Ecological Footprints in Agroecosystem: An Overview

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Contents

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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

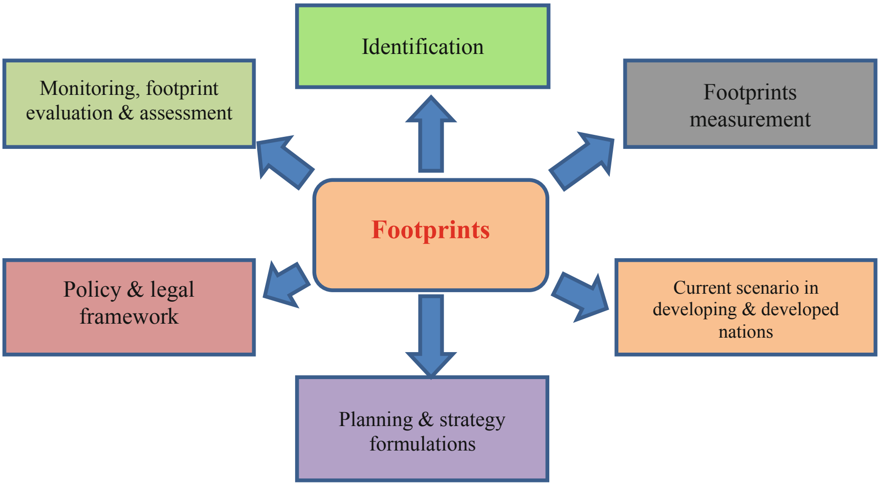

Fig. 1.1 Ecological footprint: an introductory framework

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

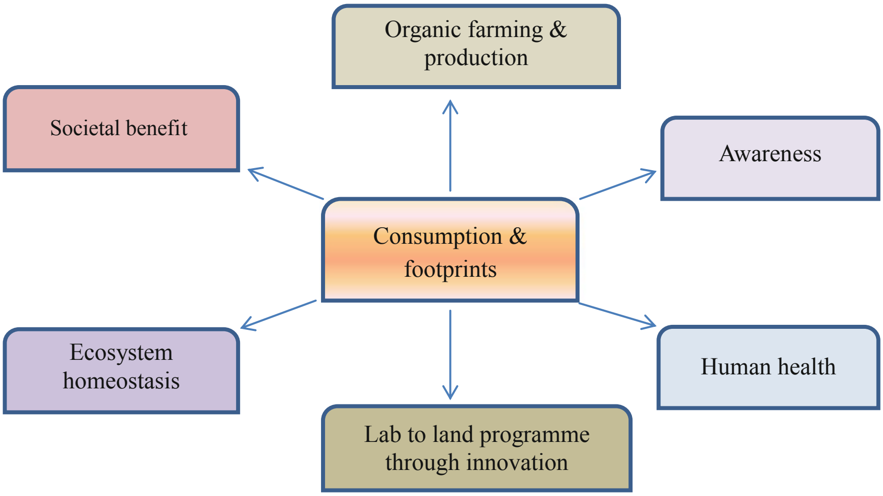

Fig. 1.2 Interaction of ecological footprint

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

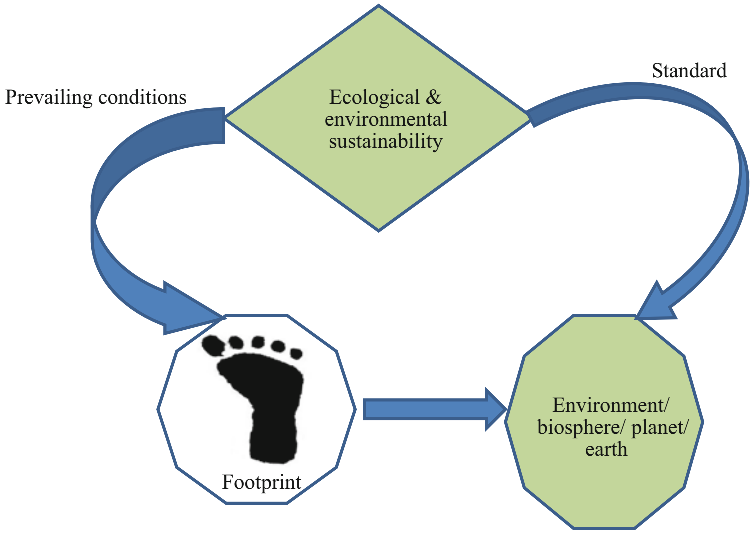

Fig. 1.3 Ecological footprint and sustainability

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:

$$EQ = P/T_p \tag{1.1}$$

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:

