis. Here, the charcoal energy production footprint ($CEF_{energy\text{-}p}$) is calculated (Eq. 15.1). Using Eq. (15.2), the charcoal energy net export trade footprint ($CEF_{energy\text{-}nt}$) is determined thereafter. Lastly, the charcoal energy footprint is obtained by deducting ($CEF_{energy\text{-}p}$) from $CEF_{energy\text{-}nt}$, as shown in Eq. (15.3), modified from (Fu et al. 2014).

$$CEF_{energy-p} = \frac{EC \times ED \times CD \times TCR}{CS \times EQ} \tag{15.1}$$

$$CEF_{energy-nt} = EF_{energy-p} \times S \tag{15.2}$$

$$EF_{energy} = CEF_{energy-p} - CEF_{energy-nt} \tag{15.3}$$

where EF_{energy} = charcoal energy footprint; $EF_{energy\text{-}p}$ = charcoal energy production footprint; $EF_{energy\text{-}nt}$ = charcoal energy net export trade footprint; EC = charcoal energy consumption; ED = charcoal energy density (the world's average calorific standard unit of fossil energy, 29.4 GJ per ton of standard coal); CD = charcoal carbon density (unit heat rate of carbon emissions standards, coal, 0.026 t standard coal/GJ, oil, 0.020 t standard coal/GJ, natural gas, 0.015 t standard coal/GJ); TCR = terrestrial carbon responsibility (69%); CS = charcoal carbon sequestration (tonnes carbon per hectare per annum, 0.95 t/ha); EQ = equivalence factor of 1.1 for energy land; S = net exports of goods as a proportion of a country's GDP (modified from Fu et al. 2014).

15.2.1.2 Calculating Charcoal Energy Footprint Using Units of Energy

The use of energy footprint (EFP) can also help to measure the energy consumption (Palamutcu 2015). The EFP can be measured in local or global hectares (gha), and in units of energy/functional unit (Cucek et al. 2012). We adopted the calculation of charcoal energy footprints from Wang et al. (2017), using the units of energy and following the definition of the demand for charcoal energy resources. The charcoal energy footprint in SSA can, therefore, be calculated as:

$$\mathrm{CEFP} = \sum E_i$$

where E_i is the consumption amount of energy from charcoal i (Mt standard coal equivalent) (modified from Wang et al. 2017).

15.3 Charcoal Demand and Production in Sub-Saharan Africa

Apart from energy provision, charcoal has been used for improving soil properties, crop productivity, and edaphic carbon sequestration as biochar (Demirbas et al. 2016). Rodrigues and Junior (2019) identified four main uses of charcoal: agriculture, domestic, industrial, and chemical purposes. However, charcoal production has also been observed to contribute up to 14% of forest degradation and deforestation in many parts of SSA (Gumbo et al. 2018; Zorrilla-miras et al. 2018; Brobbey et al. 2019a).

15.3.1 Demand for Charcoal

The demand for charcoal as an energy source is driven by urbanization and population growth and varies with the level of income among other factors in the SSA (Dioha and Kumar 2020). The demand for charcoal across SSA has been increasing (Smith et al. 2019) and is projected to double by 2030 (Zulu 2010; International Energy Agency 2016). Demand for charcoal is heavily driven by the dependency on charcoal, by residents of urban areas of the SSA countries. For instance, the proportion of urban dwellers who depend on charcoal in Bamako (Mali), Bangui (Central African Republic), Brazzaville (Congo Republic), Kinshasa (Democratic Republic of Congo), Niamey (Niger), and Ouagadougou (Burkina Faso) is at 97%, 92%, 90%, 95%, 95%, and 95%, respectively (Schure et al. 2013). Additionally, in Kampala (Uganda) and Liberia, 90% of the urban population rely on charcoal for meeting their energy requirements (Branch and Martiniello 2018; Alfaro and Brieland 2018). The preference for charcoal among urban populations is increasing probably because of the calorific value per unit weight which is high, availability, ease of packaging and transportation, affordability, and less smoke compared to firewood when cooking (van Beukering et al. 2007).

Charcoal consumption is associated with a change in an urban population. For instance, an increase of a single percentage point in the urban population can increase charcoal consumption by 14% in SSA (Neuberger 2015; van Dam 2017). Not only does the size of the market in urban areas affect the scale of charcoal production, but larger urban markets sustain the existence of small-scale charcoal producers for an extended time (Smith et al. 2019); in Ghana, charcoal produced in villages is transported to major cities for marketing from Kintampo forest district which produces 22% of all Ghanaian charcoal and supplying major cities of Accra, Kumasi, and Takarodi (Agyei et al. 2018; Brobbey et al. 2019b), while 80–90% of charcoal produced in rural Kitui, Kenya, is destined for the urban market of Nairobi City (Taylor et al. 2019).

15.3.2 Dynamics of Charcoal Production

Charcoal production in SSA is mostly done by producers in rural areas who are usually scattered and work independently of one another (Mwampamba et al. 2013). In the Miombo ecoregion, charcoal is said to provide 76% of the total energy consumed (Gumbo et al. 2018). This is the reason Mwampamba et al. (2013) argued that charcoal is too important a resource to be reduced to a mere environmental problem because its production is critical to energy sources in SSA. Evidently, out of the top ten charcoal producing countries globally, six are from the SSA – Nigeria, Ethiopia, the Democratic Republic of Congo (DRC), Ghana, the United Republic of Tanzania, and Madagascar (van Dam 2017). Charcoal production and trade have been growing from time immemorial. An example of how the charcoal production and trade have been increasing in the SSA region is observed in Food and Agricultural Organization (2014) and Alfaro and Brieland (2018) that reported an increase of 14.3% between 2010 and 2016 in charcoal production and trade.

Charcoal operations are temporal and shift whenever the wood resource and agricultural land dwindles (Kammen and Lew 2005). Malimbwi et al. (2010) emphasized this aspect across selected countries of SSA (Table 15.1). The study indicated that charcoal footprint increased from less than 50 kilometres (km) in the

Table 15.1 Spatial and temporal dynamics of charcoal supply in three SSA countries (Adopted: Malimbwi et al. 2010)

Country	City supplied	Period	Charcoal source (km)
Senegal	Dakar	1950s	<200
		1960s	200–300
		1970s and 1980s	>300
Mozambique	Maputo	1980s	50–60
		1990s	60–100
		2000s	150–200
Tanzania	Dar es Salaam	Before 2000	<200
		After 2010	>300

1980s to distances beyond 300 km in the early twenty-first century causing the industry in SSA to operate on a gradually increasing distance between the production areas and the market.

15.3.3 Contribution to Rural Livelihoods and National Economies

The value that the charcoal industry contributes to the economy of SSA was pegged at eight billion United States dollars (US $) employing more than seven million people, with a projected value, of above US $12 billion by 2030 and employing over 12 million people (Sander et al. 2011). Within the energy sector, a terajoule of energy consumed from charcoal is estimated to create between 200 and 350 jobs; this figure is thrice that of jobs created by the consumption of a terajoule of electricity and 20 times more than that created by the consumption of kerosene (Smith et al. 2019). Charcoal production is important to the rural livelihoods, with 35% of Ghanaian rural households being dependent on charcoal, while 36% of income for rural communities depends on the production and trade of charcoal (Brobbey et al. 2019a). At the macroeconomic level, the contribution of the charcoal sector to the GDP in the SSA varies from country to country with Liberia being the highest at 6% (Vollmer et al. 2017). The Mozambican GDP supports 15% of the population who are involved in charcoal trade, supplying 70–80% of the urban population (Brouwer and Falcão 2004; Cuvilas et al. 2010; International Energy Agency 2016; Peter and Sander 2009).

Charcoal production has gained recognition as part of livelihood diversification strategies for rural and urban households across the SSA region (Jones et al. 2016). Income generated for the poor from charcoal is a safety net, and to producers, it supplements their capital, who then expand their livelihood into profitable farming, other business enterprises, and for meeting other financial needs (Kambewa et al. 2007; Ndegwa et al. 2011; Smith et al. 2017). Production of charcoal is mostly done in rural areas and consumed in urban areas. As such, the size of the urban market affects the scale of production of charcoal in the rural areas (Smith et al. 2019). In SSA, the market value of charcoal has been estimated at US $ 11 million (Jones et al. 2016). This emanated from 36 million tonnes of charcoal produced in the rural areas of SSA, but fortunately, at least 50% of the revenue is retained in the rural areas. A study in three SSA countries showed a distribution of income across three main players with the transporters or wholesalers having the biggest share in the charcoal value chain (Table 15.2; Vis and Vos 2010).

Charcoal is categorized under the “high-cash” income revenue streams for rural households in SSA (Vollmer et al. 2017; Brobbey et al. 2019a). In Ghana, the industry contributes significantly to income generation in the rural and peri-urban areas and is second to crop farming (Brobbey et al. 2019a), while in Zambia, charcoal forms a key source of livelihood for the rural farming communities besides agriculture (Mwitwa and Makano 2012). This narrative is similar across the SSA region, e.g. DRC (Schure et al. 2013), Mozambique (Jones et al. 2016), and Kenya (Kiruki et al. 2019). Charcoal production is also considered as a low-income activity

Table 15.2 Income distribution among participants in the charcoal value chain (Adapted: Vis and Vos 2010)

Country	Producers (%)	Transporters/wholesalers (%)	Retailers (%)
Malawi	20–33	20–25	25–30
Mozambique	16–37	56–78	6–7
Tanzania	33	50	17
Total	100	100	100

in some areas, as a stop-gap measure for poverty alleviation (Khundi et al. 2011; Jones et al. 2016).

Stable urban demand, low initial costs, and easy access to forest resources attract large numbers of rural communities to the charcoal production and sales segment of the value chain (Arnold et al. 2006; Ellegard and Nordstrom 2003) throughout the SSA. Consequently, charcoal production represents a significant source of income and a major employer for various rural communities across the SSA (Zulu and Richardson 2013; Syampungani et al. 2009). The majority of the poor rural derive more than 60% of their household income from charcoal production and trade (Chidumayo 2013). For example, in Tanzania, estimates show that 75% of the rural poor derive cash income from charcoal production and trade (Malimbwi and Zahabu 2007).

The charcoal market also plays a very important role in creating full-time and seasonal employment in the region (Zulu and Richardson 2013). For instance, Seidel (2008) reported that in Zambia, the charcoal industry employed about 7800 people, while Kambewa et al. (2007) reported that the sector, in Malawi, employed about 92,800 people. Generally, there are considerable trade networks moving charcoal from rural areas where it is produced to urban areas where it is mostly consumed (Campbell et al. 2003). Consequently, the charcoal value chain is observed throughout the SSA ecoregion. However, the characteristics of the charcoal value chain have not received much in the literature (Shively et al. 2010). Hence, an understanding of the success and challenges of charcoal production and trade's contribution to improving rural livelihoods is masked.

The charcoal value chain is structured such that the primary participants consist of producers, transporters, wholesalers, and retailers (Kambewa et al. 2007; Shively et al. 2010; Zulu and Richardson 2013). Producers, a group of specialized individuals involved in producing charcoal, constitute the largest group along the charcoal value chain (Sepp 2008). For instance, in Kenya, it is reported that charcoal producers are about 200,000, which equates to the number of people working in the education sector (Sepp 2008; Ndegwa et al. 2011), while in Malawi, estimates show that out of the 92,800 people engaged in the charcoal industry, 46,500 people are engaged in charcoal production (Kambewa et al. 2007). Similar patterns were observed in studies conducted in Zambia and Tanzania (Seidel 2008; Monela et al. 1993).

Generally, charcoal producers tend to be the rural poor, often producing charcoal on a small scale (Kambewa et al. 2007). However, in most instances, large-scale urban charcoal traders also produce charcoal indirectly by employing rural producers as labourers (Sander et al. 2011; Kambewa et al. 2007). The "urban producers", commonly known as "financiers" earn higher income relative to rural producers because they produce charcoal in large quantities and are involved in the entire supply chain (Attwell et al. 1989). Relative to other participants along the value chain, producers tend to earn marginal profits from charcoal sales and have limited bargaining power on charcoal prices (Ndegwa et al. 2011). In Zambia, for instance, Mwitwa and Makano (2012) observed that producers earned less than US $100 per month, while other actors in the value chain were able to easily earn this amount of money. In Mozambique, Puna (2008) reported that transporters earned large amounts of income which in some cases was about 20 times what producers and retailers earned. Similarly, in Tanzania, transporters and wholesalers retain 50%, rural producers 33%, and urban retailers gain 17% only of the total profits (Peter and Sander 2009).

Reviewing the charcoal industry shows that the charcoal business displays an oligopolistic structure (Sander et al. 2011; Sepp 2008). This is because power differentials driven by the informal and unregulated nature affect the distribution of charcoal profits with producers and retailers getting the biggest chunk (Zulu and Richardson 2013). Rural producers operate individually and are not formally organized into associations, hence lacking a collective voice and a strong bargaining power to push their agenda along the value chain (Bailis et al. 2013; Ndegwa et al. 2011). However, notwithstanding these challenges, rural producers' involvement in charcoal production remains an important source of household income, providing safeguards against food shortages, lack of paid formal employment, and other poverty-enhancing aspects (Sepp 2008; Zulu and Richardson 2013). This is because most charcoal producers have limited income-generation options (Arnold et al. 2006; Peter and Sander 2009). This emphasizes the significant role charcoal plays in rural livelihoods even though the real income is not adequate to improve their standards of living (Wunder 2001).

15.3.4 Technologies and Charcoal Production Efficiency

Charcoal yield and quality are affected by the quality of the wood raw material, the type of kiln used, and the level of control exerted on the carbonization process (Rodrigues and Junior 2019). Globally, charcoal is mostly produced in earth kilns that have a production efficiency of only 10–20% (Bailis et al. 2013), and it should be emphasized that most of the world production of charcoal is from SSA (van Dam 2017). The earth kiln, pit or mound, is a chamber of carbonization which uses grass and earth as insulation. Many reasons, such as high initial investment costs, high maintenance costs, and a need for skilled labour, have hampered the use of high-tech kilns in producing charcoal, especially in low-income countries like those of SSA (Rodrigues and Junior 2019). The different types of kilns used in selected countries of SSA have adequately been documented (Table 15.3; Kammen and Lew 2005).

Table 15.3 Charcoal production kilns and efficiency in selected SSA countries (Adapted from Alfaro and Brieland 2018; Hibajene and Kalumiana 1994)

Kiln type	Production efficiency (%)	Country
Mozambique long earth mound	10–15	Mozambique
Large Suriname earth mound	20–25	Mozambique
Traditional earth mound	2–17	Tanzania
Metal kiln (vertical stacking)	39–42	Somalia
Casamance	25–30	Mozambique, Senegal
Traditional earth mound	8–20	Liberia
Improved pit earth kiln	25–30	Liberia
Earth pit kiln	12.5–20	South Africa
South Africa garage	12.5–23.5	South Africa
Mark V	20–35	Ivory Coast
Mark V	10–18	Tanzania
Mark V	25	Liberia
Traditional earth mound	5–20	Zambia

Production efficiency affects the sustainability of charcoal production and forest management. According to Mwampamba et al. (2013) if charcoal production efficiency is improved, then there would be shrinkage in the footprint of charcoal production on forests and woodlands in the SSA. For instance, moving away from using the traditional earth kiln (20–25%) in Zambia to using the metal kiln available in Somalia (39–42% efficiency) could reduce the quantity of wood used as a raw material in charcoal production (Hibajene and Kalumiana 1994; Alfaro and Brieland 2018). To make one ton of charcoal, the traditional earth kiln in Zambia would require 5–20 tons of wood (Hibajene and Kalumiana 1994). However, the Somalian improved metal kiln would only need 2.38–2.56 tonnes to make 1 ton of charcoal (Alfaro and Brieland 2018).

