14 Energy and Climate Footprint Towards the Environmental Sustainability

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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

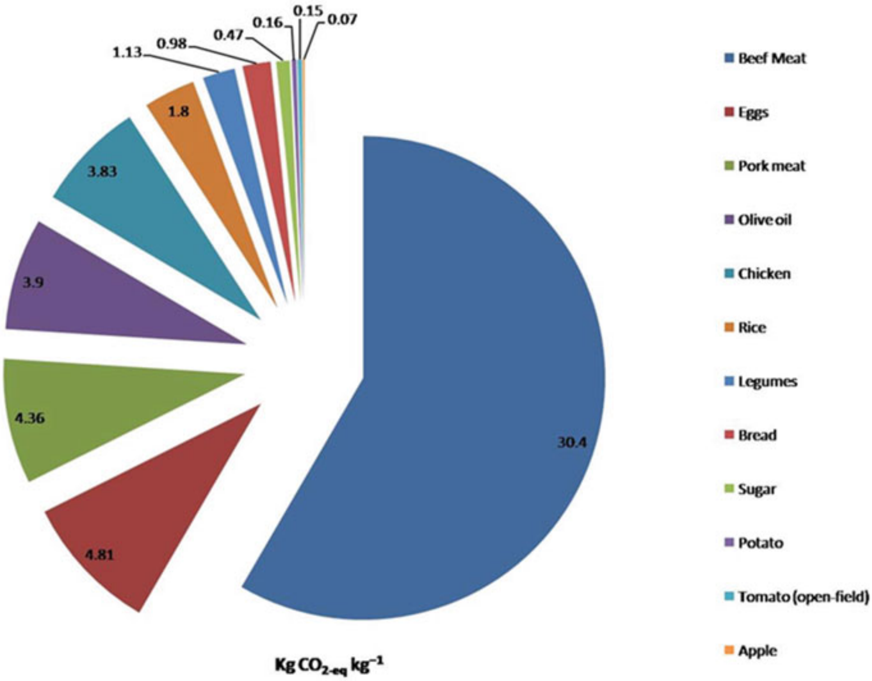

Fig. 14.1 Carbon footprints of food items in the world (Adopted Chapagain and James 2011)

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

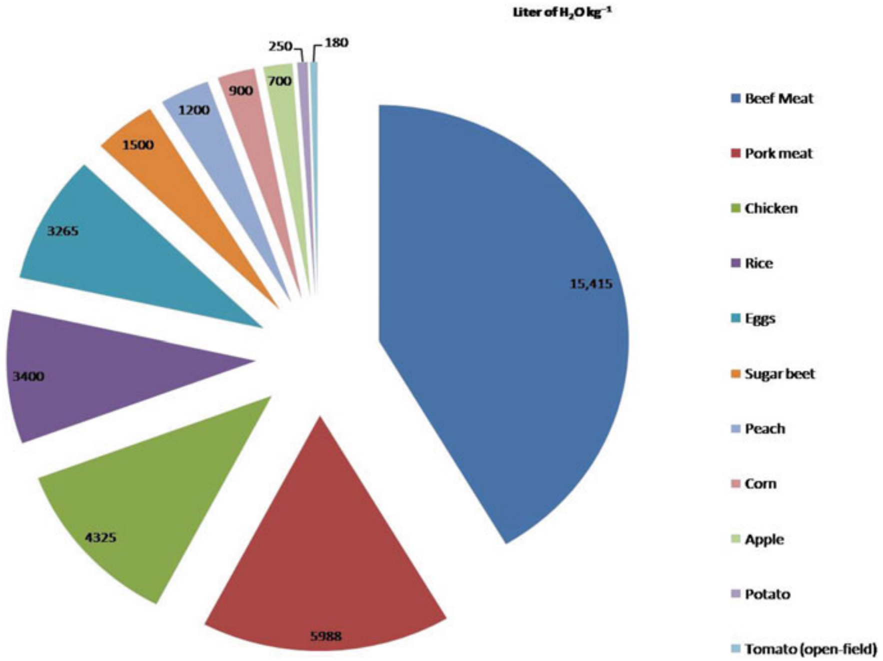

Fig. 14.2 Water footprints of food items in the world (Hoekstra and Chapagain 2008; Hoekstra 2013)

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.