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

$BC = \sum (A \times EQ \times YF)$ (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

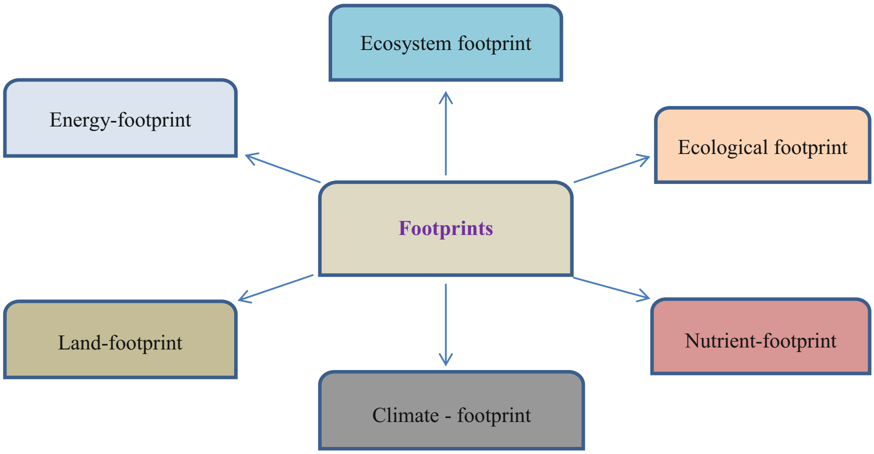

Fig. 1.4 Various forms of footprints

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

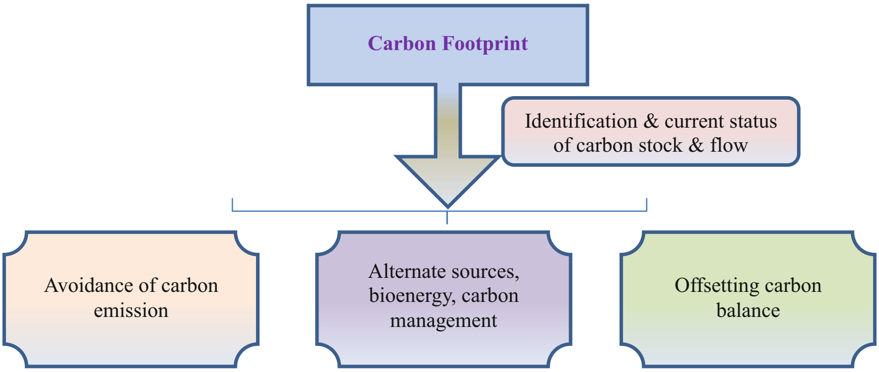

Fig. 1.5 Carbon footprint

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).