15.3.5 Charcoal Production Trends and Projections in the Past

Within the four regions of SSA, namely Southern Africa (SA), West Africa (WA), Central Africa (CA), and East Africa (EA), there has been a general increase in average decadal charcoal production over time (Fig. 15.1). The trend indicates that East Africa had the highest charcoal production throughout (1990–1999, 2000–2009, and 2010–2017). WA was the second highest producer of charcoal, while a relatively low but constant production is observed in SA. This variation trend may be attributed to differences in population size across these regions and probably advances in technology. Although WA has the highest population, EA has projected to have the highest charcoal demand followed by WA, CA (121, 625, 353), and lastly SA (68, 769, 342) (Worldometer 2020). Additionally, this may also be attributed to variations in levels of technological development and therefore use of different sources of energy.

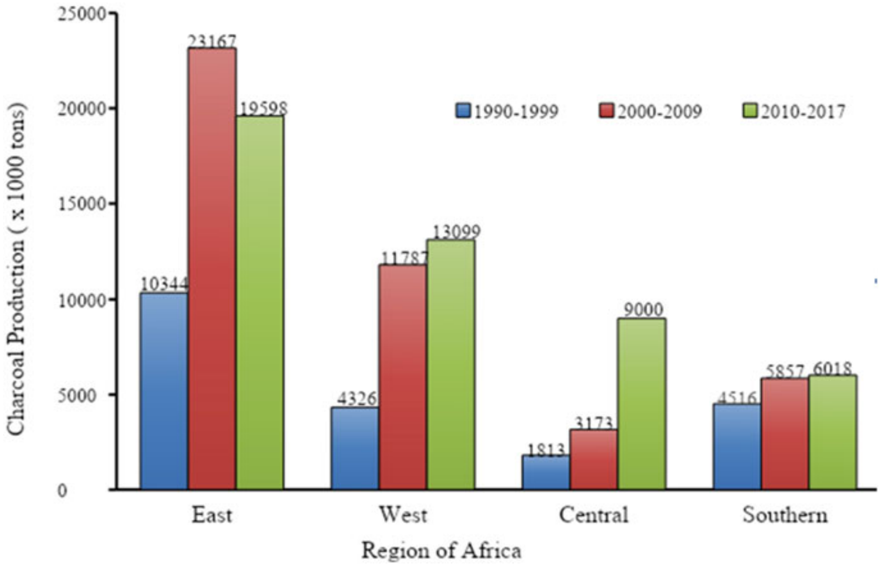

Fig. 15.1 Decadal trend of charcoal production (Source: UN Data 2019)

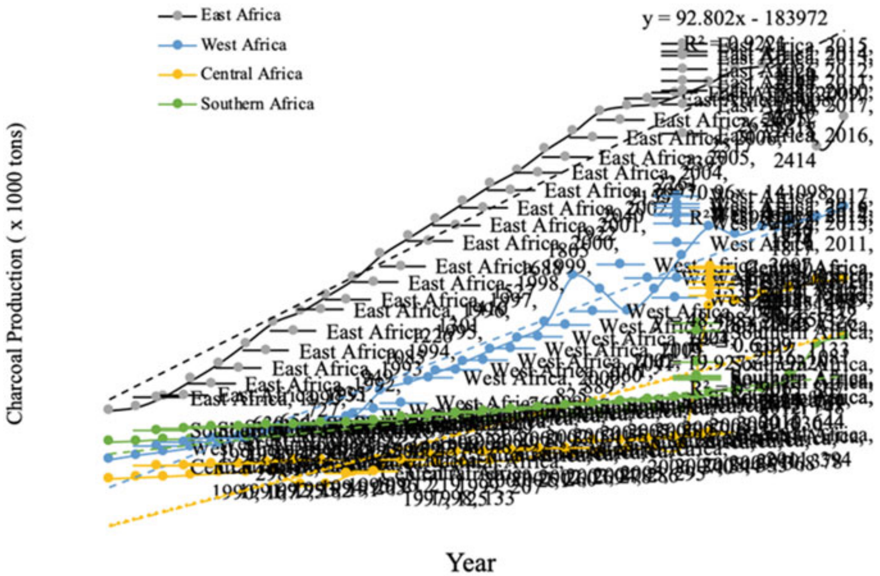

Fig. 15.2 Trend of charcoal production in SSA (Data Source: UN Data 2019)

The annual average charcoal production has similarly followed this demographic trend. Central Africa had the least until about 2011 when it overtook Southern Africa which currently has the least increment rate and quantities of production (Fig. 15.2).

As per Fig. 15.1, the statistical mean of decadal increment was 129.5%, 92%, 54.5%, and 16.5% for CA, WA, EA, and SA, respectively. If this trend continues, we hypothesize that by 2030, the average production will have soared by 73% in SSA. We also hypothesize the production will be mostly driven by demand with increasing population, and given that charcoal is a relatively affordable source of energy and easy to handle (Malimbwi et al. 2010). Furthermore, with the institutionalization and commercialization of the charcoal value chain (Doggart and Meshack 2017), production is hypothesized to transform SSA in a degraded landscape.

15.4 The Energy Footprint of Charcoal Across the Globe and Sub-Saharan Africa

Energy footprint can also be referred to as the land area needed to absorb GHGs. Globally, environmental problems such as increased urbanization, industrial development, changes in land use, desertification, or deforestation have negatively affected the ability of the land to perform the GHGs absorption task (Global Footprint Network 2009). Anthropological footprint on earth is 50% due to energy use. In 1961, the energy footprint was 2.5 billion hectares but soared to 6.72 billion hectares in 1999. For mitigating this trend of rising energy footprint plant or tree growth needs to be increased which consequently increases sequestration. Encouraging the use of solar, wind, and other renewable energy sources can equally help in the mitigation.

15.5 Impact of Energy Footprint in Charcoal Production in Sub-Saharan Africa

The two alternate value chains of charcoal could be the improved and unimproved value chains. There is a significant difference between the footprint of the unimproved from the improved value chains. An unimproved charcoal value chain would have a basic earth kiln (recovery 13.1%) for production, and charcoal would be used in common braziers (efficiency 24%), while in the improved value chain, charcoal earth kilns are improved with an efficiency of 20% and used in improved cookstoves with an efficiency of 32% (Okoko et al. 2017). The charcoal footprint is dominated by the production of charcoal at 45% followed by its combustion at 40% (Johnson 2009). The reduction in carbon footprint from the unimproved charcoal value chain to the improved one is up to an average of 77.5%, and there is a further benefit of lessened demand on the wood resources by up to 60% (Okoko et al. 2017).

15.5.1 The Biomass Energy Factor in Ecofootprint (EF) Mapping

One of the significant benefits consumed by humanity is energy, which makes it an important determinant of EF. Consumption of energy in various forms generates carbon and its derivatives, which in excess impacts the local and global climate. Globally, carbon is the most rapidly growing component of EF (Lin et al. 2019). Biomass, which includes charcoal and firewood, provides over 70% of total primary energy supply to households across SSA (Matsika et al. 2013). Fuelwood for household use and charcoal production is often harvested at unsustainable rates and has developed into a major driver for forest degradation particularly around urban centres of SSA (Denruyter et al. 2010).

15.5.2 Ecofootprint of Africa

From the Global Footprint Network (2009) statistics, Africa's total footprint in 2008 was 1.41 billion (7.7% Earth's total), equivalent to 1.4 gha average per capita footprint. Although this falls below the global average per capita footprint of 2.7 gha, it is close to the globally available biocapacity of 1.8 gha per person and is rapidly approaching the biocapacity available within Africa's borders. According to Fig. 15.3 (respective 2008, 2010, and 2016 per capita EF of SSA), Southern Africa had the highest per capita EF at 3.7 gha with carbon stocks contributing 72.9% (2.7

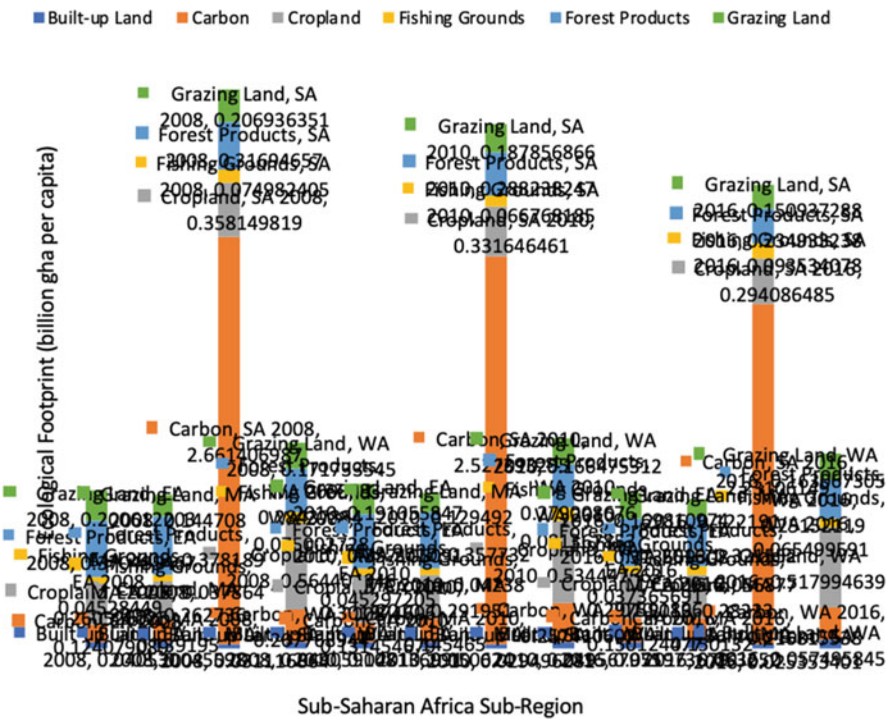

Fig. 15.3 Sub-Saharan Africa's Ecological Footprint per sub-region, per person, in 2008, 2010, and 2016 (Data source: Lin et al. 2019). Note: EA: Eastern Africa, MA: Middle Africa, SA: Southern Africa, and WA: Western Africa

gha) of its total footprint in 2008. Western Africa was the second contributor to the per capita EF at 1.4 gha in the same year. The Eastern and Middle Africa together accounted for 2.0498, which is only 56% of Southern Africa's per capita EF in 2008. In 2010 and 2016, the carbon stocks in Southern Africa remained consistently significant as a contributor to the sub-region's per capita EF and generally highest spatially. This consequently resulted in 3.4 and 3.0 gha per capita EF, respectively, which makes the region a likely hotspot for nearly 50% of carbon emissions in the continent. In Western Africa, approximately 36–37% of per capita EF is accounted for during conversion of available land resources for crop production. This should be viewed as a potential risk to forest cover and provision of critical ecosystem goods and services (e.g. including biomass supply, carbon dioxide sequestration, and biodiversity conservation in the sub-region).

15.5.3 Drivers of Ecological Footprint

EF can be considered as a function of population size, the quantity of goods and services consumed per person, and the energy resource associated with the production of goods and services. Lower population and individual consumption, more efficient use of resources, and reduction of waste emitted in the production of goods and services all result in a smaller EF.

15.6 Effect of Charcoal Production and Trade on Forests and Wetland Resources

The main driver for charcoal production is the increasing demand, which has led to rapid deforestation rate, accelerated land degradation, and upsurges in carbon emissions globally (Mwampamba et al. 2013; Khan et al. 2020a, b). For instance, Sedano et al. (2016) identified charcoal production as the key driver of degradation in Mozambican forests in the Tete Province representing nearly 30% of the country's forest cover change. The degradation could be further intensified as the human and livestock populations increase and households diversify agricultural income sources. Although changes in rural land use are a leading driver of charcoal production, agriculture has also been indirectly associated with the charcoal industry, since both support and depend on the same ecosystem services. Most charcoal producers from Mozambique showed a preference for certain tree species and of at least 15 cm diameter (Sedano et al. 2016). Although some authors (Oduori et al. 2011) have ascribed deforestation exclusively to charcoal production, others (Rueda et al. 2015) maintain that deforestation mainly results from agriculturally based activities with charcoal a by-product. Nevertheless, excessive charcoal production can cause deforestation, mudslides, soil erosion, increased greenhouse gas emissions, and climate change. According to van Dam (2017), charcoal production in the tropics annually contributes a proportionate 71.2 million tons of carbon dioxide and 1.3 million tons of methane gas, respectively.

In the East African region, the loss of biodiversity and forest degradation due to charcoal production has also been reported, e.g. in Uganda (Namaalwa et al. 2007) and Kenya (Kiruki et al. 2017). These losses have affected the socio-economic well-being of rural populations in the region through a reduction in available ecosystem goods and services. A similar scenario is reflected in SSA's dryland rural landscapes particularly on the indigenous, endangered rare tree species (Luoga et al. 2000; Namaalwa et al. 2007; Ndegwa et al. 2011). In SSA, some of the preferred tree species for charcoal production include *Colophospemum mopane, Brachystegia boehmii, Cordyla africana. Brachystegia spiciformis, Combretum imberbe, Mangifera indica* (mango), and *Vitellaria paradoxa* (shea butter trees). In Mozambique, for example, the mopane timber is 15% more preferable to other tree species (Sedano et al. 2016).

Several studies have reported a decline in wood resources required for charcoal production in SSA (Arnold et al. 2006; Ruuska 2013; Santos et al. 2017; Kiruki et al. 2019). The reduction is accredited to multiple confounding factors: Firstly, due to the demand and high dependence on charcoal production as a source of livelihood when agricultural productivity declines due to prolonged drought conditions (Mosberg and Eriksen 2015). Secondly, due to population growth, which has led to agricultural intensification causing increased demand for land clearing for farming and settlement and increased demand for charcoal (Ngugi and Nyariki 2005). Closely related is urbanization, which has led to increases in the charcoal demand and market expansion. Mwampamba et al. (2013) concur with Zulu and Richardson (2013) that the urban market is likely to be the major driver of charcoal production in SSA, thereby posing a threat to the future for forest resources in the region.

The universally adopted Ramsar Convention (Matthews 1993) definition of wetlands recognizes these systems as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters". Wetlands are rich in terrestrial and aquatic biodiversity being transitional zones (ecotones). These unique complex and dynamic ecosystems occur because of interactions between water, vegetation, and soils with both intrinsic and extrinsic attributes. Wetlands essentially provide ecosystem goods and services which support the supply of environmental goods (e.g. water, food, fibre, timber, biodiversity) and regulate different environmental resources (e.g. water, gases, minerals, soil, etc.) (Millennium Ecosystem Assessment 2005). Wetlands also enhance the aesthetic and cultural features of landscapes and offer a multitude of intangible supporting services (Langan et al. 2018).

Wetlands in the SSA can be grouped into either coastal (mangroves, estuaries, etc.), inland (lacustrine, riverine, etc.), or man-made (lakes, dams, etc.). Despite the innumerable benefits, wetlands in Africa cover a minimal 1–16% of the total area of the continent, the majority in the SSA (Davidson et al. 2018). The estimated coverage ranges from 220,000 km^2 to 1,250,000 km^2 of African land surface (Langan et al. 2018). Presently, a more accurate estimate is not possible and a robust scientific cataloguing and mapping policies need to be developed to overcome this hurdle (Davidson et al. 2018).

Table 15.4 Economic value of selected wetlands in sub-Saharan Africa (Modified: Schuijt 2002)

	Wetland area	Country/ region	Area (ha)	% of continent total	Total economic value (USD)	Economic value per ha (USD)
1	Zambezi basin wetlands	Southern Africa	2,982,000	0.098	201,253,793	67.5
2	Lake Chilwa wetland	Malawi	240,000	0.008	21,056,392	87.7
3	Hadejia-Jama're wetland	Nigeria	350,000	0.012	15,850,542	45.3
4	Nakivubo wetland	Uganda	529	0.00002	1,058,900	2001.7
	Total		3,572,529	0.11802	239,219,627	2202.2
	Average					550.55

Few attempts have been made to evaluate the economic importance of SSA wetlands depending on a real extant (Table 15.4). Schuijt (2002) estimated the economic value of 4 largest wetlands in the SSA with a total of USD 2,292,196, indicating the enormous potential of these wetlands to sustain livelihoods. The annual values range between USD 67 in the Zambezi basin wetlands in the Southern Africa region to USD 1890 in the Nakivubo wetland in the East African nation of Uganda. Furthermore, with the four wetlands covering only a dismal 0.12% of the continental surface area of 3.037 billion ha (Encyclopaedia Britannica 2020), and with an estimated total economic value of USD 239,219,627, it would be right to argue that at the optimal 16% estimated coverage, then up to USD 31.9 billion annual gain can be projected. This figure could be much higher in the last decade.

