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A comparative study of the land required for food and cooking fuel in rural India

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ABSTRACT

Land is a limited resource that provides food and cooking fuel to the rural population. In this paper, we determine the land required for food production and compare it with the land required for cooking fuel (i.e. fuelwood) for six different regions of India. We use regional data to assess the land requirements for both food and fuelwood. Dietary patterns and agricultural yields are the major drivers of land demand for food production. The average land requirement for food is about 1000 m^2/cap/yr, but the values range between 800-1300 m^2/cap/yr. The greatest proportion of this land requirement is for cereals, especially rice and wheat. Determining the land needed for cooking fuel requires biomass productivity and fuelwood use. We found that the average land requirement for fuelwood is about 3 to 7 times larger than the area required to produce food. Thus, there is a wide disparity in land demand between all the regions of India. Dietary change is not an option as rural inhabitants are already consuming less than their urban counterparts. Changes to cooking fuels could be another option. This comparative study shows the high demand for land for cooking fuel in comparison to food. It implies that, from a land requirement perspective, reducing the fuelwood consumption and shifting to a more efficient cooking fuel would be a better option.

1. Introduction

Land is a limited and significant resource for human sustenance. It is the basic provider of food, feed and energy to the global population. According to the World Bank, 2018a, the total agricultural land makes up about 37% of the Earth's total land area, and forests about 31%. The intensity of global agricultural land use is increasing and gradually the forest area is decreasing. Alexander et.al (Alexander et al., 2016) revealed that a rural Indian requires about 2000 m^2 of agricultural land for food consumption each year. However, there are large differences in the land requirement for food (LRF) depending on the dietary pattern. In most cases, high-income countries with affluent diets are associated with more LRF than low-income countries (Bosire et al., 2015).

The majority of the rural population (≈3 billion population (Anríquez and Stloukal, 2008)) residing in developing countries depends on fuelwood for cooking, and this pattern will remain significant for the coming 30 years (Malla and Timilsina, 2014; Mohan, 2017). Such fuelwood is basically sourced from either forests or open spaces. FAO stated that in 2011 about 3 billion m^3 of wood was harvested globally from forested land, and almost 50% was used as fuelwood (FAO, 2015).

In the coming years, the demand for food and cooking fuel will increase as farmers will tend to encroach on forests to expand agricultural land (Charoenratana & Shinohara, 2017). This will lead to increased competition over land for food and fuel. In the future, low and middle-income countries will alter their diets more towards meat consumption, particularly places like India (Alexander et al., 2015), where a majority of the population have traditionally had vegetarian diets (Rao et al., 2018). Bosire et al. (Bosire et al., 2015) stated that the consumption of animal products is now the major driver for land use change. Studies have been completed on the land requirement for food from a consumption perspective (Gerbens-Leenes and Nonhebel, 2005). Extensive studies have also been conducted on biomass and roundwood production potential for various purposes (Singh, 2008; Chhabra et al., 2002). However, the land requirement for cooking fuel (LRC) has not been accounted for. Keeping in mind that land is limited and demand is

Abbreviations: BEF, Biomass Expansion Factor; cap, Capita; eq., Equation; FAO, Food and Agriculture Organization of the United Nations; FSI, Forest Survey of India; g, Gram; GSVD, Growing Stock Volume Density; ha, Hectare; ICS, Improved cookstove; LPG, Liquefied Petroleum Gas; LRC, Land requirements for cooking fuel; LRC-F, LRC (fuelwood from forest); LRC-TOF, LRC (fuelwood from TOF); LRF, Land requirements for food; MAI, Mean Annual Increment; NSSO, National Sample Survey Office; t, Tonne; TOF, Trees Outside Forest; WHO, World Health Organization

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increasing, it is important to determine what proportion of land is required to produce food and cooking fuel. Joint studies on the total land required for both food and fuel have rarely been done. Such comprehensive studies are urgently required for developing nations where people rely on land for their basic sustenance (i.e. food and cooking fuel). Thus, to obtain insights in the order of magnitude in the land required for food and fuel, we assess the land requirement for the food consumed and fuelwood used by an individual from a consumption perspective. This assessment is done at the regional level. First, we determine the food intake and cooking fuel demand per capita. Ultimately, we assess the land requirement for food and for cooking fuel and compare the results.

2. Food and cooking fuel in rural India

India has the highest rural population in the world that depends on agriculture for food and solid biomass for cooking fuel (United Nations, 2014). The food diet in India is quite diversified. Rao et al. (Rao et al., 2018), stated that rural Indians have a more diversified diet, with more cereals consumption than their urban counterparts. Crop production has increased in the last 30–40 years, yet the average crop yield is much less than the global average (FAO, 2001). Rural India still practices subsistence farming, where farmers mostly produce crops and breed livestock for the household itself (Bisht et al., 2014).