References

Akiyama H, Yagi K, Yan X (2005) Direct NO emissions from rice paddy fields: summary of available data. Global Biogeochem Cycles 19:GB1005. https://doi.org/10.1029/2004GB002378

Alam MS, Alam MR, Islam KK (2005) Energy flow in agriculture: Bangladesh. Am J Environ Sci 1 (3):213e20

Albrecht A, Kandji ST (2003) Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99:15–27

Allen B, Kretschmer B, Baldock D, Menadue H, Nanni S, Tucker G (2014) Space for energy crops –assessing the potential contribution to Europe's energy future. In: Report produced for BirdLife Europe, European Environmental Bureau and Transport & Environment. IEEP, London, pp 1–69

Andreae MO, Jones CD, Cox PM (2005) Strong present-day aerosol cooling implies a hot future. Nature 435:1187

Banerjee A, Jhariya MK, Yadav DK, Raj A (2020) Environmental and sustainable development through forestry and other resources. Apple Academic Press Inc., CRC Press- a Tayler and Francis Group, Oakville, p 400. https://doi.org/10.1201/9780429276026. ISBN: 9781771888110

Bell MJ, Wall E, Russell G, Morgan C, Simm G. (2010) et al., "Effect of breeding for milk yield, diet and management on enteric methane emissions from dairy cows," Anim Prod Sci, 50 (8):817–826

Beringer J, Hutley LB, Tapper NJ, Coutts A, Kerley A, O'Grady AP (2003) Fire impacts on surface heat, moisture and carbon fluxes from a tropical savanna in northern Australia. Int J Wildland Fire 12:333–340

Blengini GA, Brizio E, Cibrario M, Genon G (2011) LCA of bioenergy chains in Piedmont (Italy): a case study to support public decision makers towards sustainability. Resour Conserv Recycl 57:36–47

Bouwman AF, Boumans LJM, Batjes NH (2002) Modeling global annual N_2O and NO emissions from fertilized fields. Glob Biogeochem Cycles 16:1080

Brankatschk G, Finkbeiner M (2015) Modeling crop rotation in agricultural LCAs-challenges and potential solutions. Agric Syst 138:66–76

Bryngelsson D, Wirsenius S, Hedenus F, Sonesson U (2016) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. Food Policy 59:152–164

Busari MA, Kukal SS, Kaur A, Bhatt R, Dulazi AA (2015) Conservation tillage impacts on soil, crop and the environment. Int Soil Water Conserv Res 3:119e29. https://doi.org/10.1016/j.iswcr.2015.05.002

Cannell MGR (2003) Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. Biomass Bioenergy 24:97–116

Cerri CC, Bernoux M, Cerri CEP, Feller C (2004) Carbon cycling and sequestration opportunities in South America: the case of Brazil. Soil Use Manag 20:248–254

Chapagain A, James K (2011) The water and carbon footprint of household food and drink waste in the UK. Waste and Resources Action Programme (WRAP), Banbury

Chen GQ, Jiang MM, Chen B, Yang ZF, Lin C (2006) Energy analysis of Chinese agriculture. Agric Ecosyst Environ 115:161–173

Chen Y, Ale S, Rajan N, Munster CL (2017) Assessing the hydrologic and water quality impacts of biofuel-induced changes in land use and management. Glob Change Biol Bioenergy 9(9):1461–1475

Cherubini F, Bird ND, Cowie A, Jungmeier G, Schlamadinger B, Woess-Gallasch S (2009) Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: key issues, ranges and recommendations. Resour Conserv Recycl 53:434–447