In consideration of the economic importance of wetlands to livelihoods including the supply of water, fuel from wetland forest timber, and other biomass, there is a need to conserve wetlands from natural (e.g. climate change) and anthropogenic threats, mainly deforestation, infrastructure developments, and mismanagement. Most of the human-related threats, which also influence natural climatic changes, are demographically and economically driven.

15.7 Research and Development Activities

The unsustainable and inefficient charcoal production methods used in SSA cause significant GHG emissions, thereby increasing the energy footprint. Research and innovation aimed at the greening of the charcoal value chain, to reduce GHG emissions by using improved earth kilns in SSA, is needed (van Dam 2017). Charcoal production, which is on the rise due to increasing demand from urban centres of SSA, causes forest degradation and deforestation, as well as the emission of GHGs which cause global warming (Malimbwi et al. 2010). As such, there is a need to invest and further the activities in research and development that can reduce energy footprint while focusing on access to improved charcoal stoves and alternative energy sources, according to the Africa Renewable Energy Access programme (AFREA 2011). Research efforts in SSA have included life cycle assessments where carbon footprinting is an important aspect; carbon footprinting is a method applied to assess various technologies in developing countries where there is rapid urbanization (Okoko et al. 2017). Countries of SSA do fit this description. In a study conducted in Kenya and Tanzania, to assess alternative value chains for biomass energy, one of the inferences was the application of more research effort to the production end of the charcoal value chain (ibid). This is a view already deduced by Vis and Vos (2010) that it is essential to make the production of charcoal more efficient and more environmentally sound than it is currently deemed.

15.8 Policy and Legal Framework Gaps and Challenges for the Charcoal Industry

To date, charcoal remains a key energy source and also contributes to rural livelihoods in the SSA. However, this fact hardly meets the attention of policymakers (Lambe et al. 2015; Peter and Sander 2009). Generally, charcoal production attracts little to no priority in national energy policies in the majority of SSA countries (Mwampamba et al. 2013). The industry, considered informal, lacks direct regulations compared to closely linked sectors such as forestry, energy, and agriculture (Cerutti et al. 2015). Moreover, any existing "policies and institutional arrangements" on charcoal production lack enforceability due to complex bureaucratic and resource bottlenecks (Chidumayo and Gumbo 2013). As a result, the charcoal industry remains informal and poorly regulated (Lambe et al. 2015; Sander et al. 2011; Peter and Sander 2009), thereby driving this critical sector underground (Lambe et al. 2015).

Consequently, little attention is given to considerations of sustainable harvesting or long-term forest management objectives (Peter and Sander 2009) that support charcoal production and trade. Further, since charcoal aspects are scattered across different sectors, provision for their coordination, implementation, and enforcement tends to be difficult (Sander et al. 2011; Mugo and Ong 2006). These barriers to synergy in policy, regulatory, enforcement, promotion, and other factors that sustain the charcoal value chain (Peter and Sander 2009) have been observed in several SSA countries including Tanzania (Peter and Sander 2009), Zambia (Mwitwa and Makano 2012), Malawi (Kambewa et al. 2007), and Kenya (Ndegwa et al. 2011). In turn, the barriers have resulted at the minimum in (1) oligopolistic nature of the charcoal industry whereby the bulk of the charcoal profits are concentrated within a narrow band along the charcoal value chain, hence undermining charcoal's contribution to improving rural livelihoods; (2) inability for governments to generate the much-needed tax revenues from potentially regulated exploitation; (3) corrupt transactions and exploitation by law enforcement authorities and regulatory bodies, e.g. extortion, kickbacks, and undocumented road charges; and (4) elevated cost of charcoal to consumers to compensate for the increased costs along the value chain. This eventually masks the real market value of charcoal (Cerutti et al. 2015; Kambewa et al. 2007; Sander et al. 2011; Peter and Sander 2009). Therefore, to effectively and significantly contribute to fostering rural livelihoods while upholding environmental integrity, the charcoal production sector needs to be formalized for sustainability as an energy source across the SSA (Peter and Sander 2009; Zulu 2010; Zulu and Richardson 2013). However, certain assumptions regarding charcoal production have been made and have disenfranchised the effective implementation of regulatory frameworks and enforcement of existing policies. Firstly, there is a generalized notion that the charcoal value chain is a venture for the very low-income, loosely organized individual or household dealers (Branch and Martiniello 2018). It is also generally assumed that charcoal production and trade greatly impact on sustainable forest management and biodiversity integrity. Furthermore, the charcoal value chain is marked by several intermediaries or brokers between the producer and the consumer, such that there is no interaction between the two ends (Shively et al. 2010).

According to Zulu and Richardson (2013), the charcoal production and trade industry is fundamentally disorganized, without effective policy and regulatory framework or capacity. The end result is innumerable loopholes along the charcoal value chain. For instance, in Malawi, Smith et al. (2015) reported that, due to non-existent policies, the charcoal industry is not officially recognized by the government. In Tanzania, nearly 80% of charcoal production is unregulated (Sander et al. 2013), while the value chain in Uganda is mosaiced by varying regulatory policies which culminate into a high degree of ineffectiveness (Shively et al. 2010). In Liberia, policies to regulate the production in the charcoal are lacking (Alfaro and Brieland 2018). Therefore, the debate around the institutionalization of policy and regulatory frameworks on the charcoal value chain for sustainable management is a critical component in this renewable energy pathway.

Most countries in the SSA are lagging in formulating and/or institutionalizing policies that provide for sustainable production and/or management of alternative energy sources (Mulenga et al. 2017). Policies are urgently needed to ensure secure and sustainable charcoal production, especially to safeguard against deforestation and degradation while providing for sustainable rural livelihoods. However, Doggart and Meshack (2017) identified many policy gaps relating to charcoal production and trade in SSA, namely (1) provision of adequate and affordable modern fuel alternatives to consumers; (2) intensification of measures to ensure sustainable charcoal production; and (3) ensuring effective governance mechanisms. Sound forest management policies form a solid foundation for sustainable charcoal production. Several SSA member states have outlined sustainable forest management strategies and institutional frameworks and further incorporated these components into the environmental and development roadmaps (Food and Agriculture Organization 2014). The key shortfall of most of the policies, however, is the delayed or lack of enactment of regulations regarding sustainable charcoal value chain, charcoal being a significant forestry resource (Minten et al. 2013). Charcoal generally accounts for a negligible proportion of the national energy policy documents; in most instances, it may even be completely omitted (Alfaro and Brieland 2018).

15.8.1 Past and Emerging Approaches for Forest Policy Design and Implementation

Banning charcoal production and trade to stimulate a gradual shift to cleaner fuel sources seemed to have been the most viable option in most SSA countries from time immemorial. This has, however, proved counterproductive since production has shifted towards the "black market" in most of these economies (Seboka 2009). Additionally, strategies such as high taxation in the form of charcoal licence fees, which was targeted at discouraging new entrants into the charcoal value chain, have failed to stop charcoal production and trade, and therefore increased the forest degradation rate (Kiruki et al. 2019). To date, the sustainable management of charcoal production still experiences numerous constraints because the sector is largely informal (Schure et al. 2013; Iiyama et al. 2015). Wood fuel is generally considered a minor component of the energy policies in most SSA countries; at times charcoal production policy is lacking therein (Alfaro and Brieland 2018). This has generally delayed the recognition of wood fuel products as significant energy sources, particularly in developing economies. The delay is a major pitfall of most existing energy policies in SSA sustainability master plans.

15.8.2 Institutionalization of Natural Resource Management and Local Participation

Sustainable management of natural resources is a key to enhancing the provision of ecosystem services. Natural resource management should incorporate the different but relevant institutions to formulate, harmonize, and implement policies and legislation which promote sustainable utilization of forest resources. The management of natural resources can be implemented via several approaches from local to regional/community-based adaptive management, integrated management, land management, or at the ecosystem level (Hutton et al. 2005). This implies involvement and synchronization of the different institutional policies and legal frameworks across the SSA with stakeholder engagement being incorporated in tackling community-based natural resource management (CBNRM) at the ecosystem level.

Institutional policies focused on sustainable resource management by integrating the socio-economic needs of the local people are more effective in the management of forest resources. This calls for adaptation to local situations to incentivize forest-dependent communities on sustainable forest management (Hashiguchi et al. 2016). Institutional resource management policies should target energy efficiency programmes as a tool for saving significant energy produced in the charcoal industry (Mogotsi et al. 2016).

15.9 Conclusion

Charcoal production, an important component in the support of rural livelihoods, is a crucial activity in the SSA woodlands. The charcoal business supports rural livelihoods through income generation and job creation. However, although rural communities derive income from charcoal production, they mostly receive marginal profits. Large charcoal profits are concentrated within a narrow band of mostly urban elite transporters and wholesalers, thereby hindering the sector's ability to improve rural livelihoods. This is as a result of the informal and poorly regulated nature of the charcoal sector. Policies on charcoal are scattered across various sectors including forestry, energy, and agriculture. Consequently, provision for their coordination, implementation, and enforcement tends to be difficult. Furthermore, given the informal and poorly regulated nature of the charcoal industry, little attention is given to considerations of sustainable harvesting or long-term forest management objectives. Therefore, unsustainable harvesting of wood resources threatens the African Savanna ecosystem given the high demand for charcoal across the ecoregion coupled with inefficient tradition production methods prevalent in the ecoregion.

Notwithstanding the challenges the industry faces, charcoal production remains important in supporting rural livelihoods. To enhance this contribution to improving rural livelihoods while sustaining the African savanna ecosystem, there is a need to formalize the charcoal industry. This requires a major shift in the policy perception and institutional management of the charcoal production sector. Developing and implementing policies that focus on all charcoal aspects is crucial in this respect. To foster the implementation of the charcoal policy to regulate all charcoal aspects, there is a need to enhance state capacity. This is vital given that the current implementation of policies on charcoal that are scattered across various sectors is problematic due to limited state capacity. Further, policy interventions should be informed by value chain analysis that encourages the equitable distribution of revenue which will eventually improve rural livelihoods. Policies must be integrated to create synergies between the charcoal value chain and the regulatory authorities to minimize conflicts and promote sustainability. There is also a need to seriously consider promoting the implementation of efficient production methods in the ecoregion. This requires improving the regulatory and fiscal frameworks of the charcoal sector to ensure that charcoal is produced legally through the payment of licences and levies to reflect the real market value of charcoal to consumers. Charcoal prices that reflect the actual market prices can foster the producers' ability to invest in energy efficiency savings such as improved energy conversion production and fuel-efficient consumption technologies.

15.10 Future Perspectives

To ensure sustainable energy consumption in SSA, there is a need for a differentiated approach. Policy options can also help to promote sustainable energy consumption, thus increasing the energy footprint in SSA (UN DESA 2004). The following are options to ensure sustainable provision and consumption of wood energy:

- Promote community-based natural resource management (CBNRM) and utilization of forest resources to ensure sustainability.
- Improving the collection and updating of data on the different conventional uses of biomass in the SSA forest resources production.
- A three-pronged approach to ensure the efficient utilization of biomass energy at the household, community, and national levels.
- Promotion and provision technologies that facilitate efficiency and affordability of biomass energy utilization in the SSA region. Technologies which encourage cheaper, eco-friendly alternative, or complementary fuel sources should be promoted for gradual uptake.
- Promote sustainable, regulated, and controlled tree harvesting for fuelwood or charcoal production.
- Fuel switching where possible.

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River Sand Mining and Its Ecological Footprint at Odor River, Nigeria

16

Angela Oyilieze Akanwa

Contents

Abstract

Globally, natural resources are under intense pressure especially in Africa where high consumption levels have brought changes that have driven the economies of rural communities towards reckless exploitation. The main drivers for increased ecological footprints of extractive industries have been identified as population

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growth, increased demand for construction works and city expansion. Sand removal is largely practiced all over world and it covers over 80% all natural resource exploration. It is estimated that the sand industry is worth over 4.0 billion dollars with a fast increasing rate of about 6% annually. In Nigeria, sands and aggregates are the most common and easily withdrawn natural resources even above the extraction rates of crude oil. It is cheap, readily available and easily extracted from using a simple shovel in remote areas in global South regions and its transition to the world's largest multinational mining companies in global North countries. The most desired sands are sand removed from river beds and coast due to their ability to bind with concrete for construction purposes. This has placed the natural environment especially river resources in danger since it underpins the economy and sustains life in most developing countries specially fishing, irrigating agricultural lands and other domestic uses. River mining has gained global attention due to high consumption levels that by far outweighs the levels of sand renewal as a time-constrained resource. Basically, it is considered as the least regulated mineral processing activity with high destructive tendencies. This present chapter examined the impact of river sand mining and its ecological footprint at odor river, Amaokpala, Anambra State, Nigeria. A mixed method approach was adopted in the case study that included qualitative (in-depth interview with 30 sand miners, transect walks, field observations and photography) and quantitative methods (160 questionnaires were randomly administered to residents). The concept of ecological footprint was used as a lens to further inform the effects of commercial river sand mining on the environment. Findings from the study showed that an estimated value of 156,400 m^3 of sands have been removed from Odor River for the past 40 years. Also, the ecological impacts of mining in Odor River include loss of river bank vegetation, increased turbidity, erosion, river shrinking and lowered riverbed. There is need to enhance biocapacity of our sands while ensuring ecological security in riverine and coastal environments. Hence, policy enforcement, education on human lifestyles towards resource consumption rates, youth engagement and community based participation research (CBPR) among others were recommended.

Keywords

Ecological footprint · Nigeria · Odor river mining · Sand mining · Sand security

Abbreviations

BBC	British Broadcasting Corporation
ECOWAS	Economic Community of West African States
EECCA	Eastern Europe, Caucasus, and Central Asia
GDP	Gross domestic product
MMSD	Ministry of Solid Minerals and Steel Development
NEMA	National Emergency Management Agency
NPC	National Population Commission

SMEDAN	Small and Medium Enterprises Development Agency of Nigeria
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Program
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Program
WBCSD	World Business Council for Sustainable Development
WWFCNNR	World Wide Fund for Conservation of Nature and natural resources
ZSL	Zoological Society of London

16.1 Introduction

Sand is an indispensible natural resource used in civil works, land reclamation, and industrial applications. It is one of the most abundant resources in the world, comprising of perhaps 20% of the earth's surface (Meena and Lal 2018). However, the rates of renewal are extremely slow even taking thousands of years of gradual disintegration of eroded materials. This makes it a fast diminishing commodity since annual global withdrawals are quantified to about 32 billion to 50 billion tonnes of sands (Koehnken and Rintoul 2018; Ashraf 2010).

The global sand industry is growing at very fast rates with accrued benefits to nations. In 2017, the foreign exchange rate of sand resources was been placed at over 5 billion dollar and presently it is rapidly galloping at the rate of about 6% annually (Chatham House 2018; NEMA 2006). In sub-Saharan African, sand mining has contributed significantly to the economic development by creating employment opportunities, a major source of resource for all construction and industrial activities, and more so generates export revenue and alleviates the high levels of poverty in developing countries.

Sand mining in Togo is second to agriculture and a source of revenue generation and rural employment. It satisfies the major requirements of households especially food, shelter and even entertainment (National Report Togo 2007). Similarly, in Nigeria, Kenya and Ghana, sand extraction generates income through the sale of sand products, diversification of skills and job opportunities (Mutisya 2006; Musa 2009). Studies have identified that sand mining has become an industry that provides employment for large number of people in global South (Padmalal et al. 2008; Akanwa and Ikegbunam 2019; Akanwa 2020; Stebbins 2006; Dagodzi 2010). Thomas (2003) confirmed that the economies of most African countries are dependent on sand resource extraction for example sand removal has contributed about 34% to the Gross Domestic Product (GDP) of Botswana.