Nearly 90% of the total energy consumed by households in India is used for cooking, the rest is used for lighting and heating purposes (Ranjan and Singh, 2017). Fig. 1 shows the percentage distribution of rural and urban households by the primary source of energy used for cooking. The National Sample Survey of India described in their “Energy Sources of Indian Households for Cooking and Lighting” report (NSSO, 2015) that rural households are still dependent on fuelwood for cooking and urban households on LPG. Other solid fuels like dung cake and charcoal, are also used, however, their contribution is much smaller than fuelwood (EkouevI and Tuntivate, 2011; Cheng and Urpelainen, 2014). The pie and bar graph below for rural areas show that there are inter-regional disparities in cooking fuel use. About 90% of the households in Central India use cooking fuel, but in North India about 40% of the households use fuelwood. North India has a greater variety of cooking energy source, which means that they use substantial amounts of other cooking fuels like LPG, kerosene and dung cake. The source of this fuelwood is mostly from forests or trees-outside-forest (TOF). According to a study on one Indian state (Gujarat) (Singh, 2008), the continuous extraction of fuelwood from forests directly links with the degradation rate,[1] which eventually affects the livelihoods of rural households.

The Forest Survey of India (FSI) recognizes two types of sources for fuelwood production: forests and trees-outside-forest (TOF). The FSI (FSI, India State of Forest Report, 2013), has defined the forested land as all the land which has a tree canopy density of 10% and above, over a minimum of one hectare. Trees-outside-forest (TOF) refers to the land where all trees grow outside recorded forest areas irrespective of patch size. In 2011, a total of 3.2 million m^3 of wood was produced in India, and the majority of the wood came from TOF (GAIN, 2014; Pandey, 2008). The forests and TOF area available varies from zone to zone depending upon their geographical and climatic conditions (Fig. 2). It shows that Central India has 6.7 million ha and 15 million ha of forest and TOF respectively, which makes them the highest of all the zones. Northern India has the lowest forest area (i.e. 0.9 million ha). TOF for the North-Eastern area is only 1.1 million ha, making it one of the lowest of all the zones.

[1] According to FAO, degradation rate is defined as the reduction of the capacity of a forest to provide good and services (FAO, 2011).

3. Methods and data

In this study, we divided India into six regions (i.e. North, South, East, West, Central and North-East). To assess the land requirement for food (LRF), we followed the methodology developed by Kastner et al. (Kastner and Nonhebel, 2010). This means that the data on food consumption per person and the yield per hectare were combined to determine the area needed for food for one person. For estimating the land required for cooking fuel, we used the same approach: firewood consumption per person was combined with the fuelwood production per hectare. Fig. 3 shows all the steps required in the calculation of LRC and LRF.

In the coming sections, we give a detailed description of the data collection and analytical methodologies involved in this study.

3.1. Land requirement for food (LRF)

The food diet is the end product of cooked food items consumed by one person in one year. We took an average of the food items intake for all the six regions of India (Annexure A (Table A.1)). We also estimated the calorie intake (i.e. energy intake in kcal) of a rural person on the basis of the food items consumed per day.

We used the food consumption data for rural people from the National Sample Survey Office (NSS Round 68) for the year 2011–12 (NSSO, 2014). The NSS dataset provides consumption data on the basis of a 30-day recall at the household level. We compiled 69 food items into 9 categories; namely, cereals and millets pulses and legumes, green leafy vegetables, spices, roots and tubers, fruits, oils and fats, sugar and jaggery and animal products. The food consumption data is in kg/cap/day.

The LRF per capita was estimated using methodology developed by Kastner et al. (Kastner and Nonhebel, 2010). Since this study is explicitly focused on rural consumption, to calculate the LRF we take crop yield data (Annexure B (Table B.1)) and cropping intensity (Government of India, 2015) for extensive agriculture. The calorie intake is calculated by using caloric content data from FAO (2000, 2019).

3.2. Land requirement for cooking fuel (LRC)

Fuelwood is the energy carrier for rural households that is used for cooking. Fuelwood demand data was collected from NSSO (NSS Round 68, 2011–12) (NSSO, 2014). We assembled all the data and averaged it for all the six regions. To link fuelwood demand in t/cap/yr with the land required for fuelwood use in m^2/cap/yr, we estimated the amount of biomass yield in t/ha/yr.