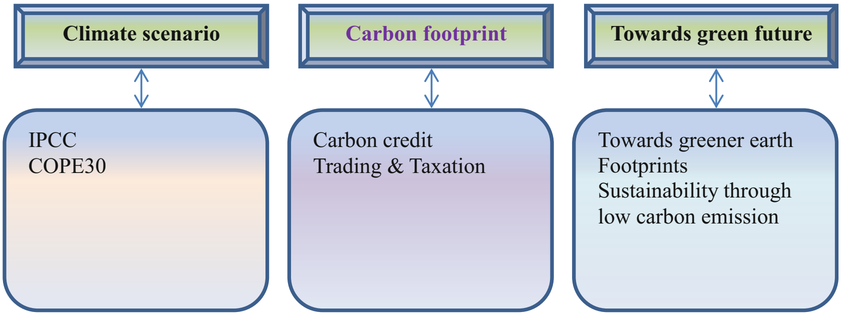

Fig. 1.6 Climate footprint

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

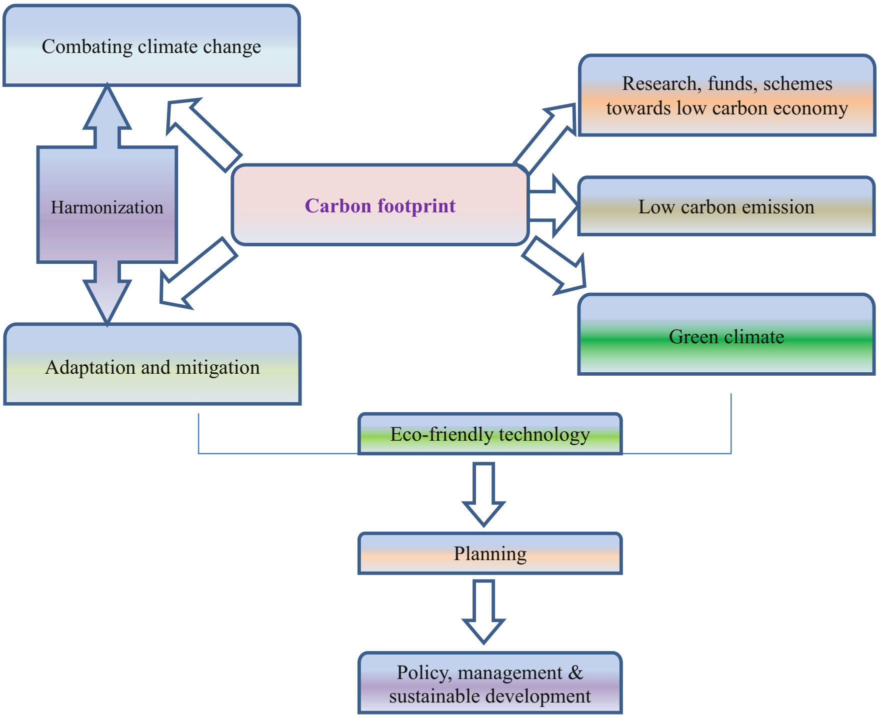

Fig. 1.7 Policy for regulating carbon footprint

(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

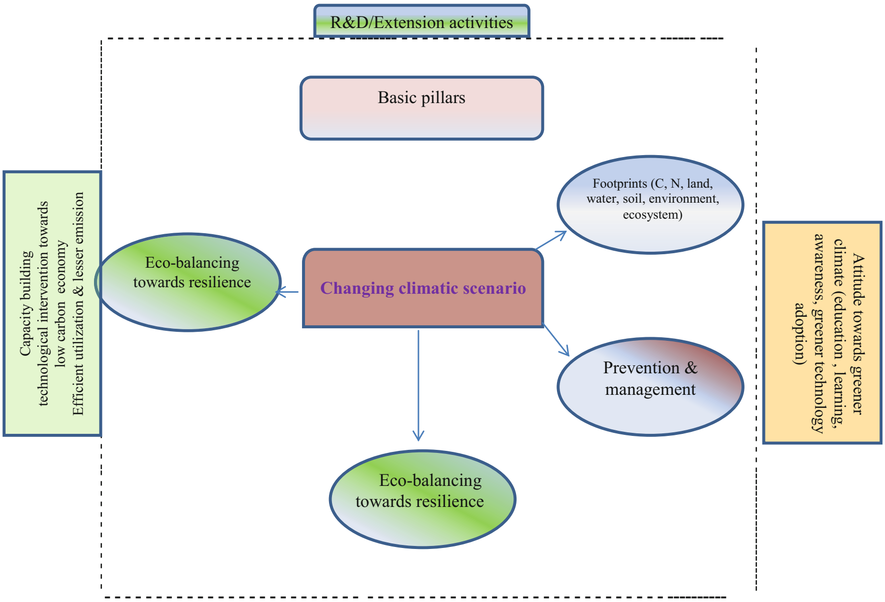

Fig. 1.8 Research and extension activities for ecological footprint

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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