Majority of the high-quality sands are buried in rivers, lakes, oceans and seas. Riverine and coastal sands have high quality because of its coarse nature and absence of salts that would otherwise corrode metal and other building materials. This makes it easily mix with cement during construction works. This explains why, Dubai which is located at the edge of a large desert area with enormous desert sands still imports sand from Australia (Beiser 2018).

In Nigeria, there are large vulnerable groups who live and depend on rivers for livelihood mostly farmers and fishermen/women. Rivers serve as an essential source of water use particularly in rural communities for domestic activities such as washing, bathing, cooking, drinking and irrigation of farmlands. It also provides habitation for aquatic plants and animals and drinking water for livestock. However, its ability to provide large quantities of sands for industrial purposes has escalated indiscriminate sand harvesting activities from rivers globally (Beiser 2018; Bendixen et al. 2019). For instance, it was noted that in 2009, sands removed from glaciers and rivers amounted to 24 billion tonnes per year (Peduzzi 2014). The combination of sands and cement-concrete contribute to 90% of asphalt pavements and 80% of concrete roads. The sporadic demand of sands is derived from the diversified construction of buildings offices, shopping mall, building windows, infrastructure and even industrial uses such as glass production, electronics and aeronautics.

The high demand of sands is driven by global population increase and urbanization in global South region especially China, India, Asia and Africa (Sverdrup et al. 2017; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). United Nations statistics showed that it is expected that Africa will harbour a large population of about 1.3 billion people that will constitute the global population in the next thirty years. Scientific proofs are inclined that the present and projected frequency of urbanization has impacted African cities particularly housing shortages. Clearly, the population in Nigeria is about 200.96 million people (World Bank 2018) and its continued increase will eventually place more pressure on sands extraction for housing supply and development of infrastructure as well. In addition, the Global Aggregates Information Network estimated that globally the overall quantity of sands and its associated resources required annually will increase tremendously to about 60 billion tonnes by 2030 (Global Aggregate Information 2019).

This demand has promoted reckless withdrawals of sands from rivers especially in global South region with little regard for sustainable mining practices that would protect river ecosystem (Naveen 2012). The Vietnamese Institute of Transport Science and Technology warned that the supply of sand in the country could be depleted by 2022 due to excessive exploitation rates (The Strait times 2017). This implies that the sand resources are at a great risk of exhaustion even at faster rates in certain countries since its renewal rates are time–constrained (Peduzzi 2014; Sverdrup et al. 2017; Meena et al. 2020a, b).

Notably, this is perceived as a foreseeable issue in Nigeria since sustainable mining conditions are absent especially in parts of the country where excessive extraction in rivers are carried out. Added to the fact, absence of national data on consumption rates to account for the ecological footprint in these rivers, this makes it totally impossible to know when planetary health has reached its limit in Nigeria and other developing countries (Akanwa 2020).

Mining along riverine and coastal areas threatens the ecology, infrastructure and livelihoods of 3 billion people living within these sensitive locations (Best 2019; UNEP 2019; Koehnken and Rintoul 2018; Akanwa and Ikegbunam 2017a). At least 24 Indonesian Islands disappeared off the map due to the enormous volumes of sand removed from these islands exported to develop Singapore (Beiser 2018). A study in Anambra State reported that river sand mining has vacuumed 33,235 m^3 of sands from Ulashi Riverbed and banks (Akanwa 2020).

Studies have confirmed that sand mining on land have destroyed arable lands, vegetation, economic trees and erosion, displaced humans and animals, species extinction, air and noise pollution, drought or disastrous flooding (Aromolaran 2012; Sen 2009; Akanwa and Ikegbunam 2017b; Akanwa 2019).

Additionally, impacts of in stream mining include insecure floodplains due to damaged waterways, pollution of water sources, damaged riverbeds and river bank, altering the flow and capacity of rivers, high turbidity levels that can affect habitats health and survival especially during extraction were particulate matter or oil pollutants from machines affect the water quality and light penetration thereby hindering biological processes (Bagchi 2010; Ruckelshaus 2009; Byrnes 2010). Other impacts of sand mining include conflicts, deaths, murder, politics, gangsterism and visually unpleasant landscapes (Saviour 2012).

Mining can also have long term environmental consequences on global warming; climate change risks and the overall environmental performance. This has created increased attention on the ecological footprint of sand mining sector. Notably, the concept of ecological footprint promotes key sustainable principles such as policy formulation, monitoring and enforcement of byelaws that complements the complex interaction between economic, demographic, social and political sectors and people's behavior towards consumption of sand resources. The concept of Ecological footprint when applied maximally can minimize the adverse effects of sand mining on river environments. It against this background, that this chapter investigated river sand mining and its ecological footprint at odor river, Nigeria.

16.2 Sand Extraction and Ecological Footprint in Global South.

Globally, 55% of the 7.62 billion people on earth live in cities and it is estimated that in 2050, two thirds of the population, which is (68%) or 2.5 billion people will live in the world largest cities mostly in Asia and Africa (UN 2019). However, more people in cities will place an exponential increase in demand for sand globally where current estimates of sand consumption is 50 billion tons (Koehnken and Rintoul 2018; United Nations 2018; Meena et al. 2018).

Asian countries like China and India have experienced tremendous increase in their cities. Where over 500 thousand Chinese are domicile in growing cities and this has tripled in the last 60 years equaling to the total populations of people residing in America, Canada and Mexico (Beiser 2017a). The demand rates for sands required for various development and engineering works in India since 2000 has increased three times and is still highly demanded (Beiser 2017a). Apart from construction works, sands are also demanded for industrial production of soaps, detergents, computer/solar panel (silicon), glass, women body parts (silicon), porcelain, food and wine production among others.

The mining sector has contributed immensely to economy of nations such Eastern Europe, Caucasus, and Central Asia (EECCA) region. This is through creation of job opportunities, income generation, foreign revenue and many more. For example, in 2000–2012 Chinese government and its economy experienced high growth rates and demands for all its natural minerals including metals (Sverdrup et al. 2017). Also, in Kazakhstan, there has been surplus creation of employment opportunities in the mining and quarrying sector for about 277,000 people contributing about 3% of total employment rates in the region (KAZ Stat 2019). Similarly, in the Kyrgyz Republic, the Kumtor Mine is the singular largest employer in the region and equally the highest singular provider of processed products and services (Price 2018).

World Bank (2014) indicated that the mining sector in Armenia is responsible for the high employment rates of about 10% covering the total industrial allocations for employment in the region. In India, illegal market for sand was worth about 23 billion dollars in Tamil Nadu, where 50,000 lorry loads of sand were mined daily (Finance and Economics 2017). However, in Nigeria, the mining industry has experienced a boom between 1940 to late 1960s and was globally recognized as a main producer of mineral resources especially tin, columbite and coal. But the discovery of oil as 1957 caused a decline in output in the sector. The Nigerian civil war of 1967 to1970 ushered many expatriate mining professionals out of the country and this crumbled the sector and it was left at the hand of artisanal miners, illegal miners, and medium scale operators mostly in remote areas.

Since majority of mining operations are carried out in local or lowly populated communities, historically the availability of data, monitoring on environmental performance have been low and attention is only drawn when there is the occurrence of a national catastrophes. However, this has changed in recent times since environmental concerns have gained global attention (Jenkins and Yakovleva 2006).

In developing countries like Nigeria open pit or surface mining is the most common mining approach and it causes vast ecological destruction within and outside the mined area and also the adjoining inhabitants are not left out (Akanwa et al. 2016). Open pit technique can causes damages on watersheds, agricultural lands and contributes to climate change (UNDP 2017; Odell et al. 2018). Further, it destroys ecosystem, biodiversity, and emission of greenhouse gases; water quality, toxic metals, and poisonous materials during and after mining operations have been completed especially if environmental interventions were neglected before and after mine closure. Generally, apart from damages caused by resource extraction on lands, water resources are also susceptible to water pollution, increased acidity levels of water which affects the biological processes exercised by the aquatic animals and plants thereby threatening the extinction of rare species (World Bank 2014; Virah-Sawmy et al. 2014; Rolfe 2001).

In Ukraine, during the process of natural resource extraction the industrial emissions was about 37% that accounted for about 20 million tons of generated wastes from mining sector in 2004 annually (UNECE 2007). Mining operations contribute heavily to climate risks through energy use on daily activities as greenhouse gases are emitted mostly during industrial processes, and through the deforestation of green areas which serve as carbon sinks (Nelson and Schuchard 2010; Gagan 2018; Khan et al. 2020a, b).

Moreover, mining companies in global North are minimizing carbon footprints through appropriate environmental friendly strategies especially in the lowered use of fuel especially through the use of green energy sources and electric driven automobiles to minimize the persistent issue of carbon emission (Odell et al. 2018). In developing countries due to the low technology and remote mining locations, dependence on river mining, minimal environmental monitoring over illegal operations and exposure to severe weather changes exposes extractive industry to greater ecological problems and climate change impacts.

Sand trade and exportation and transactions across the globe are mostly poorly documented and it is surrounded by illegal dealings, politics, deaths and fights. For instance, Cambodia has moved sands for 10 years and yet only about 4% of the 80 million tonnes of sands to Singapore was confirmed to be transported by Cambodia (Lamb et al. 2019). The clandestine nature of sand extraction has been reported to be responsible for the deaths of hundreds of people killed during the fight of sands across India, Kenya especially government officials, local community members and police officers (UNEP 2019).

However, sand extraction from rivers has huge impacts on ecology, infrastructure and livelihoods of host communities who depend on the rivers were sands are removed. In Nigeria, 33,235 m^3 of sands were vacuumed from Ulashi River which changed the river system, affected the fish diversity and lowered the riverbed and the water quality was polluted by heavy metals with risks on human health (Akanwa 2020). Sand mined from Pearl River (Zhujiang) in China has decreased tremendously to the point that it is unable to harness portable drinking water from the river and further damaged river system, bridges and embankments (Best 2019).

Similarly, the Vietnamese government has projected that half a million people will lose their homes located along the waterways of the Mekong delta due to large removal of sands on river channel and this has threatened the collapse of the river bank and human migration (Piesse 2018). In northern India, the Ganges River bank to be precise has been destroyed due to massive sand extraction activities that removed the natural habitat of fish-eating Gharial crocodiles (*Gavialis gangeticus*). Unfortunately, this particular species is threatened with only about 20 adults remaining within India and Nepal since the rest has been destroyed during sand extraction (Piesse 2018).

In addition, Poyang lake in Jiangxi Province is positioned to be the earth's largest commercial river where sediments extraction is active and it is projected that yearly about 236 million cubic metres of sand are recklessly cleared from the lake. The lake is a tributary of the Yangtze River system and partly because of the vast amount of water flowing out of the lake into river has almost doubled (Black 2018). This has raised the risk of riverbank erosion and waterlogging affecting agricultural lands. In Australia, sand mining has flood plains which harbour the earth's largest group of scarce carnivorous plants which are being threatened even to the point of extinction (Cross 2019).

In Cambodia mining has threatened mangrove forests, beds of sea grass and threatened species like Irrawaddy and spinner dolphins and the royal turtle (Cross 2019). Also, sediments mining have removed groups of swaths located in beaches within Jamaica and Russia. In Wisconsin and Minnesota, farmers have been affected by a present increase in sediment removal and the resultant atmospheric and water pollution on land while sand mining in Vietnam has destroyed hundreds of acres of forests thereby increasing global warming (Cross 2019).

Further, river mining is responsible for the collapse of bridges and numerous deaths. In Ghana, sand mining has created large trenches that have threatened the buildings built on the hillside placing the life of the inhabitants at great risk. In 2000, Taiwan also experienced the destruction of a bridge due to sand mining activities and in Portugal over 70 people was killed over the collapse of a bridge damaged by sand mining. In India, in 2016 another bridge collapsed killing 26 persons (Kondolf et al. 2002; BBC 2001; Times of India 2016).

It is important to note that river ecologists have indicated sustainable and environmentally friendly means of river mining. It informed that river mining should be carried out with measures on a determined quantity that would easily replenish without threats on the system and its inhabitants. This includes offshore–sand mining which is practiced in Britain where sands for land reclamation projects are sourced offshore to protect rivers and coastal ecosystems. Also, sands collected at the bottom of reservoirs are an untapped source of sand. Since, dredging reservoirs will provide sand while expanding its storage capacities as well (UN 2019).

Recycling sand products such as glass and rubble from demolished buildings can be used to produce concrete reducing the need, cost and environmental consequences of for fresh sands from rivers. Further, mining sands from floodplains is less destructive and can minimize the pressure of sand from rivers beds and river banks. Moreover, floodplains also have fragile ecosystems, in Australia, floodplains habour rare carnivorous plant species that are being threatened by mining activities (Kondolf et al. 2002). Finally, sands can be replaced in concrete with ash from incinerators and dust from stone quarries (Rafieizonooz et al. 2016; Balamurugan and Perumal 2013). This substitute can serve in the place of sands while producing concrete to reduce the harvest of sands from rivers.

16.3 Mineral Extraction and Poverty in Africa

Globally, African continent has a vast spread of natural resources that has brought about significant foreign exchange earnings and also attracted international investors. The continent has a deposit of about 30% of the world known reserves (Mining Review Africa 2019). These include cobalt, uranium, diamonds, and gold and large quantities of oil and gas reserves. The exploitation of natural resources in the region has hugely increased the global mineral and oil prices (Moyo 2018).

Within the periods of 2000 to 2008, Africa's extractive industry has contributed to over 30% to its GDP (Mining Review Africa 2019). In addition, there have been direct annual foreign exchange earnings and investments in Africa and these investments have risen from 9 billion dollars to 62 billion dollars. Unfortunately, its resource-rich reserve and tripled mining sector in the past decade has brought about minimal benefit. It is still classified as a high poverty stricken region where almost half of the populace lives below 1.25 dollar daily (Moyo 2018).

Africa's is surrounded by mineral wealth and yet the extraction of its natural resource has brought about extreme violence and abject poverty. This is a consequence of its contention with foreign investors over the proceedings from the exploitation of its resource-rich continent (Moyo 2018).

According to the report by (Mining Review Africa 2019) it estimated that the commercial worth of unapproved mining and clandestine activities surrounding the trade of precious metals and diamonds amounts to 7 billion in local currency. Also, there is an increased surge in illegal mining making it almost extremely difficult to verify the appropriate worth of GDP of mining industry to the economy and its contribution to miners as well (Mining Review Africa 2019).

This presents serious risks to the mining industry and affects the environmental performance coupled with consequences in various areas such as social, economic and health risks. According to Mining Review Africa (2019) the increase in illegal mining in Africa is driven by high unemployment rates, poverty and the migration of unapproved immigrants into the continent that end up in illegal mining dealings in the country. In 2017, 70% of arrested illegal miners in South Africa were documented to be foreign nationals.

In Zimbabwe, the mining of diamonds has brought about the huge loss of revenue amounting to billions of dollars. These losses were accrued through unapproved dealings and leakages carried out by foreign corporations have fed from Zimbabwe's diamonds. Many Zimbabweans still live in abject poverty in the midst of this precious money-making gem. Zambia has rich deposits of minerals such as copper which has contributed over 75% to the nation's foreign income totaled to about 61 billion dollars in 2017 (Monks 2018).

In Africa, the country that is positioned as the second biggest producer of copper is Zambia and it has a population of 18 million people. Unfortunately, major earnings from the billion dollars copper mining industry have been unaccounted for and diverted into foreign accounts. This left the nation poor and highly undeveloped where about 60% of Zambians still lives in poverty and 42% in extreme poverty and highly undernourished (Word Bank 2018). This is as a result of the transfer of the nation's wealth by multinational mining companies in the guise of mining (Lebert 2015). These foreign corporations are involved in illegal dealings over tax payments and expenses where they maximize profits earned from mining copper artificially. This enables these foreign corporations to minimize tax payments illegally and transfer the revenue abroad (Lebert 2015).

Similarly, the illegal dealings seen in Zambia are equally experienced in Angola which happens to the second largest producer of oil in Africa with a population of 29.3 million people. Its economy is driven by the oil sector and has earned 54% of its GDP and about 89% from exports of oil (Organization of Petroleum Exporting Countries 2019). But an audit in 2011 revealed that 32 billion dollars disappeared from official accounts between 2007 and 2010, which happens to be a quarter of the

State's income (IMF Country Report 2011) and yet Angolan elites refused to be accountable for this discrepancy (Monks 2018).