We considered the possibility that fuelwood was harvested from either forests or TOF. The estimation of LRC was done separately for both forest and TOF. LRC is the combination of biomass yield from forest or TOF with the individual fuelwood use. Biomass yield was calculated using the amount of annual growing stock multiplied by weight density and annual increment of the wood. The annual increase in the volume of wood grown per hectare is termed mean annual increment (MAI). We used MAI for the biomass yield so that there is no deforestation after fuelwood harvest. Growing stock volume (in m^3) and area available (in km^2) for forest and TOF for all the regions were collected from the FSI report (FSI, India State of Forest Report, 2013). The growing stock volume density (GSVD) (in m^3/ha) was calculated by dividing growing stock volume by the available area. We estimated the annual growth of trees per year for forest and TOF, by dividing GSVD by the age of the forest or TOF, respectively. Based on the study done by Bhojvaid et al. on TOF, we assumed that the standing age for TOF is 7 years (Bhojvaid and Kant, 2014). Similarly, Gautam et al. did their study on forests, where they considered the standing age of a forest to be about 35 years (Gautam and Devoe, 2006; Bhaduria and Ramakrishnan, 1991). Biomass yield refers to the dry weight of tree biomass expressed in tonnes. The aboveground biomass yield for each

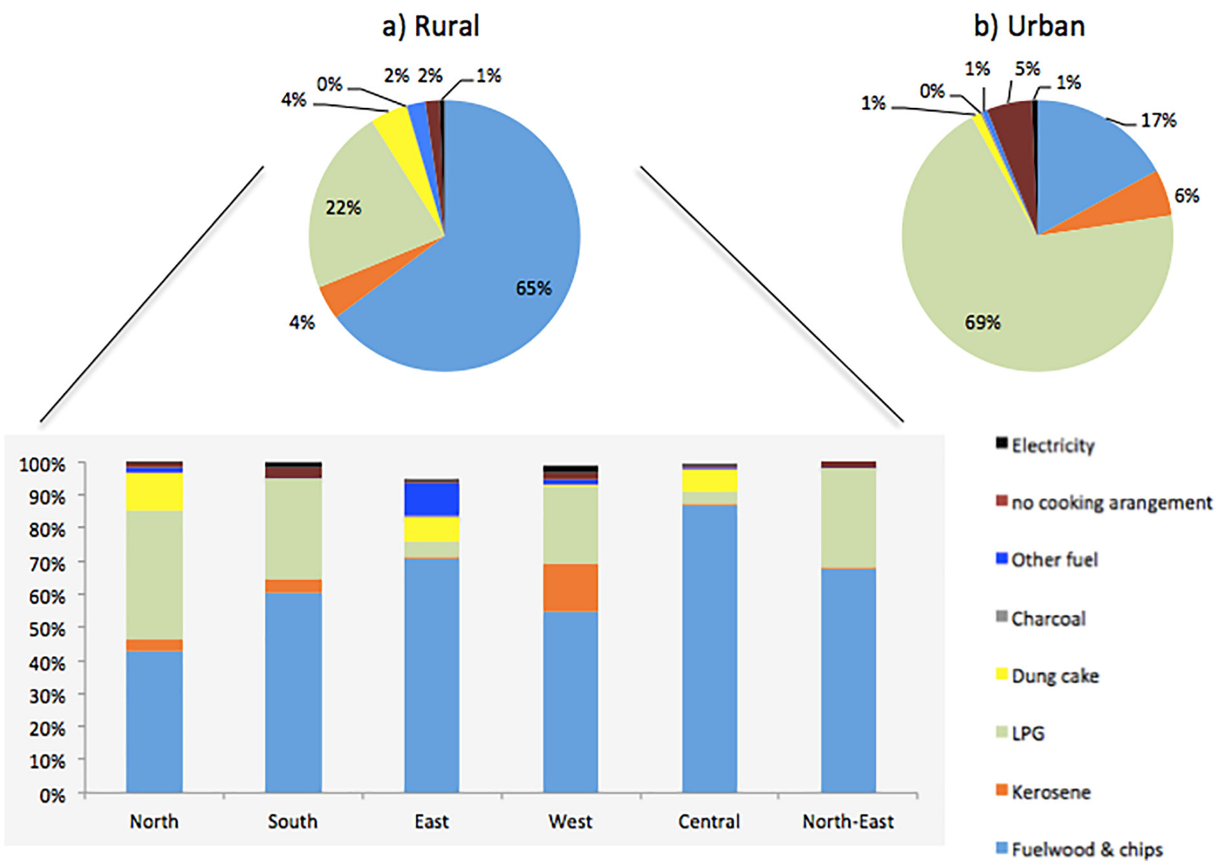

Fig. 1. Percentage distribution of households for a) rural (detailed figure is in the bar graph) and b) urban households using the primary source of cooking energy, 2011–12 (NSSO, 2015). *States divided under each zone has been given in Annexure A (Table A.1).

