Land Footprint Management and Policies

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Contents

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Abstract

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

Keywords

Footprint · Extended land footprint · Challenges · Mitigation strategies

Abbreviations

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

7.1 Introduction

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

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

7.2 Concept of Land Footprint

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

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

7.2.1 Extended Land Footprint

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

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

7.2.2 Land Footprint as an Integrated Concept

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

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

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

7.3 Land Footprints at Global Scale

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

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

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

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

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

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

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

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

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

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

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

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

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

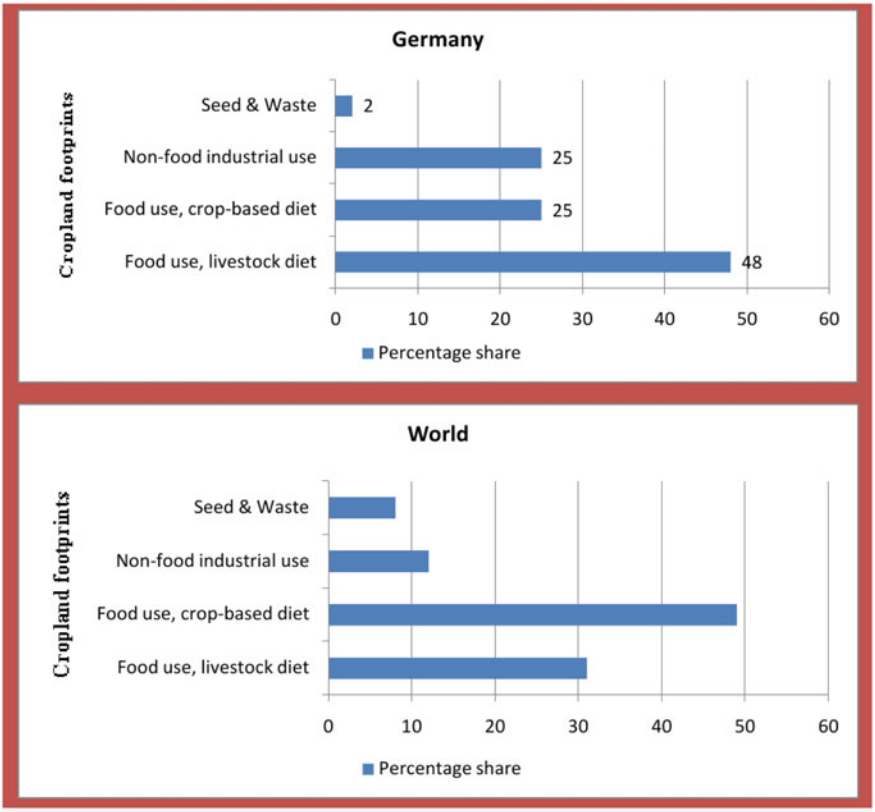

Fig. 7.1 Cropland footprints in Germany Vs World (Fischer et al. 2017a)

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

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

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

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

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

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

7.4 Livestock, Human Consumption Pattern, and Land Footprint

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

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

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

7.5 Alterations in Land Footprint and Land Use

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

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

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

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

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

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

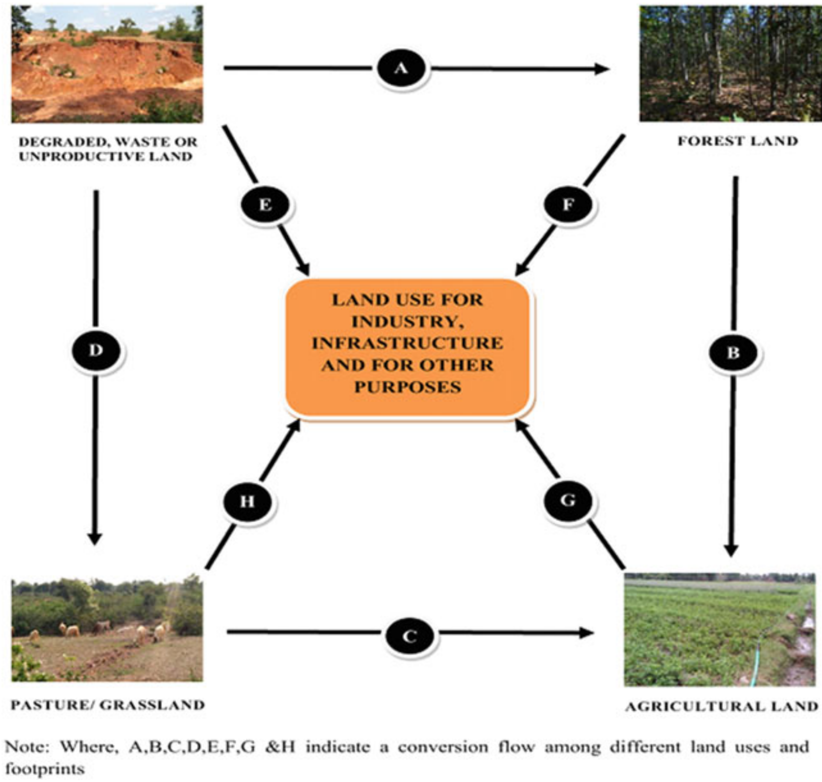

Fig. 7.2 Land use types, footprints, and conversion flows (Fischer et al. 2017b)

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

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

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

7.6 Measurement of Land Footprint for Specific Land Uses

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

7.6.1 Estimation of Footprint of Cropland Through Cropland Productivity

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

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

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

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

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

7.6.2 Estimation of Footprint of Cropland Through Land Quality

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

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

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

7.6.3 Footprint of Grassland Through Biomass Productivity

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

7.6.4 Footprint Estimation for Deforestation

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

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

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

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

7.7 Strategies for Reducing Land Footprint

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

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

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

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

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

7.8 Challenges of Land Footprints

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

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

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

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

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

7.9 Policies and Management Perspective of Land Footprint and Its Evaluation

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

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

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

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

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

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

7.10 Conclusions

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

7.11 Research and Development in Land Footprint and Future Perspectives

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

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

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

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

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

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

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