Also, Mozambique has experienced economic growth over the past 20 years in extractive industries of export of coal resource. However, the massive growth has not reflected in increased levels of national development and wealth. Unfortunately, there has been looming poverty in the nation of a population of 31 million people and more than half of them live in poverty (World Bank 2018). Further, the Republic of Congo has large deposits of minerals such as diamonds, gold and tantalum and it has a population of about 87 million people (Garside 2019). Majority of these minerals are deposited in the Katanga province where owned assets are worth over 5 billion dollars from the state mining sector. These large sums of revenue was transferred to foreign companies controlling mining activities without compensation or benefits given to the nation's state treasury for 3 years during Kabila regime (UN 2002).

Also, a similar experience was seem in Mozambique where the three largest steel companies in Europe were extracting coal from mines in Mozambique for a long time. The people living within the mines had to be resettled to other areas due to rising impacts. However, the new settlement lacked basic facilities such as housing, water and food coupled, worse still they were given insufficient compensation with rising threats on their health and livelihoods.

In Zambia and Mozambique mineral extraction has been ongoing for almost a century. Thousands of people have faced risks their health and livelihoods all in a bid to boost their mining industries. Apart from the economic consequences, air and water pollution were direct effects of mining actions on environmental and health consequences. It is unfortunate, that African governments have given mining licenses to foreign corporation that have rarely re-invested into the vulnerable communities they have extracted their resources over the years.

Nigeria has been faced with historical issues of corruption since the extraction of crude oil, mining of gold, aggregates and other mineral resources in Zamfara and Osun States and in other parts of the country (Vanguard 2019; Sumaina 2020). These illegal dealings especially by foreign corporations have frustrated the attempts of developing the mining sector in Nigeria (Emmanuel 2020). In recent times, the extraction of hydrocarbons has been the core source of revenue from Nigeria's extractive sector, which has provided the potential to substantially contribute to the development of the nation's economy.

Unfortunately, it continues to suffer huge revenue losses due to decades of failure to strengthen institutional shortfalls of the sector. It is projected that Nigeria has lost about 1.54 billion dollars annually from illegal gold exploitation added to other revenues and royalties that could have been remitted from the unaccountable mining and smuggling of other minerals and metals aided by corrupt Nigerians and foreign investors (Sumaina 2020).

The government of Nigeria has made attempts to prosecute all suspects (Nigerians and foreign) of illegal mining in the country. This will be starting point to block all avenues of revenues losses to foreigners. The present regime in Nigeria has also made its intentions clear on diversifying the economy from the singular dependency on oil extraction to agriculture and other areas. Since, African countries are becoming poorer in spite of the extraction of minerals, oil and gas resources by foreign companies (World Bank 2018).

The attention of foreign investors and extensive mining projects in Zambia, Congo, Mozambique, Zimbabwe and Nigeria and other African countries have had little impact on the poverty status of these nations. Hence, the African development approach on foreign direct investment have become counterproductive, mostly leaving damages on the continent's ecological health. The pressing problems of low development of African countries supposedly rich in energy and minerals have been attributed to the concept of resource curse also known as the paradox of plenty (Ross 1999). This concept further explained the unfortunate circumstances where countries privileged with abundant natural and mineral resources under poor management still remain undeveloped economically, socially while being besieged with health and environmental risks even much more than countries with fewer natural resources (Venables 2016; Sachs and Warner 1995; Torvik 2009).

Resource rich African countries are encumbered by peculiar development challenges to transform their exhaustible resources into assets that can contribute to generate income and employment and more so sustained development (World Bank 2018). However, the experience is quite different for Botswana and South Africa who have diversified their economy. This was achieved by developing skilled industries from natural resources rather than just exporting raw materials such as diamonds polishing or manufacturing goods.

However, there should be concerted efforts to reform the Nigerian's Mineral and Mining Act and other extant regulations to conform to the ECOWAS mining directive in order to develop the sector. This is expedient since fossil fuel-carbon-based wealth has all the indices to guarantee fast economic growth in African continent but, it is highly vulnerable due to price uncertainty, advances in technology and targeted policies directed at global decarbonization to minimize climate change (Akanwa and Joe-Ikechebelu 2020).

With the recent 5 year projection of exponential growth for Nigeria's mining sector from the current 0.33% contribution to Nigeria's GDP to 3% by 2025 (Venture 2020). It is important for Nigeria and other African countries to note the need for transparency in their transactions with foreign corporation. This should include the creation of protective economic polices coupled with stringent tax schemes that would expose and fight corrupt officials and practices while promoting the beneficiation of such minerals in order to enhance their value and fiscal maximization of the sector.

Ultimately, African continent needs to diversify its economy to further enhance the potentials of mining sector and its growth and development. It is estimated that Nigeria could earn over 12 billion dollars from gemstones annually if it invests in a laboratory to certify the value of the precious stone (Venture 2020). This will address the problem of quality-finished products and also curb smuggling of gemstones to foreign refineries. This way nepotism, neo-colonialism and corruption will be taken care of.

16.4 The Concept of Ecological Footprint

The concept of ecological footprint is referred to as an approach employed by the global footprint Network to determine population pressure on natural resources and the estimated quantity of nature required to satisfy the population or an economy (Ecological Footprint 2017). It reveals human unending demands on earth and equally estimates the renewable resources consumed and the regenerative bio-capacity of the planet. It also determines the extent of human impact on the environment using an accounting system.

The aim of the concept of ecological footprint accounting is on renewable resources. It measures the total quantity of natural resources produced and the produced resource according to this model is named biocapacity. The concept of ecological footprint is globally employed in the process of analyzing sustainability assessments. Globally, ecological footprints assessments reflect the vast pressure of human population on the earth in comparison with the earth's renewability potentials. The ecological footprint concept aids economic development through human assessment and resource management while it explores the sustainability of individual actions, corporations, industrial processes, flow of goods and services around neighborhoods, cities, regions and nations (Ecological Footprint 2017).

In 2013, the global average ecological footprint was 2.8 global hectares per person (Ecological Footprint 2017). While in 2014, Global Footprint Network estimated that the world population has used up natural capital which is 1.7 times the earth's renewability capacity. This confirmed that the world's ecological footprint corresponds to 1.7 planet earth (Ecological Footprint 2017). In 2007, the average biologically productive area per individual worldwide was approximately 1.8 global hectares (gha) per capita. The US footprint per capita was 9.0 gha, and that of Switzerland was 5.6 gha, while China's was 1.8 gha (Wayback Machine Living Planet Report 2008; Chambers et al. 2004).

According to WWF/ZSL (2012) the Africa living planet Index showed that the state of the earth's ecosystems has reduced to 39% in animal populations over 38 years (1970–2008). However, the ecological footprint of all African countries increased by 240% between 1961 and 2008 due to increased population growth added to rising per capita consumption in most minority countries (Global Footprint Network 2011). More so, in 2008, Africa's total footprint was 1.41 billion gha or 7.7% of humanity's total footprint. This corresponds to an average per capita footprint of 1.4 gha (Global Footprint Network 2011).

Notably, the 1.4 gha African footprint was far below the global average per capita footprint of 2.7 gha, however, it is still within the global available biocapacity of 1.8 gha per person while it is fast rising to the biocapacity available within Africa's borders. Similarly, Nigeria has an EF of 1.8 gha which is same with the global biocapacity of 1.8 gha per person though there are detectable changes among individuals within the country (WWF 2012). The footprint of many African citizens reflects a level of consumption that is insufficient to meet their demands (Global Footprint 2010).

Globally, and in Africa, majority of the countries have exhausted their average withdrawal levels of natural capital from the earth beyond its ability to renew these resources that they have become biocapacity debtors. For example in Africa, about 37 countries have a farmland deficit where their consumption of crop-based biocapacity exceeds their domestic production. Furthermore, 24 have reflected forest land deficit, 17 grazing land deficit and 15 countries showed fishing ground deficit (Global Footprint Network 2011).

It is pertinent to note that there are scientific estimations where Africa population will rise to 1.23 billion people in 2050. This is almost three times its 2020 population of 413 million people equivalent to 61.6% of Africa's total population (UN DESA 2011). By 2050, African cities will face rapid expansions that will exceed the population of people living in large cities such as Europe, Latin America or North America. Unfortunately, the rising shortage in housing supplies in African countries have brought about low standard, unregulated and underserviced houses and buildings, making them the highest level of inequality in the world (UN Habitant and UNEP 2010). Similarly, Nigeria population estimates shouw exponential increase and projected to 398 million by 2050. This will make it the world's third largest country and this will place greater pressure on sand consumption especially for construction of houses and infrastructure. Where, Nigeria is facing a housing deficit at 22 million units and the bulk of that is in urban areas (Federal Mortgage Bank Nigeria 2018).

In Nigeria, river mining is a common lifestyle and the demand for sand has increased tremendously over the years. Sands withdrawn from rivers reduce their natural beauty and heighten the intensity and frequency of natural disasters. It is highly disruptive to the ecosystem as river habitats are destroyed without the extent of damaged being determined especially in remote villages in Nigeria. Where most farmers and fishermen and largely the youth population have turned away from their occupation to venture into both in land and in stream mining of sand (Akanwa 2020). Other African countries have also witnessed similar results for example Kenyan government issue an official document claiming that sand harvesting has brought about destruction to the rivers, farms and lands to the point where it is now a human catastrophe (Beiser 2017b).

Further, most of the sand excavations are carried out in rivers without accountability to governing bodies. Unfortunately, the unavailability of data on sand loss by government officials has led to research frustration and shortage of data that would have accounted for the levels of ecological footprints and the resultant sustainable solutions. However, it is expedient that more extensive studies that would account for the quantity of sands mined or the amount of sands required to renew the lost sands at river bottom be carried out.

This has become a state of emergency as huge amounts of sands are lost daily. According to UN (2019) report extraction rates of sands are exceeding natural replenishment rates as increasing volumes of aggregates extracted are often illegal especially from riverine and marine ecosystems results in river and coastal erosion and have become threats to freshwater and marine fisheries and biodiversity. River sand mining has consequential ecological footprints on rivers, floodplains and deltas by changing the slope of the riverbed, alteration to in stream habitats, erosion, loss of riverside vegetation, water pollution, loss of adjoining farmlands and river shrinking among others (WWF 2018a). Worse still, the health and well-being of the miners and residents that are dependent on mined rivers are ecologically impacted as well (Akanwa 2020).

Further, the concept of ecological footprint and its methodologies can be applied in river sand mining activities as a tool to inform policy by examining to what extent sands have been withdrawn and the consequences in Nigerian Rivers. Equally, EP can be used to educate people in order, to alter their personal behavior towards mining that would lead to overconsumption of sands thereby, having dire consequences on river systems. Arguably, EP envisages that many current practices of natural resource extraction are unsustainable, hence, showing clarity on inequalities of resource use.

16.5 Nigerian Mining Sector

Nigeria operates a vibrant solid mineral industry and in recent times, it has received attention both at the national and international levels. It has a promising wealth yet to be harnessed with over 40 minerals including varieties of sands, tantalite, zinc, silver, bitumen, laterite, granite and gold among others (MMSD 2012). However, most of these minerals resource are sparsely located and distributed (Ministry of Solid Minerals and Steel Development. The Nigerian government provided a reliable strategy for the Nigerian Minerals and Mining Act in 2007 with focus on boosting the Nigerian mining activities and the mining industry as a whole.

The ministry responsible for mining activities in Nigeria is the Ministry of Mines and Steel Development (MMSD). However, a new law has been passed through the National Assembly to regulate the frequency of issuing mining licenses, mineral titles and documentations at the MMSD. Previously, there were no stringent means of issuing mining licenses and title since any officers in care of MMSD state offices had the power to give to issue licenses without restrictions, hence, this provided the platform for bribery and corrupt practices to take place.

Presently, the mining procedure in Nigeria insists that all mining licenses and titles are processed, given and documented at only the Mining Cadastre headquarters located in Abuja, the Federal Capital Territory (FCT). The Act happens to be the major legal document that determines the operations regulating the Nigerian mining sector. The Act places all authority power and management that all mineral resources in Federal Government of Nigeria (FGN) are owned by government. Additional legal regulations of the National Minerals and Metals Policy and the Minerals and Mining Regulations also regulate the mining sector. The Mining Regulations contain specific provisions with respect to royalties, fees and compensation payable by holders of mining rights.

MMSD operates in its administrative capacity through the following four departments namely, Mining Cadastre Office, Mines Inspectorate Department, Environmental Compliance Department and Artisanal and Small-Scale Mining

Department. The artisanal and small scale mining department has an outlined process for sand mining business in Nigeria.

The first step as required from the perspective of the MMSD documentation is to carry out a sand search using a GPS to capture the coordinates of the location at the area of interest and the type of sand to be mined. The search is to determine the abundance of the type of desired sands and the coordinates are used for record and allocation purpose. This ensures that no other person can lay claims to it once the allocation is obtained and taken to the MMSD office.

A sign of ownership is indicated mostly using an electronic flag attached to the coordinates. For the next 25 years, the land area belongs to the proprietor and is renewed every 20 years. The mining license stipulated whether the intended resource was gravel, sharp sand or filing sand among others. The sand type ought not to be breached once an operator identified his choice sand, this was an offence and the offence was that the offenders will be enlightened and later freed. This is rather too easy for the offenders since how long the leniency would last was not indicated. Such lapses leave the control of resources at the hands of illegal miners (Jeremiah 2019). This aspect of the regulatory framework needs to be revised for enforcement to avoid avenues for environmental disaster.

The next step, after the area has been allocated to the proprietor is to specify the quantity of sands to be mined. This is to determine the stipulated amount (28.0 naira per ton) of loyalty to be paid to the federal government through MSMSD. After approving the quantity of sands extracted and sold, the operator makes another payment covering a new campaign of sand extraction on the same location. It is required for the operator to obtain other documents from another related regulatory body such as the National Inland Waterways Authority, NIWA targeted at completing and validating the process.

However, what measures are taken to monitor operators who mine from away from their offices. The MSMSD monitors mostly busy spots once in a while. Clearly, there are lapses in monitoring because most sites are in remote communities where operators can extract sands severally without being accountable and apprehended. This is where most illegal operations are carried out without keeping to regulations, though MSMSD team usually scouts hinterlands to track down illegal operators, but often times unauthorized miners have their way. Unfortunately, the inefficiency of Nigerian mining regulators has caused huge loses of revenue worth billions that should be accounted to the federal government. The NEITI report that covers a 3 years investigation between 2007 and 2010 revealed that over 70% of mining title holders and operators in Nigeria's solid mineral sector are inactive companies that have contributed to revenue losses (Premium Times 2020). Only few companies who are title holders and have been issued licenses pay their annual fees as demanded in the Nigerian Minerals and Mining Act, 2007, hence, revenue loses prevail.

It was also indicated that in the previous Nigerian mining Act, that artisanal and small scale miners who had possession of lands and later transferred it to their children were not required to participate in the rigorous demands of license approval. Presently, the revised law demands registration and license allocation no matter the previous engagement. The required amount for license fee for small scale mining is 5000 naira, but large corporations are required to provide their company documents and other information. Here, the regulatory should be strengthened so foreign prospective investors should be given an operational guideline prioritizing strict adherence to environmental and reclamation laws as practiced in countries such as Canada and Australia. Moreover, the law also included a directive made for small scale miners to receive loans to expand their mines through the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN).

It is noted that these local investors are uneducated in mining business, therefore, SMEDAN, should also cover the aspects of training since they lack capacity and expertise apart from money (Jeremiah 2019). Notably, preference is given to small scale mining in the Nigeria mining sector. This is essential to encourage local miners, but there is need to develop the capacity of artisanal miners to professional levels and large scale if diversification of the economy must be achieved.

The MSMSD in this new dispensation is required to inspect the levels of operator's adherence to environmental requirements especially for the water-logged mine pits not to flow into residential buildings were humans live or activities restricted to licensed locational boundaries. Once the team observed any breach of these laws, the mine is sealed off until remedied.