Clemens J, Ahlgrimm HJ (2001) Greenhouse gases from animal husbandry: mitigation options. Nutr Cycl Agroecosyst 60:287–300

Colomb V, Touchemoulin O, Bockel L, Chotte JL, Martin S, Tinlot M, Bernoux M (2013) Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry. Environ Res Lett 8:015029

Conant RT, Paustian K, Del Grosso SJ, Parton WJ (2005) Nitrogen pools and fluxes in grassland soils sequestering carbon. Nutr Cycl Agroecosyst 71:239–248

Conant RT, Paustian K, Elliott ET (2001) Grassland management and conversion into grassland: effects on soil carbon. Ecol Appl 11:343–355

Dalal RC, Wang W, Robertson GP, Parton WJ (2003) Nitrous oxide emission from Australian agricultural lands and mitigation options: a review. Aust J Soil Res 41:165–195

Denef K, Paustian K, Archibeque S, Biggar S, Pape D. (2012) Report of greenhouse gas accounting tools for agriculture and forestry sectors. Interim report to USDA under Contract No. GS23F8182H, p 1–135

Derner JD, Boutton TW, Briske DD (2006) Grazing and ecosystem carbon storage in the north American Great Plains. Plant Soil 280:77–90

Diekow J, Mielniczuk J, Knicker H, Bayer C, Dick DP, Kögel I, Knabner I (2005) Soil C and N stocks as affected by cropping systems and nitrogen fertilization in a southern Brazil Acrisol managed under no-tillage for 17 years. Soil Tillage Res 81:87–95

Ellen MacArthur Foundation (2017) A new textiles economy: redesigning fashion's future. 150 p. http://www.ellenmacarthurfoundation.org/publications

European Commission Directive (2009) EC of the European Parlament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. In: Union OJotE, editor. Brussels: The European Parliament and the Council of the European Union

Eurostat (2014) Final Energy Consumption by Sector and Fuel. 2014. Available online: https://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment-1#. Tab-related-briefings. Accessed 5 Feb 2019

FAO (2001) Soil carbon sequestration for improved land management. World Soil Resources Reports No. 96. FAO, Rome, 58pp

FAO (2003) World agriculture: towards 2015/2030. An FAO perspective. FAO, Rome. 97pp

FAOSTAT (2006) FAOSTAT Agricultural Data. Available at: http://faostatfaoorg/. Accessed 26 Mar 2007

FAOSTAT (2019) Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billionaround 2100," United Nations un.org, Food and Agriculture Organization of the United Nations, Accessed 13 Sept 2019. fao.org

Farooq M, Flower KC, Jabran K, Wahid A, Siddique KHM (2011) Crop yield and weed management in rainfed conservation agriculture. Soil Tillage Res 117:172e83. https://doi.org/10.1016/j.still.2011.10.001

Favier A, De Wolf C, Scrivener KL, Habert G (2018) A sustainable future for the European cement and concrete industry. Technology assessment for full decarbonisation of the industry by 2050. doi:https://doi.org/10.3929/ethz-b-000301843

Foley JA, DeFries R, Asner G, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Dailey GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309:570–574

Follett RF (2001) Organic carbon pools in grazing land soils. In: Follett RF, Kimble JM, Lal R (eds) The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton, pp 65–86

Food and Agriculture Organization (FAO) (2019) Agroforestry. Available online: http://www.fao.org/forestry/

Forsgren M, Ostgren E, Tschiesner A (2019) Harnessing momentum for electrification in heavy machinery and equipment. April 2019. McKinsey.com

Freibauer A, Rounsevell M, Smith P, Verhagen A (2004) Carbon sequestration in the agricultural soils of Europe. Geoderma 122:1–23