However, there are major challenges to the growth and establishment of the mining industry in Nigeria. The huge shortage in infrastructural supply in urban and rural communities particularly, poor electricity supply, and poor transportation network to mine sites hinders productivity and transportation of mined products. Also, the issue of social conflicts between local community and Mining Corporation creates security concerns for investors especially the Niger Delta region. It is important to note that unauthorized mining is a pressing problem in Nigeria cities where these illegal activities constitute economic and environmental sabotage.

According to WWF (2018b) in over 70 countries sand mining is operated illegally and large volumes of sands are extracted with the support of corrupt government officials. In recent times Nigeria has experienced increased illegal mining activities. These illegal miners were guised as Artisanal and small-scaled miners who connived with powerful monarchs in Nigeria. These illegal Miners were about nineteen (19) foreign nationals largely Chinese and a handful of Bukinabes and Senegalese where discovered mining sand illegally in Osun and Zamfara States. However, the illegal Miners have been handed to the federal government for prosecution. This is a sign that Nigerian States are safeguarding the mineral deposits within their jurisdiction (Sumaina 2020).

16.6 Sands and Sand Mining: Study from Odor River

Amaokpala is comprised of the distinguishable Ameki geologic formation (Otti and Ezenwaji 2019). The sands lie below typical Oko Mountains passing beneath the lignite group. Stream sections of the community have shown thin beds of uncompact sand which is responsible for the large deposits of sand resources which consist of clay, fine grained sand lignite and carbonaceous shaley clays (Otti and Ezenwaji 2019). The well drained and weakly consolidated sediments are carried by runoff during wet seasons and deposited at Odor River bank thereby attracting sand mining activities.

The Odor River has become the centre for sand mining by local miners in the community. The community according to 2006 Nigeria population census, had a population of 31,351 (NPC 2006). It was projected using the approved population growth rate of 3.2% to 44,393 people in Amaokpala town. The high industrialization, population growth and urbanization rates in Anambra State have fueled demands for sands from rivers within rural areas which have become targets to meet this explosive sand demand. It is notable that river mining in the study area happens to be a significant employer of labour though it is not at a national level considering that it is a rural area. However, it still makes significant impact on income generation and livelihoods.

In addition, it is vital to note that sand mining actions in Odor River are operated as a small and informal industry and this makes it difficult to monitor and control. Miners in the study area apply low technology coupled with the fact that it is a labour intensive and extraction activity. Notably, it pays little attention to policy enforcement and thus, impedes the promotion of good practices in mining.

Desirable sands are extracted from Odor River beds and banks due to its angular nature which makes it suitable for construction and industrial purposes (Akanwa 2020). Unfortunately, sands extracted from rivers and oceans make up less than 1% of the earth's lands deposits (Allen and Pavelsky 2018). Globally, scientific investigations have confirmed that sands are withdrawn from rivers more than three times the natural capacity of all water bodies including rivers and glaciers on earth can replenish them annually (Waters et al. 2016). This places sand use at huge risk and also the rivers where they are extracted from.

The miners use local tools like shovels and bare hands to dig and extract sands from rivers during the day and at night. With the growing demand for river sands, majority of the extracted sands are transported to neighbouring towns and villages where they are utilized mostly for construction and industrial uses. Also, these water bodies are major sources of water supply to the rural dwellers and are employed for domestic activities such as washing, agricultural and industrial activities. The rivers can become polluted during and after sand dredging placing the survival of aquatic inhabitants in danger.

It is unfortunate that sands can be removed 40 times faster than it can be replaced causing riverbeds to be lowered by about 6 feet (Pearce 2019). Regardless of this, authorities mostly in developing countries like Nigeria give local communities the license to mine sands; without adherence to policies and environmental impact assessments (EIA) and treaties to govern its extraction and good practice. In the process, of excessive sand removal, environmental footprints become unavoidable (Akanwa and Ikegbunam 2019).

These problems obviously have environmental and health consequences on Amaokpala and its inhabitants. Clearly, river mining changes the form of the stream/river floors and flood paths ways thereby altering the living conditions of aquatic life and pollution of water quality, river bank erosion and river shrinking. In addition, river mining can cause reduction in fish diversity and abundance of fish. It is important to note that river mining results in wicked problems that are predatory in nature such as climate change and deforestation due to enormous energy that is released.

According to World Business Council for Sustainable Development (WBCSD 2020) extracted sands are mixed used with cement and water to make concrete for construction purposes and hence, the production of cement at high temperatures releases tonnes of CO_2 annually. In fact, it is estimated that the cement industry accounts for 8% of the world's CO_2 while the manufacture of Portland cement alone accounts for 5% of the world's CO_2 (Winkless 2016).

This portrays the great need to protect wet areas and aquatic life support systems by monitoring river mining. Since, riverbank vegetation which serves as temperature control, recreation, flood control, micro-climate balance, natural resources conservation, wild life and most especially carbon sinks are threatened in the process of river sand extraction.

Notably, sands are mined across Africa and in Nigeria on large scales, but few data are collected and documented on these operations. Even global estimates of sand mining are hardly authentic since little attention is given to commercial extraction (Torres et al. 2017). Also, majority of mined rivers are remote and shrouded with mystery over data access and transparency with huge political and industrial interests. This calls for this urgent scientific study that would quantify the amount of extracted sands and document the ecological footprints on sand mining in Odor River in Amapokpala, Anambra State.

16.6.1 Study Area

Amaokpala is a town in Orumba North Local Government Area of Anambra State. It is bounded to the East by Ndiowu, to the North East by Omogho and Ndikelionwu, to the North West by Omogho, to the West by Nanka and to the South by Oko. It has a Latitude and Longitude of 6.10274 and 7.14437, respectively (Figs. 16.1 and 16.2).

Amaokpala is divided into three villages which are Amokwe, Ndikpa and Umudike and its environs are made up of plain lands and hills. To the South lies the alluvial plains and the North lays the Ajalli-Ufuma uplands with elevation ranging from 30 to 80 m (Iwena 2010). The area is part of the coasted east that consist of mainly tertiary rocks lying in south of the eastern coastal plain slope. At different locations of the community, there is an upper layer of 67 m of lignite facies including massive clays above 700 m beneath the lignite (Iwena 2010).

The study area has a tropical vegetation rich in economic crops and the forest is rich in high quality wood products. Various species of animals are abundant in the forest. As the study area lies in what is referred to as the high forest belt where the wet season is long, the harmattan short and the forest cover dense, the soil would be expected to be naturally fertile as well.

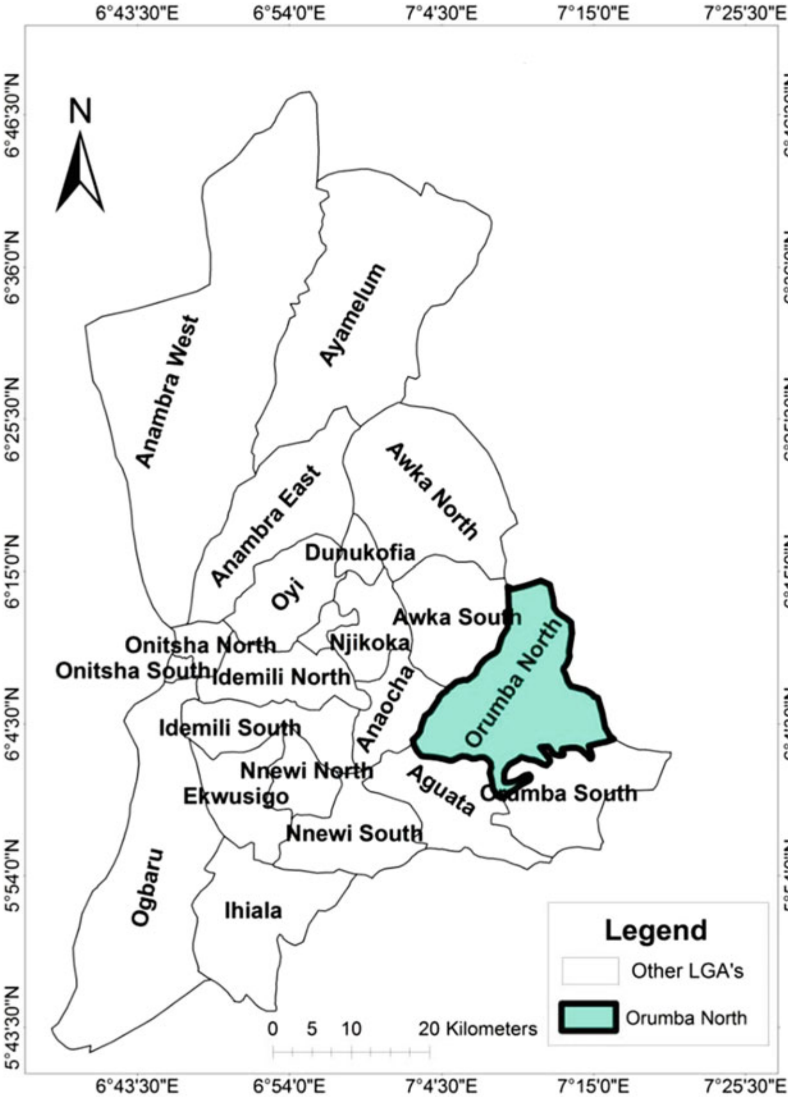

Fig. 16.1 Location of Orumba North local government area in the map of Anambra State

However, it has a tropical climate with an average daily temperature ranging from 22 to 35 °C during dry season and 18 to 29 °C in the wet season. Average yearly rainfall ranges from 2000 to 3000 mm. The relative humidity is 75% yearly and reaches 85% during wet season. It has two climatic seasons: the wet season which is experienced from the month of March–October and the dry season which is felt from November–February. The climatic condition of Amaokpala community is

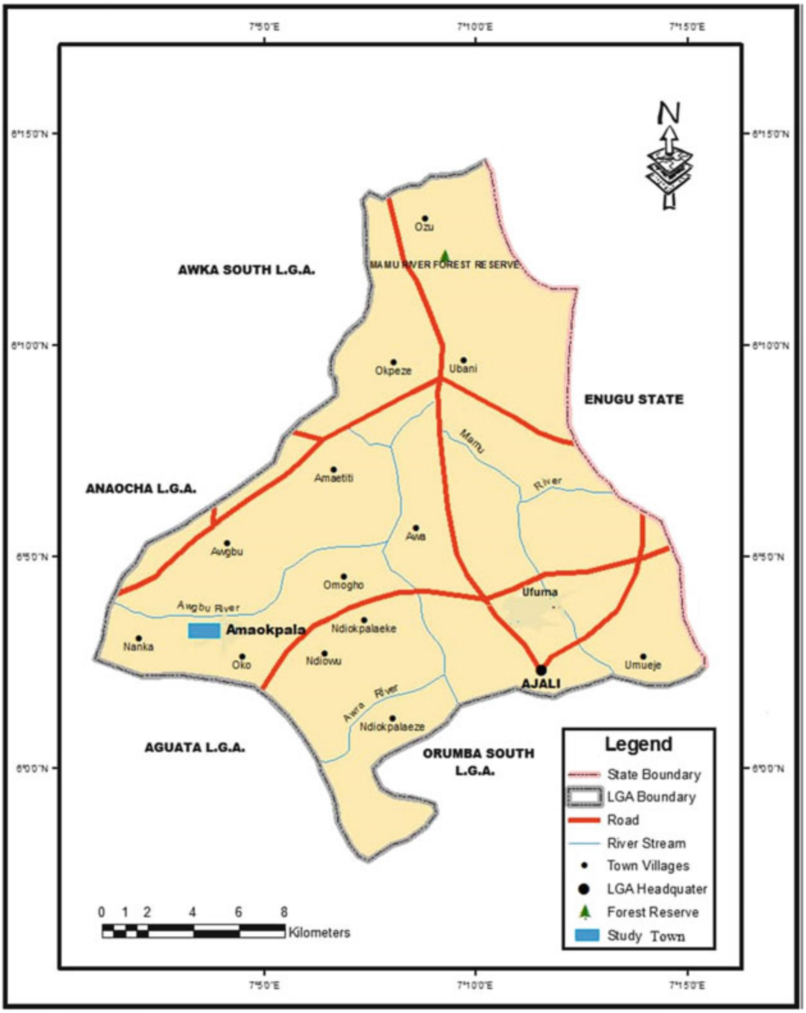

Fig. 16.2 Location of Amaokpala in Orumba North local government

influenced by two main air masses; wind system and the tropical maritime air mass. The inhabitants engage predominately in farmers and business people especially commercial sand miners.

16.6.2 Data Gathering

A mixed method, case study approach was used to investigate river sand mining and its ecological footprint at Odor River in Amaokpala, Orunmba North LGA of

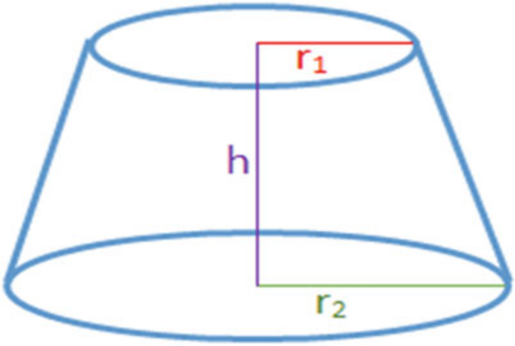

Fig. 16.3 Frustoconical model used to calculate the volume of material removed from Odor River. (Source: Adapted from Borges 1994; Veiga 2007)

Anambra State. Data utilized in this study was sourced from primary and secondary origins. The primary data included administration of questionnaires to residents living within the study area. In addition, measurements, Google Earth aerial photograph and geographical information systems (ArcGIS). Also, key informant interviews, observation, photography were also fundamental in acquiring information from the study area. The estimated volume of extracted sands from Odor River was determined by finding the volume (Fig. 16.3) of the total trips of sands removed using the measured dimensions of a typical truck used in transporting extracted sand from the river. Secondary data were sourced from books, relevant articles from journals and reports.

16.6.3 Sampling Technique

Probability and non-probability sampling methods were used in this study covering purposive, simple random and systematic sampling. However, purposive sampling technique was the dominant technique used in this study. This is because the questionnaires and interview data included different variables of the target population in terms of occupation, socio-economic data of the respondents and interviewees perception towards river sand mining and its ecological footprints. Amaokpala was selected as the study community based on its proximity to Odor River.

The aim of utilizing purposive sampling was to determine that the voices and views of the consulted key informants on river sand mining were appropriately represented. 20 key informants were interviewed and they include sand miners, truck drivers, sand loaders, contractor, bricklayers, and officials at the local government. Others within the locality were also contacted for relevant information. Moreover, there were field observations and photographs to capture the situation at the sand mining in Odor River.

Green (1991) sample size model "rules-of-thumb" was used to examine the model overall with minimum sample size of $50 + 8k$ (k = no. of determinants). The number of determinants for the study is 14, giving a sample size of

160 respondents. Simple random sampling technique was applied to sample 106 persons from the projected population of the area targeted at an annual growth rate of 3.2 and 44,393 persons. Systematic random sampling which gave an interval to every third household at a random starting point was applied in the selection of household respondents for the administration of structured questionnaires in the community.

The minimum model sample size was applied in this study alongside with other varied data sources in order, to avoid bias while arriving at similar solution from different perspectives (Pinnock et al. 2014). Other sources of data were meant to validate the results and reflect the peculiar findings in Odor River.

16.6.4 Data Analysis

There were field observations and photographs to capture the situation at the sand mining at Odor River. Chi-square (X^2) formula was applied in the study. Results were interpreted with descriptive statistics such as tables, charts, and percentages.

16.6.5 Results and Discussion

The socio-economic, environmental consequences of river mining data gathered from questionnaires in Amaokpala are presented. Also, in-depth interviews, observation, photographs and analysis were presented and discussed as well. The socio-economic variables that were measured by questionnaire include sex, age, income, occupational status, education, monthly income and monthly volume of sand transported by tippers.

Table 16.1 summarized the derived information of 160 respondents in Amaokpala community. The age structure of the respondents indicated that 8% of the sampled respondents were less than 20 years, 15% were between 20–30 years, 39% were between 31–40 years, and 26% were between 41–50 years and 13% were 50 years and above. This age structure shows that majority of the respondents were between 31–50 years and could contribute significantly to the present study. The sex of the respondents revealed that 82% of the respondents were men while women were 17%. This showed that men were mostly the family heads in the study area.

The educational levels of the respondent showed that 20% had their first school leaving certificate, 48% had WAEC certificate, 12% were NCE holders, 12% had obtained B.Sc. degree and 6% had their MSC. This indicated that majority of the respondents were literate and can collaborate in this scientific study. Also, 37% of the respondents were single, 53% married, 3% widowed and 4% divorced. This showed that majority of the respondents were married. The household sizes of the respondents showed that 50% had 1–4 members, 30% had 5–9 members and 20% had 10–14 members. This revealed that the largest household was between 1 and 4. The duration of sand mining activities showed that 25% of the miners have been in the business for less than 5 years. 15% have been active for 5–10 years, 18% for

Table 16.1 Analyzed data of sampled population in amaokpala community

Variables	Frequency (160)	Percentage (%)
Age		
Less than 20 years	12	08.00
20–30 years	15.00	15.00
31–40 years	62	39.00
41–50 years	42	26.00
50 years and above	20	13.00
Sex		
Male	132	82.50
Female	28	17.50
Education level		
FSLC	32	20.00
WAEC/WASC	77	48.10
NCE/OND	20	12.50
BSC/HND	20	12.50
MSC/MBA	11	06.87
Marital status		
Single	60	37.50
Married	86	53.75
Widowed	05	03.10
Divorced	07	04.30
Household size		
1–4	80	50.00
5–9	48	30.00
10–14	32	20.00
Duration of sand mining activities		
Less than 5	41	25.60
5–10	25	15.60
10–15	3	18.70
15 years and above	64	40.00
Income level (weekly)		
₦1000–10,000	25	15.60
₦10,000–₦15,000	42	26.30
₦15,000–₦20,000	51	31.90
₦20,000 and above	42	26.30
Occupation of respondents		
Farmer	38	18.80
Traders	32	20.00
Sand industry	30	18.70
Private/public sector	35	21.80
Student	25	15.60
No of trucks of sand removed (weekly)		
Below 50	18	11.20
50–80	28	17.50

(continued)

Table 16.1 (continued)

Variables	Frequency (160)	Percentage (%)
80–100	22	13.70
100–150	42	26.20
200 and above	50	31.20

10–15 years and 40% for 15 years and above. This indicated that the majority of the miners were those less than 5 years and those above 15 years in the river mining business. This showed how lucrative river mining is since it had a high level of new Miners and had sustained 40% of the respondents for more than 15 years, hence, they can provide vital information on river sand mining in Odor River.

The range of monthly income of the respondents indicated that 15% of the respondents earn between ₦1000–₦10,000, 26% earn between ₦10,000–₦15,000, 31% earn between ₦15,000 and ₦20,000, 26% earn between ₦20,000 and above weekly. This showed that over 26% of the respondents earn more than ₦20,000 weekly. It was also revealed that the respondents involved in river mining business were 18%, farmers were 20%, the private and public sector was 21% and unemployed students were 15%.

The analysis also revealed the monthly volume of sand mined from Odor River and loaded into trucks monthly. 11% of the respondents agreed that less than 50 trucks of sand mined monthly, 17% for 50–80 trucks monthly, 13% for 80–100 trucks monthly, 26% for 100–150 trucks monthly, and 31% for 200 trucks and above monthly.

16.7 Economic Opportunities of Sand Mining in Odor River

Findings from the study showed that majority of the respondents (82.5%) were males who were heads that represented their families. 17.5% of the females were available mainly because their husbands were not at home during the course of questionnaire administration. Also, majority of the respondents were within a workable age bracket of 31–40 years. In Africa more than 60% of the populations are youthful below the age of 25. Similarly, Nigeria has one of the largest populations of youth in the world comprised of 33, 652, 424 members (Nigeria Youth Policy 2009). This is significant because the youthful population would engage in executing sustainable initiatives that would alleviate river mining consequences in the area.

In addition, the majority of the respondents (48%) had secondary school education which made it possible for the investigator to gain access to information. Further, it was noted that majority of the respondents had attained other levels of higher education. This was traced to the location of Federal Polytechnic, Oko within the community. Also, majority of the respondents were married (53.75%) with the highest (50%) number of families between 1 and 4 members. It was also identified that most of the single people were students of the higher institution who had taken residency within the community.

Again, findings also showed that the respondents were basically farmers, private/ public sector and those involved in the small scale river mining business. During the course of in-depth interviews, it was discovered that farmers engaged in agricultural production of crops such as yam (*Dioscorea* sp), maize (*Zea mays*), cassava (*Manihot esculenta*), cocoyam (*Colocasia* sp), Banana/plantain (*Musa* sp). They were also involved in fishing and hunting. The private sector involved self-employed respondents who were involved in petty trading, artisans and craft making such as hairdressing, sewing, trade in household utensils and other forms of petty trade.

However, the public sector included government workers and civil servants. It is noted that most of them were non-teaching staff of Federal Polytechnic who happen to be indigenes of Amaokpala. However, according the to the community Chief of Amaokpala during interview session, he added that farming, trading, government workers were some of the major economic activities in the community combined with few cottage industries such as palm oil and kernel processing mills, poultries, water packaging plants and the products from these activities were sold at the Afor-Eke local market. However, he informed that due to construction boom within the locality many miners and labourers became interested in river mining business in Amaokpala community. He further informed that **-.**

> Sand river business became a greater economic attraction when the community began to expand as more people began to build houses, roads and other public needs in Amaopkala and its environs. This placed a lot of demand on Odor river sands coupled with the fact that the business gives quick money for everyone involved.

Also, during in-depth interviews, the sand loaders and sand miners (see Plate 16.1) added that sand mining provided opportunity for everyone interested in the business to participate. First of all, it was easy to join the union of sand miners by indicating interest whether as a stranger or an indigene. The new Miner is introduced to the leader and other members of the union. A stipulated amount is paid monthly to the group leader and the new Miner begins digging sands from the river and heaps it on the river bank waiting for the trucks to come for them. The rules of the group include punctuality, strength and agility and peace towards the leadership and other group members.

The interviewees further informed that river sand was readily available since the floods during the wet season flushes large quantities of sediments from the upper ends of the river and deposits it at the river bank for easy extraction (see Fig. 16.4). River mining has become a direct source of income, employment and livelihoods for sand miners, truck loaders and drivers. In addition, it also provides royalty and tax revenue to the local governing body. Indirectly, it has increased the production of related goods and services which is purchased locally.

It has aided in the development skills and economic diversification leading to the emergence and growth of related industries such as block industry, sale of cement,

Plate 16.1 Miners extracting huge volumes of sand from the riverbed using shovels and transferring the sands into the trucks. It also showed the knee/ankle-depth level of the river, indicating river alteration, width reduction, and change in river channel network

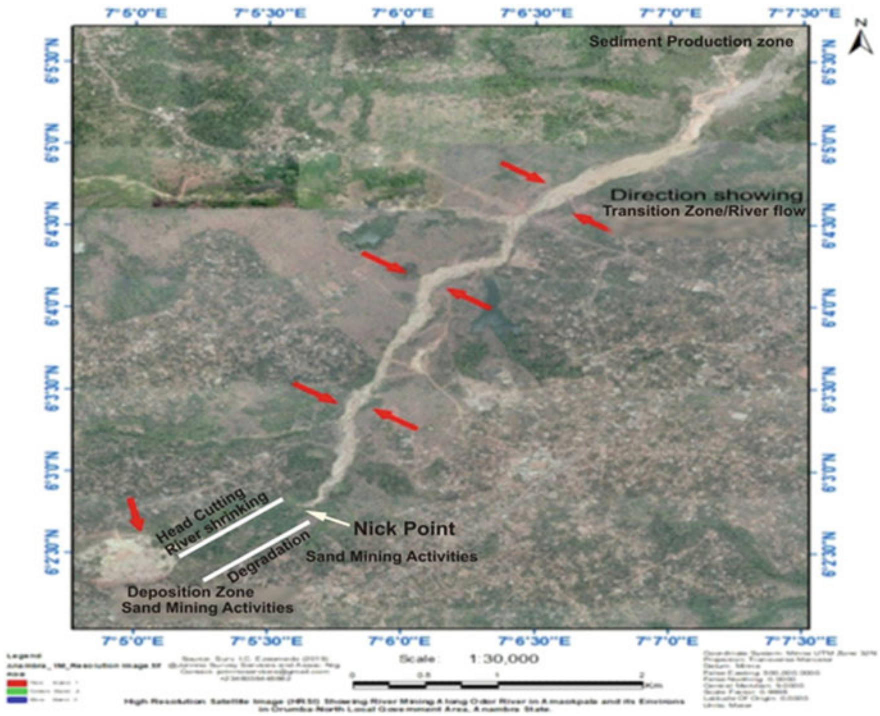

Fig. 16.4 Satellite image showing Odor river in Amaokpala, Orumba North local government

sale of building materials ranging from wood, paint, nails, roofing sheets among others. This has increased the building of houses, road networks and infrastructure. River mining has also supported linkages between sand agents and clients. Sand agents locate interested clients and get paid from the sales of truckloads of sands. These direct and indirect benefits have brought exponential increase in sand demand. One of the sand Miner further added that-.

> The Odor River is the major source of quality sand for construction works within Orumba North, Orumba South and its enviorns. Majority of the people involved in the business were young unemployed and semi-employed men and students who need quick money to survive and pay their bills.

Initially, the activities of river mining were overseen by the local authorities and this generated internal revenue and royalties to LGA at Orumba. However, a couple of years ago, there was conflict between the LGA and the community. The leader of the sand union informed that the conflict was because the LGA increased demand of income from the mining business. However, a staff at the LGA gave a different reason for the conflict. He said that there were illegal mining activities that the community members could not account for and when they questioned these clandestine actions, it caused conflict between the community and government officials.

After, the conflict, the community has completely taken over the affair of mining at Odor River and stopped paying revenues to LGA and since then the activities of sand mining at the river has remained largely illegal. According to Beiser (2017a) sand mining and its transactions globally have resulted in conflicts of interests and control, illegal dealings, politics, deaths and fights.

The occupation status of the respondents in the study area showed that sand mining (18.7%) is a major source of livelihood in the community (Table 16.1). However, river mining is competing with farming (18.7%) while trading and private/public sectors are slightly higher than sand industry (20% and 21.8%) respectively. In addition, majority of the farmers, traders and others income earners are indirectly linked to sand industry and hence gain additional income from river mining business. The weekly income levels showed that 15% of the respondents earn between ₦1000 and ₦10,000 (US$25.65). 26% earn between ₦10,000 and ₦15,000 (US $38.48), 31% earn between ₦15,000 and ₦20,000 (US$51.30), 26% earn more than ₦20,000 (US$61.56) and above weekly. This showed that over 26% of the respondents earn more than US$61.56 weekly.

Again, the vibrant economic status of river mining is perceived from the duration of the industry where majority of the Miners have been involved within 5 years (25.8%) and above 15 years (40%). This buttresses the fact, that river mining is a thriving economic activity that contributes to community growth and livelihood. It is recognized that its highest peaks was in the first 5 years of influx of miners and above 15 years where it has also sustained the income and livelihood of a large proportion of miners in the community.

From the foregoing, the analyzed results drawn from the survey and interview of key informant confirmed that commercial sand extraction from rivers is a major employer of labour in the study area. Hence, it has contributed to rural development as well as a fundamental key to poverty alleviation, crime reduction, skill diversification, development of related industries and business for youth engagement in Amaokpala. Considering that, an estimated 1.8 million Nigerian youths complete their education yearly, but only a few are gainfully employed due to poor employment opportunities (Falusi 2014). High youth unemployment leads to high poverty levels and social inequalities. Small scale industries such as river mining business have become an attractive and vibrant economic supplement for the unemployed youths and semi employed Nigerians to survive the hardship in the country.

16.8 Quantifying the Volume of Sand Extracted from Odor River and Its Effects

The Odor River (Fig. 16.4) is about 16 km in length and it provides vital ecological and social services to both the Amaokpala community and the surrounding Oko town. People living in the villages surrounding the river rely on farming and sand trade for sustenance and livelihood, while the river serves as a major water supply for domestic activities and agricultural activities in the community. The villages have stopped drinking the water due to large commercial activities of sand excavation along the river channel (Otti and Ezenwaji 2019).

In addition to the above mentioned vital services, Odor River further fulfills various environmental roles to the ecosystems. This involves the regulation of the hydrological cycle and the dramatic seasonal changes the river experiences to produce a wide range of different habitats (Otti and Ezenwaji 2019).

Also, its favourable location within the rainforest supports rich biodiversity characterized by abundance of plant species, variety of terrestrial animals and aquatic life. Its rich alluvial soils are transported from upstream and deposited at the river bank during heavy floods. The sands suitability for construction works has expedited sand extraction and trade.

Unfortunately, sand mining at Odor River is carried out in the crudest means lacking an environmental friendly approach. The community miners practice in-stream or wet mining by the direct use of shovels to dig sands from the riverbed/bank (see Plates 16.1 and 16.2). This has had dramatic impacts on the vital river system and environment.

According to one of the key informant, the community Chief informed that sand mining has been carried out at Odor River for over 40 years. It was noted that over 200 trucks of sands were extracted and transported from Odor River weekly (see Table 16.1). This showed that large volumes of sand resources are mined from the river to meet up with the community's teeming demands. The estimated volume of extracted sands from Odor River was determined by finding the volume (Fig. 16.3) of the total trips of sands removed using the measured dimensions of a typical truck (Fig. 16.5) used in transporting extracted sand from the river. Two hundred (200) truckloads of sand were extracted weekly (Table 16.1).

Plate 16.2 Showed miners digging sands from Odor River and others in the truck spreading the sands without the use of PPE. Also, an aerial view of the river showed many trucks coming and leaving the mine site and the shrinking channel of the river with the absence of vegetation along the river

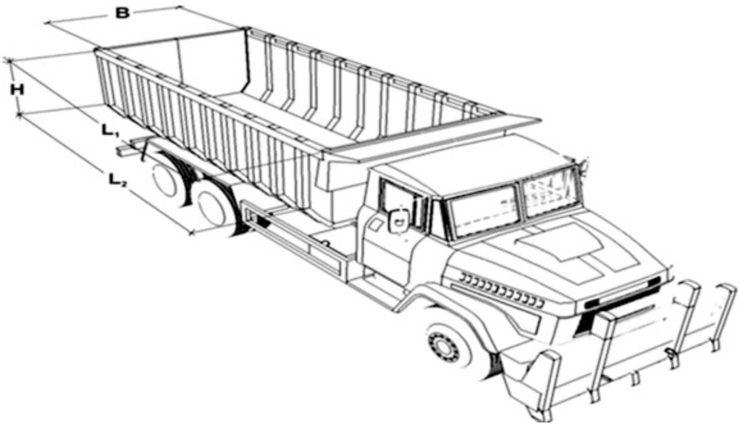

Fig. 16.5 Dimensions of a truck loader

The dimensions of a sand loader used to quantify the volumes of sand extracted. The volume of one trip of sand was calculated using the formula (Borges 1994; Veiga 2007).

$$\text{Volume of Dumper} = L \times B \times H.$$

where l_1, $l_2 = 6$ m and 5.5 m, $B = 1.7$ m and $H = 2$ m.
$L = l_1 + l_2/2 = 6 + 5.5/2 = 11.5 \times 1.7 \times 2/2 = 19.55\ \text{m}^3$ (for One Trip of Sand).
For 200 trips of sand for 40 years is $200 \times 19.55 \times 40 = 156{,}400\ \text{m}^3$.

It was estimated from the study that 156,400 m^3 of sands have been removed from Odor River for the past 40 years.