Galloway JN (2003) The global nitrogen cycle. Treatise Geochem 8:557–583

Ghorbani R, Mondani F, Amirmoradi S, Feizi H, Khorramdel S, Teimouri M, Sanjani S, Anvarkhah S, Aghel H (2011) A case study of energy use and economical analysis of irrigated and dryland wheat production systems. Appl Energy 88:283e8. https://doi.org/10.1016/j.apenergy.2010.04.028

Gissén C, Prade T, Kreuger E, Nges IA, Rosenqvist H, Svensson S-E, Maikael L, Jan Erik M, Pal B, Lovisa B (2014) Comparing energy crops for biogas production – yields, energy input and costs in cultivation using digestate and mineral fertilisation. Biomass Bioenergy 64:199–210

Gregorich EG, Rochette P, van den Bygaart AJ, Angers DA (2005) Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. Soil Tillage Res 83:53–72

Harmsen JHM (2019) Non-CO_2 greenhouse gas mitigation in the 21st century. Utrecht University, Utrecht

Helgason BL, Janzen HH, Chantigny MH, Drury CF, Ellert BH, Gregorich EG, Lemke E, Pattey PR, Wagner Riddle C (2005) Toward improved coefficients for predicting direct NO emissions from soil in Canadian agroecosystems. Nutr Cycl Agroecosyst 71:87–99

Hillier J, Hawes C, Squire G, Hilton A, Wale S, Smith P (2009) The carbon footprints of food crop production. Int J Agric Sustain 7:107–118

Hobbs PR, Sayre K, Gupta R (2008) The role of conservation agriculture in sustainable agriculture. Phil Trans R Soc B 363:543e55

Hoekstra AY (2013) (2013) the water footprint of modern consumer society. Routledge, London

Hoekstra AY, Chapagain AK (2008) Globalization of water: sharing the planet's freshwater resources. Wiley-Blackwell, Hoboken, pp 12–15

Hristov AN, Oh J, Giallongo F, Fredreick TW, Harper MT, Weeks HL, Branco AF, Moate PJ, Deighton MH, Williams SRO, Kindermann M, Duval S (2015) An inhibitor persistently decreased enteric methane emission from dairy cows with no negative effect on milk production. PNAS 112(34):10663–10668. https://doi.org/10.1073/pnas.1504124112

Hulsbergen KJ, Feil B, Biermann S, Rathke GW, Kalk WD, Diepenbrock WA (2001) Method of energy balancing in crop production and its application in a long-term fertilizer trial. Agric Ecosyst Environ 86:303–321

International Standardization Organization (ISO) (2014) Environmental Management—Water Footprint—Principles, Requirements and Guidelines. ISO 14046: 2014. European Committee for Standardization, Brussels

IPCC (2001) Climate change (2001) the scientific basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. 881pp

IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories. In: Agriculture, forestry and other land use, 4. Hayama, Japan: Prepared by the National Greenhouse Gas Inventories Programme

IPCC (2014) Summary for Policymakers. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K et al (eds) Climate Change 2014: Mitigation of Climate Change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 1–32

IPCC (2018) C40, protecting our capital; intergovernmental panel on climate change (IPCC), 'chapter 3: impacts of 1.5°C of global warming on natural and human systems' in global warming of 1.5°C: an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

IRP and UNEP (2018) The weight of cities: resource requirements of future urbanization. 280 p, Job No: DTI/2172/PA; ISBN: 978-92-807-3699-1

Janzen HH (2004) Carbon cycling in earth systems - a soil science perspective. Agric Ecosyst Environ 104:399417

Jhariya MK, Banerjee A, Meena RS, Yadav DK (2019a) Sustainable agriculture, forest and environmental management. Springer Nature Singapore Pte Ltd., Singapore. eISBN: 978-981-13-6830-1, Hardcover ISBN: 978-981-13-6829-5, p 606. https://doi.org/10.1007/978-981-13-6830-1