This result showed that over the years, a quantifiableamount of sand has been extracted from the Odor River. However, the quantity of sand excavated using other meduims of transport such as buckets, headpans and wheelbarrows were not included in this estimation. This implies that the total quantity of sands removed from Odor River is far beyond 156,400 m^3. Further, the consequences of the large volume of excavated sand as noted during the in-depth interview by one of the miners who have been involved in commercial sand mining along Odor River. He reported that there have been drastic changes-.

> He said intially the Odor River used to be wide and high flowing withburstling energy and a heavy force that reaches up to the shoulders and waistline of users that children were discouraged from swimming because of the fear of drowning. However, over the years they have observed that the river height have reduced drastically to knee-level depthand even lower during the dry seasons and its width has narrowed as well due to indiscriminate sand mining activities.

During the dry seasons, Odor River has reduced dramatically in width and in depth compared to its initial shape. This has affected its natural flow with a recognizable increased decline in the surface area and these changes have been hugely impacted by consistent river mining activities over the years. Sand mining at the deposition zone (see Fig. 16.4) have been atrributed to with lowering the riverbed. Theminers were individually interviewed and their reports corresponded that in-stream mining of sands is carried out across the river during wet and dry seasons and by removing large volumes of sands over the years, the river system have been greatly altered. The Chief miner who happened to be the leader of the union for miners reported that -.

> There have been noticeable and drastic changes that have taken place in Odor River where the removal of sharp sands from the river for commercial purposes have shown visible signs of riverbed lowering and shrinking. Also, riverbank erosion have been intensified altering river flow.

By removing large quantity of sands, the miners have partially drained the river making it vulnerable to drought occurrence during dry seasons (see Plate 16.2). The interviewee maintained that sand removal have continued along the river despite its impact on the river system due to the high quality of the sand specially for construction and its suitability for cement production. Bejar et al. (2017) explained that riverine sands are usually forced to undergo extented periods of transportation in water and hence, the process of constant movement sorts outs undesirable sediments sizes through the processes of abrasion and attrition, leaving durable, well refined and preffered sand sizes highly desired for construction purposes.

Clearly, the reports from the indepth interview with key informants who have mined the river over the years can be confirmed from the satelite image (Fig. 16.4). The image captured the Odor Riverwatershed and the river profileshowing the lenghty movement as the river flows from sediment productionzone (upstream) as seen in the energy of the river with its expanded width as it transported along its channel network carrying a largevolume of sediments and associated habitats as it flows and deposited downstream.

However, it is observed that the river experiences three major meanders (as indicated by the red arrows) and inbetween the last meander and the sand depsoition point, it is noticed that the river experiences a "Nick point" showing initial disturbance where sand extraction has taken place previously as confirmed by transiet walks during ground data surveys. This propagated the "nick point"where intensive sand removal has taken place. This affected the river flow by headcutting, thus changing its morphology with immense degradation and shrinking along the river channel. Also, increased erosion downstream has deposited large volumes of sediments at the deposition zone during intense floods as a result of the risen bed slope it escalates commercial sand mining (see Plates 16.1 and 16.2).

It is important to note changes to the channel of Odor River morphology whereby alterations regarding the movement of sands, changes in river features, channel incision, flow regime, erosion and river shrinking. The river shrinking is further escalated by the high temperatures based on the location of Nigeria and its proxmity to the equator in the tropical zone. The high temperatures hastens the river shrinking especially at the deposition zone. The miners confirmed that there has been drastic reduction in sediment load excavated from the river presently compared to the quantity they mined in previous years. The findings along Odor River showed nick point, altered sediment transport, composition of riverbeds and reduced sediment loads and this was confirmed by various previous studies (Gonzalez et al. 2016; Mingist and Gebermedhin 2016; Podimata and Yannopoulos 2016).

According to Kondolf et al. (2002) reduction in the supply of sands through river mining affects the river channel. This is because the total sediment load and its arrangement in rivers makes up the complex natural structure of sand-gravel-bed channels and thus, performs a huge enviornmental and sustainable role.

It provides a conducive place for small aquatic animals at their young stages of breeding who are burrowed into the bottom sands and sediments of the river as their habitat (Kondolf 1994). The river channel, floodplain and the fluvial flow system create a distinct environment for aquatic and riparian habitats, however, indiscriminate sand removal, added to the number of years and climate factors coupled with the poor scientific technology practiced in Odor River hugely alters the river channel and disrupts its natural fluvial process of rejuvenation.

Further, the turbidity levels of the Odor river have been altered as a result of sand mining as seen in (Plates 16.1 and 16.2). This has altered the water quality leading to high river siltation levels, temperature changes, increased pollutants and notably the fisheries and other aquatic organisms domiciled in the river are threatened. The increased turbidity levels hinder the penetration of direct sunlight thereby inhibiting the process of photosynthesis. Otti and Ezenwaji (2019) confirmed in their study that the water quality of Odor River has been badly destroyed by commercial sand mining activity and this has made it impossible for the community to harness the water for drinking. Also, the high siltation levels are a disadvantage to

Plate 16.3 Showed the condition of adjoining farmlands that have been abandoned due to high levels of flooding during the wet seasons. This has affected agricultural production along the Odor River and led to land fragmentation

micro-organism and aquatic habitat domiciled in the river. Bejar et al. (2017) reported in their study that recovered sands extracted from rivers are similar to those sands common during high intensity floods which has varying effects on different groups of aquatic plants and animal life living at the riverbeds.

A key informant to this study also reported that over the years they have noticed that river mining has affected the fish populations along the river where intense mining is occurring.

> Mining has affected the fish populations in Odor River negatively so that one can hardly fish from the river anymore. More so, most of the fishermen have moved to other occupation due to drastic reduction of fishes along the river.

In addition, a similar study showed that sand mining causes water quality changes and high turbidity levels decrease fish population and affects fishing business in Ulashi River and Eze River in Anambra State (Akanwa 2019, 2020). Mingist and Gebermedhin (2016) also confirmed that river mining negatively affects the number of fishes. This destroys their breeding places, movement away from unfavourable climatic conditions hence, huge population of fishes and their varying species are lost. Apparently, sand mining in rivers can cause severe declines in local fish population thereby affecting livelihoods. In addition, the lowering of the riverbed and shrinking of the water body have affected the area and volume of the water affecting fish habitat and fishing business and it has limited the water available for agricultural irrigation both around the river and downstream.

Again, it was noted that sand mining has also increased flood frequency and intensity during the wet seasons and this has reduced the flood regulation capacity of Odor River. Consequently, the floods overflow to adjoining farm lands creating erosion networks (see Plate 16.3). Since water flows out through its sloppy ground surface causing the wearing away of the riverbank and hence, contionous outflow of water from the river during rainfall becomes inevitable.

Besides, these ecological footprints at Odor River, health risks were also noted as none of the sand miners used PPE in the course of their daily mining activities (see Plates 16.1 and 16.2). This action could have health impacts since these rivers can accommodate toxic chemicals from degraded sand particles and particulate matter from air pollution of sand trucks that constantly transport sands. Constant exposure to such fumes from exhaust pipe of trucks and loaders can be sources of health risks and in most cases the source of health events are not traced to river mining.

It is unfortunate that majority of the rivers in Anambra State are being subjected to commercial sand mining with glaring ecological footprints that have not received state or national attention (Akanwa 2019, 2020). The sand miners in Odor River were able to recognize and attest to these major drastic changes occurring in the river system, but obviously, the scientific knowledge of their actions is yet to be fully understood. Their greater pursuit and interest is to make a living through sand mining regardless of the dire consequences of their actions. Saviour (2012) added that developing countries have regulations guiding mining and dredging, but sand mining studies are often carried out without environmental compliance. River mining have been declared illegal and stopped in most global North countries, though not totally but the consequences of sand mining activity have been taken into full consideration. However, in developing countries like Nigeria, river mining continues to expand as an unsustainable economic activity, lacking scientific methodology, mostly an illegally operated business and driven by poverty and unemployment.

Owing to the undeniable consequences of sand mining on river systems in the study area, it has become expedient to provide scientific means of accounting for sand footprints since majority of rural communities located along rivers in Nigeria are dependent on commercial river mining as their source of livelihood. The concept of ecological footprint as a resource and emissions accounting tool, is designed to track the demand on the biosphere and its regenerative capacity. It is however, being applied in developed countries as an indicator by organizations and corporate firms in order to ascertain the levels of environmental performance and product sustainability, According to Limpitlaw et al. (2017) reported in their study that for the size of a mine's (land/river) ecological footprint to be determined, it requires all the categories of consumption and waste discharge to be totaled. Unfortunately, the shortage and inaccessibility of data in developing countries like Nigeria is a huge setback to compiling consumption and emission data. Since footprint results highlight the most critical aspects of the local community's impacts on river systems and the environment and hence foster sustainable actions for education and best practices (Akanwa and Ikegbunam 2019).

A number of methods or indicators to measure ecological footprints or the sustainability of human actions on the environment has been duly provided by scientific bodies. Fang et al. (2013) presented a comparative review of these footprint approaches where a combination of footprint family of related fields such as ecology, energy, carbon and water footprints have been compared and integrated. However, particular emphasis on sand footprints were not indicated in their study, but rather their aim was to combine selected footprints that would address different aspects of environmental issues into an integrated system thereby understanding their connections and interactions.

Also, in another study Koc and Christiansen (2018) evaluated ecological footprint methodology for buildings where the model was used to measure the environmental performance of architecture. They described the fact that buildings have two types of footprints; firstly, a literal physical footprint that directly consumes the area and secondly, a theoretical ecological footprint that summaries all resource flows and waste sinks translated into the land area. Here, the ecological footprint is comprehensive and assesses the magnitude of different materials consumed during construction.

Other methods for determining ecological footprint of human activities include life cycle assessment model, material flow analysis, capacity studies and environmental audit procedures among others (Hardoy et al. 2013; Lillemo 2000; Barret et al. 2002). From the foregoing, the ecological footprint of river sand mining in Odor River can provide a useful input to the policy making process that would address the present challenges while protecting Amaokpala community and its enviorns.

16.9 Sustainable Strategies Towards Reducing Ecological Footprint in Odor River

River sand mining and trade is responsible for severe ecological impacts in Odor River. Arguably, it could be assumed that the sand extractions where carried out on small-scale levels. However, regardless of the mining technique, since there have been consistent mining activities for more than 40 years, it all adds up to significant cumulative effects that have disrupted the channel morphology.

One of the sustainable means to minimize ecological footprints of in-stream extraction in the study area is through the creation of public awareness and education by researchers. This is a veritable tool that has been employed in developed countries in dealing with sand mining problems. Environmentalists in developed parts of the world are pressurizing their governments to shut down sand mining on rivers due to the ecological footprints. According to Beiser (2017b) in Northern Ireland protesters have raised alarm on dredging in Lough Neagh which is a large bird habitat. In southern England there has been uproar by protesters on the endangered seals, birds and other aquatic life inhabiting the port of Dover which is proposed for dredging (Vaughan 2016).

In North of Monterey California, activists have demonstrated about an estimated 270,000 cubic metres of sand lost annually from their pristine shore and gradually disappearing beach due to sand mining (Kondolf et al. 2002). Other sand mines along the California coast have been shut down in the 1980s due to erosion being suffered. Nigeria and other affected developing countries where river sand mining has caused ecological footprints should raise alarm through campaigns to get public attention. This campaign can also involve the youths since they make up the largest population involved in river mining. A scientific detail of their actions will be a starting point to sustainable mining practice. This will enable State and LGA to take actions and require community miners to be responsible for the maintenance and development of affected ecosystems.

In addition, environmental agencies at the State and local government levels are entrusted with the guidelines of regulation and monitoring the process of river sand mining in order to meet all forms of environmental compliance and sustainability. This can be achieved by community participation embracing everyone who has related interest in sand mining such as land owners, tipper truck drivers, chiefs and sand miners and other key persons in communities. This will settle conflicts between the governing body and the community miners (Aromolaran 2012).

As suggested by Dagodzi (2010) buffers like vegetation should be developed along riverbanks to reduce the problems of flooding of the river channels and erosion of adjoining farmlands. Notably, vegetation will control rates of heat loss due to high temperatures that also encourage river shrinking. Also, greater caution should be given to monitor the illegal activities of sand miners. This can be achieved by creating a larger body where the voices of these local miners can be heard, their fears and concerns towards river mining. Also, an introduction of scientific mining operations targeted towards ecological restoration where annual sand loads excavated can be estimated is expedient. This will aid in monitoring the removal and renewal rates of sands. Further, considerations should be made towards substitute and sustainable use of resource that would reduce its impact on the environment (Chauhan 2010; Jhariya et al. 2018a, b, Banerjee et al. 2018).

16.10 Research and Development Towards Reducing Ecological Footprint Under River System

Developing countries are presently undergoing diverse footprints from commercial river sand mining since the process of sand extraction causes immense destruction on the river system. It is vital that a better approach that would place huge emphasis on environmental performance is expedient so there can minimization of ecological and health risks while maximizing social and economic benefits that the mining industry brings.

It is noted that the consequences of mining on river and coastal bodies have been well known and documented by the literature. However, there are presently no studies in Nigeria that have directly addressed and removal rates at the deposition zone and renewal rates at the production zone. The comprehensive awareness of impacts of river sand mining and also studies that provide post- mining sustainable strategies for ecological restoration in Nigeria is still few. Hence, this literature gaps makes this present study expedient and relevant since it a provides an in-depth study on Odor River which can be used as a foundation to assess and study other rivers in Anambra State where sand mining is active. Also, this study documented the ecological footprints while proposing a community based participation research (CBPR) especially youths engagement to tackle the present ecological impacts in order, to develop best practices for sustainable mining and sand security in Anambra State.

16.11 Policy Implications

Findings from this study revealed that river mining poses ecological risks that affect the river system and livelihoods such as farming and fishing in the community. It also places environmental risks on river shrinking, riverbed lowering, increased flood and erosion, climate crisis though it contributed immensely to the economy of the community and the state generally. However, there is need to raise national awareness that would enable differing stakeholders to contribute to policy development through voluntary actions. This would build a collective voice to raise concerns over sand mining in Nigerian rivers with aggressive public enrollment, participation and engagement. Also, there is need to mobilize researchers and campaigners especially the youths who are aggressively involved in mining activity. Nigeria has vast resources that are yet to be exploited due to poor investment opportunities, unavailability of data and information, poor extraction techniques and poor facilities. These challenges are worth publicizing so that governments can provide their support especially in sand mining development in rural areas.

16.12 Conclusion

Findings from the study showed that sand mining in Odor River has significant positive impacts on the economy of Amaokpala indigenes and its environs. This includes income generation, high-paying opportunities for youth employment, increased diversification of skills, emergence of small scale businesses related to building materials, generation of tax revenues for local governments. It has added to the economic diversity in Amaokpala community which was heavily dependent on trading and agriculture and generally improved the living conditions of the people.

It was noted that river mining is intensively carried out by predominantly small-scale miners using low technology, minimal administrative capacity and without the application of scientific mining methods. It was estimated from the study that 156,400m^3 of sands have been removed from Odor River for the past 40 years. This has identified significant ecological impacts such as river shrinking, lowering of riverbed, and change in river morphology, loss of river bank vegetation, flooding and erosion, loss of fish population and diminished farming and fishing livelihoods. Also, there are changes in water quality, increased turbidity and reduction in water levels.

There is need for synergy between stakeholders, youths and the community in creating awareness, transference of skills, knowledge and community mobilization using the innovative alternative participatory research approach over the present ecological footprints. Also, policy development can play an important role in providing new technology supported by incentive structures. This can be achieved by application of sci-tech knowledge and mandatory training before the issuance of mining licenses. This will encourage corporations at the local levels to invest in order to meet internationally approved standards.

16.13 Future Perspectives

The youths can be fully engaged, educated and also trained to develop skills and experiences critical for sustaining rivers and mining. This is crucial for sustainable rural and national growth and development. The role of research especially community partnership and participatory inquiry will bring about the basic innovations to the community while economic benefits can be sustained.

Also, the government at the federal, state and LGA need to invest in community mining especially with loans and improved mining equipment that would encourage safe mining and reduce ecological footprints. Further, scientific measures and best practices should be undertaken to ensure the possible rehabilitation of rivers and the right conditions for aquatic life sustenance during and after river mining process.

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