Jhariya MK, Banerjee A, Yadav DK, Raj A (2018a) Leguminous trees an innovative tool for soil sustainability. In: Meena RS, Das A, Yadav GS, Lal R (eds) Legumes for soil health and sustainable management. Springer, Singapore, ISBN 978-981-13-0253-4 (eBook), ISBN: 978-981-13-0252-7 (Hardcover), pp 315–345. https://doi.org/10.1007/978-981-13-0253-4_10

Jhariya MK, Yadav DK, Banerjee A (2018b) Plant mediated transformation and habitat restoration: phytoremediation an eco-friendly approach. In: Gautam A, Pathak C (eds) Metallic contamination and its toxicity. Daya Publishing House, A Division of Astral International Pvt. Ltd, New Delhi, pp 231–247. ISBN: 9789351248880

Jhariya MK, Yadav DK, Banerjee A (2019b) Agroforestry and climate change: issues and challenges. Apple Academic Press Inc., CRC Press- a Tayler and Francis Group, Oakville, p 335. https://doi.org/10.1201/9780429057274. ISBN: 978-1-77188-790-8 (Hardcover), 978-0-42957-274-8 (E-book).

Jørgensen A, Bikker P, Herrmann IT (2012) Assessing the greenhouse gas emissions from poultry fat biodiesel. J Clean Prod 24:85–91. https://doi.org/10.1016/j.jclepro.2011.11.011

Kehagias MC, Michos MC, Menexes GC, Mamolos AP, Tsatsarelis CA, Anagnostopoulos CD, Kalburtji KL (2015) Energy equilibrium and carbon dioxide, methane, and nitrous oxide-emissions in organic, integrated and conventional apple orchards related to Natura 2000 site. J Clean Prod 91:89–95

Khalil MAK, Shearer MJ (2006) Decreasing emissions of methane from rice agriculture. In: Soliva CR, Takahashi J, Kreuzer M (eds) Greenhouse gases and animal agriculture: an update. Elsevier, Amsterdam, pp 33–41. International Congress Series No. 1293

Khan N, Jhariya MK, Yadav DK, Banerjee A (2020a) Herbaceous dynamics and CO_2 mitigation in an urban setup- a case study from Chhattisgarh, India. Environ Sci Pollut Res 27(3):2881–2897. https://doi.org/10.1007/s11356-019-07182-8

Khan N, Jhariya MK, Yadav DK, Banerjee A (2020b) Structure, diversity and ecological function of shrub species in an urban setup of Sarguja, Chhattisgarh, India. Environ Sci Pollut Res 27 (5):5418–5432. https://doi.org/10.1007/s11356-019-07172-w

Kizilaslan H (2009) Input–output energy analysis of cherries production in Tokat Province of Turkey. Appl Energy 86:1354–1358
Korontzi S, Justice CO, Scholes RJ (2003) Influence of timing and spatial extent of savannah fires in southern Africa on atmospheric emissions. J Arid Environ 54:395–404
Lal R (2004a) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627
Lal R (2004b) Soil carbon sequestration to mitigate climate change. Geoderma 123:1–22
Li TX, Balezentis T, Makutenie ED, Streimikiene D, Krisciukaitiene I (2016) Energy-related CO emission in European Union agriculture: driving forces and possibilities for reduction. Appl Energy 180:682–694
Lima BL de C, Silva ÊF de F, Santos HRB, De Souza ER (2018) Potassium fertilization and irrigation with treated wastewater on gas exchange of colored cotton. Rev Bras Eng Agríc Ambient 22(11):741–746
Lobell DB, Gourdji SM (2012) The influence of climate change on global crop productivity. Plant Physiol 160:1686e97
Machado PLOA, Freitas PL (2004) No-till farming in Brazil and its impact on food security and environmental quality. In: Lal R, Hobbs PR, Uphoff N, Hansen DO (eds) Sustainable agriculture and the international rice-wheat system. Marcel Dekker, New York, pp 291–310
Madari B, Machado PLOA, Torres E, Andrade AG, Valencia LIO (2005) No tillage and crop rotation effects on soil aggregation and organic carbon in a Fhodic Ferralsol from southern Brazil. Soil Tillage Res 80:185–200
Mandal K, Saha K, Ghosh P, Hati K, Bandyopadhyay K (2002) Bioenergy and economic analysis of soybean-based crop production systems in Central India. Biomass Bioenergy 23:337e45. https://doi.org/10.1016/S0961-9534(02)00058-2
Material Economics (2018) The circular economy: A powerful force for climate mitigation. Transformative innovation for prosperous and low-carbon industry. In: Executive summary. The Council, Olympia, pp 1–8
McSwiney CP, Robertson GP (2005) Nonlinear response of NO flux to incremental fertilizer addition in a continuous maize (*Zea mays* L.) cropping system. Glob Chang Biol 11:1712–1719
Meena RS, Kumar V, Yadav GS, Mitran T (2018) Response and interaction of *Bradyrhizobium japonicum* and arbuscular mycorrhizal fungi in the soybean rhizosphere: a review. Plant Growth Regul 84:207–223
Meena RS, Lal R (2018) Legumes for soil health and sustainable management. Springer, Singapore, p 541. https://doi.org/10.1007/978-981-13-0253-4_10. ISBN 978-981-13-0253-4 (eBook), ISBN: 978-981-13-0252-7(Hardcover)
Meena RS, Lal R, Yadav GS (2020a) Long term impacts of topsoil depth and amendments on soil physical and hydrological properties of an Alfisol in Central Ohio, USA. Geoderma 363:1141164
Meena RS, Lal R, Yadav GS (2020b) Long-term impact of topsoil depth and amendments on carbon and nitrogen budgets in the surface layer of an Alfisol in Central Ohio. Catena 194:104752
Mekonnen MM, Hoekstra AY (2014) Water footprint benchmarks for crop production: a first global assessment. Ecol Indic 46:214–223
Michos MC, Menexes GC, Kalburtji KL, Tsatsarelis CA, Anagnostopoulos CD, Mamolos AP (2017) Could energy flow in agro-ecosystems be used as a “tool” for crop and farming system replacement? Ecol Indic 73:247–253
Michos MC, Menexes GC, Mamolos AP, Tsatsarelis CA, Anagnostopoulos CD, Tsaboula AD, Kalburtji KL (2018) Energy flow, carbon and water footprints in vineyards and orchards to determine environmentally favourable sites in accordance with Natura 2000 perspective. J Clean Prod 187:400–408
Monteny GJ, Bannink A, Chadwick D (2006) Greenhouse gas abatement strategies for animal husbandry. Agric Ecosyst Environ 112:163–170
Moomow W, Yamba F, Kamimoto M, Maurice L, Nyboer J, Urama K et al (2011) Introduction. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S et al (eds) IPCC

special report on renewable energy sources and climate change mitigation. Cambridge University Press, New York

Mosier A, Kroeze C (2000) Potential impact on the global atmospheric NO budget of the increased nitrogen input required to meet future global food demands. Chemosphere-Global Chang Sci 2:465–473

Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K, Johnson DE (1998) Mitigating agricultural emissions of methane. Clim Chang 40:39–80

Munoz R, Llanos J (2012) Estimation of the lifespan of agricultural tractor using a diffusion model at the aggregate level. Cien Inv Agric 39(3):557–562

Nemecek T, Hayer F, Bonnin E, Carrouée B, Schneider A, Vivier C (2015) Designing eco-efficient crop rotations using life cycle assessment of crop combinations. Eur J Agron 65:40–51

Oenema O, Wrage N, Velthof GL, van Groenigen JW, Dolfing J, Kuikman PJ (2005) Trends in global nitrous oxide emissions from animal production systems. Nutr Cycl Agroecosyst 72:51–65

Ozkan B, Fert C, Karadeniz CF (2007) Energy and cost analysis for greenhouse and open-field grape production. Energy 32:1500–1504

Ozpinar S, Ozpinar A (2011) Influence of tillage and crop rotation systems on economy and weed density in a semi-arid region. J Agric Sci Technol 13:769e84

Pan GX, Zhou P, Zhang XH, Li LQ, Zheng JF, Qiu DS, Chu QH (2006) Effect of different fertilization practices on crop C assimilation and soil C sequestration: a case of a paddy under a longterm fertilization trial from the tai Lake region, China. Acta Ecol Sin 26(11):3704–3710

Parihar CM, Jat SL, Singh AK, Kumar B, Pradhan S, Pooniya V, Dhauja A, Chaudhary V, Jat ML, Jat RK, Yadav OP (2016) Conservation agriculture in irrigated intensive maize-based systems of northwestern India: effects on crop yields, water productivity and economic profitability. F Crop Res 193:104e16. https://doi.org/10.1016/j.fcr.2016.03.013

Paustian K, Babcock BA, Hatfield J, Lal R, McCarl BA, McLaughlin S, Mosier A, Rice C, Robertson GP, Rosenberg NJ, Rosenzweig C, Schlesinger WH, Zilberman D (2004) Agricultural mitigation of greenhouse gases: science and policy options. CAST (Council on Agricultural Science and Technology) Report R141:2004. ISBN 1-887383-26-3, 120pp

Pimentel D, Herdendorf M, Eisenfeld S, Olander L, Carroquino M, Corson C, McDade J, Chung Y, Cannon W, Roberts J (1994) Achieving a secure energy future: environmental and economic issues. Ecol Econ 9(3):201–219

Platis DP, Anagnostopoulos CD, Tsaboula AD, Menexes GC, Kalburtji KL, Mamolos AP (2019) Energy analysis, and carbon and water footprint for environmentally friendly farming practices in agroecosystems and agroforestry. Sustainability 11:1664

Raj A, Jhariya MK, Yadav DK, Banerjee A (2020) Climate change and agroforestry systems: adaptation and mitigation strategies. Apple Academic Press Inc., CRC Press- A Tayler and Francis Group, BurlingtonISBN: 9781771888226, p 383. https://doi.org/10.1201/9780429286759

Ramachandra TV (2019) Energy footprint of India: scope for improvements in end-use energy efficiency and renewable energy. In: Muthu S (ed) Energy footprints of the energy sector. Environmental footprints and eco-design of products and processes. Springer, Singapore. https://doi.org/10.1007/978-981-13-2457-4_3

Recanati F, Arrigoni A, Scaccabarozzi G, Marveggio D, Melià P, Dotelli G (2018) LCA towards sustainable agriculture: the case study of Cupuaçu Jam from agroforestry. Procedia CIRP 69:557–561

Rochette P, Janzen HH (2005) Towards a revised coefficient for estimating NO emissions from legumes. Nutr Cycl Agroecosyst 73:171–179

Roy P, Nei D, Orikasa T, Xu Q, Okadome H, Nakamura N, Shiina T (2009) A review of life cycle assessment (LCA) on some food products. J Food Eng 90:1–10

Salim I, Lijó L, Moreira MT, Feijoo G (2019) Addressing environmental criteria and energy footprint in the selection of feedstocks for bioenergy production. In: Muthu S (ed) Energy footprints of the energy sector. Environmental footprints and eco-design of products and processes. Springer, Singapore. https://doi.org/10.1007/978-981-13-2457-4_1

Sanchez PA (2002) Soil fertility and hunger in Africa. Science 295:2019–2020

Sass RL (2003) CH4 emissions from rice agriculture. In: Good practice guidance and uncertainty management in national greenhouse gas inventories. Institute for Global Environmental Strategies/IPCC, Hayama, pp 1–19

Schlesinger WH (1999) Carbon sequestration in soils. Science 284:2095

Schnabel RR, Franzluebbers AJ, Stout WL, Sanderson MA, Stuedemann JA (2001) The effects of pasture management practices. In: Follett RF, Kimble JM, Lal R (eds) The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton, pp 291–322

Scholes RJ, Biggs R (2004) Ecosystem services in southern Africa: a regional assessment. CSIR, Pretoria

Scholes RJ, van der Merwe MR (1996) Sequestration of carbon in savannas and woodlands. Environ Prof 18:96103

Schuman GE, Herrick JE, Janzen HH (2001) The dynamics of soil carbon in rangelands. In: Follett RF, Kimble JM, Lal R (eds) The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Boca Raton, pp 267–290

Siregar K, Tambunan AH, Irwanto AK, Wirawan SS, Araki T (2015) A comparison of life cycle assessment on oil palm (Elaeis guineensis Jacq.) and physic nut (Jatropha curcas Linn.) as feedstock for biodiesel production in Indonesia. Energy Procedia 65:170–179

Snape WJ III (2010) Joining the convention on biological diversity: a legal and scientific overview of why the United States must wake up. Sustain Dev Law Policy 3:6

Sorensen CG, Halberg N, Oudshoorn FW, Petersen BM, Dalgaard R (2014) Energy inputs and GHG emissions of tillage systems. Biosyst Eng 120:2–14

Soussana JF, Loiseau P, Viuchard N, Ceschia E, Balesdent J, Chevallier AD (2004) Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use Manag 20:219–230

Taxidis ET, Menexes GC, Mamolos AP, Tsatsarelis CA, Anagnostopoulos CD, Kalburtji KL (2015) Comparing organic and conventional olive groves relative to energy use and greenhouse gas emissions associated with the cultivation of two varieties. Appl Energy 149:117–124

Unakitan G, Aydin B (2018) A comparison of energy use efficiency and economic analysis of wheat and sunflower production in Turkey: a case study in Thrace region. Energy 149:279–285

UNEP and IEA (2017) Towards a zero-emission, efficient, and resilient buildings and construction sector, Global Status Report 2017. UN Environment and International Energy Agency, Paris

US (2009) Global change research program, global climate change impacts in the United States. Available at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

US-EPA (2006a) Global Anthropogenic Non-CO Greenhouse Gas Emissions: 19902020. United States Environmental Protection Agency, EPA 430-R-06-003, June 2006. Washington, D.C. http://www.epa.sgov/nonco2/econ inv/downloads/GlobalAnthroEmissionsReport.pdf. Accessed 26 Mar 2007

US-EPA (2006b) Global mitigation of non-CO22 greenhouse gases. United States Environmental Protection Agency, EPA 430-R-06-005,Washington. http://www.epa.gov/nonco2/econ-inv/downloads/GlobalMitigationFullReport.pdf. Accessed 26 Mar 2007

Van Wilgen BW, Govender N, Biggs HC, Ntsala D, Funda XN (2004) Response of savanna fire regimes to changing fire-management policies in a large African National Park. Conserv Biol 18:1533–1540

Venkataraman C, Habib G, Eiguren-Fernandez A, Miguel AH, Friedlander SK (2005) Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. Science 307:1454–1456

Wang B, Neue H, Samonte H (1997) Effect of cultivar difference on methane emissions. Agric Ecosyst Environ 62:31–40

Weidema BP, Thrane M, Christensen P, Schmidt J, Løkke S (2008) Carbon footprint. A catalyst for life cycle assessment? J Ind Ecol 12:3–6

Xu H, Cai ZC, Tsuruta H (2003) Soil moisture between rice-growing seasons affects methane emission, production, and oxidation. Soil Sci Soc Am J 67:1147–1157

Zhang WF, Dou ZX, He P, Ju XT, Powlson D, Chadwick D, Norse D, Lu YL, Zhang Y, Wu L, Chen XP, Cassman KG, Zhang FS (2013) New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. PNAS 110(21):8375–8380. https://doi.org/10.1073/pnas.1210447110