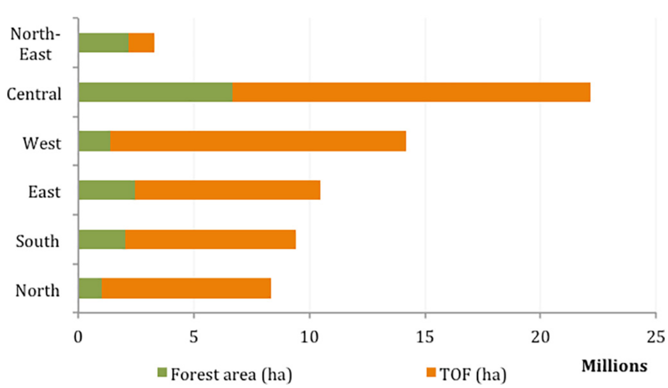

Fig. 2. Forest and Trees outside forest area in ha available in six zones of India (Forest Survey of India, 2015).

zone was calculated using MAI, the weight density of the trees and a biomass expansion factor (BEF). BEF is a factor used to convert timber volume to all biomass (Giri et al., 2014; Fang et al., 2005). It takes into account the biomass of the other aboveground components (Petersson et al., 2012; Tobin and Nieuwenhuis, 2007). BEF was subsequently multiplied by weight density to convert it from a volume to a mass. The weight density of trees varies from tree to tree and country to country (World Agroforestry Centre, 2018). We take the value for tropical trees in Asia (in t/m^3) from FAO paper (Brown, 1997a). For our study, we also included scrubland. Scrubland is the degraded forest land with a canopy density of less than 10%. In this study, we excluded mangrove areas, since we were only concerned with land area.

MAI for forested land or TOF was calculated by using the following equation:

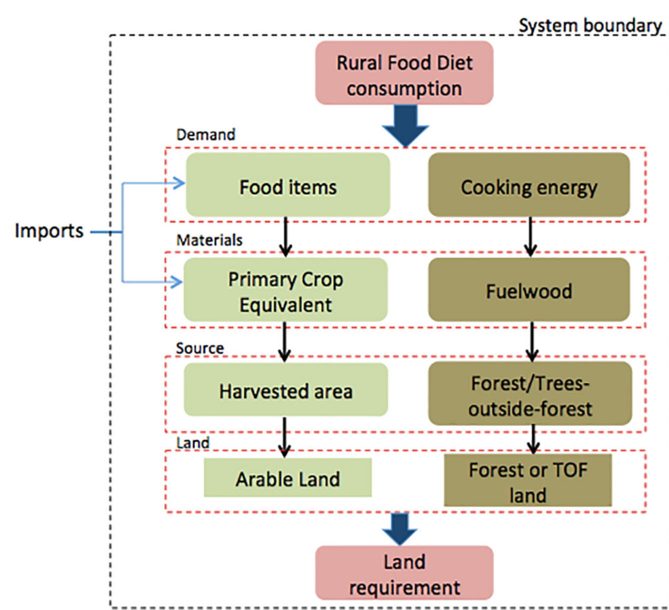

Fig. 3. A simplified flowchart showing all the steps involved in the assessment of LRF and LRC.

$$\text{MAI} = \frac{GSVD}{Forest\ or\ TOF\ standing\ age\ (in\ yrs)} \tag{1}$$

where;

$$\text{GSVD} = \text{Growing stock volume density (m}^3\text{/ha)} = \frac{Growing\ stock\ volume}{Recorded\ forest\ area}$$

3.2.1. Estimation of biomass yield from forest

The biomass yield from a forest was calculated using the following equation (Brown, 1997b; Sheikh et al., 2011; Navar, 2010);

$$\text{Biomass yield (tha} - 1\text{ yr} - 1) = \text{MAI} \times \text{WD} \times \text{BEF} \quad (2)$$

where;

WD = Vol.-weighted avg. wood density (t/m^3)

$$\text{BEF} = \text{Biomass Expansion factor} = \frac{\textit{Aboveground oven} - \textit{dry biomass of trees}}{\textit{Oven dry biomass of inventoried volume.}}$$

Finally, land demand per capita was computed by dividing the biomass yield by the level of fuelwood demand per year.

3.2.2. Estimation of biomass yield from trees outside forest (TOF)

The above-ground biomass production of trees outside forest (TOF) per year was calculated using the stock volume and the wood density (Ramesh et al., 2015; Simpson, 1993).

$$\text{Biomass yield (t)} = \text{MAI}_{\text{tof}}\ (\text{m}^3) \times \text{Wood density (t/m}^3) \quad (3)$$

Finally the land required for cooking fuel (LRC), was estimated by using the following equation:

$$\text{LRC} = \frac{\textit{Fuelwood use } (t/cap/yr)}{\textit{Biomass yield } (t/ha/yr)} \quad (4)$$

Detailed definitions of the terms are given in Annexure A (Table A.2).

4. Results

4.1. Land required for food consumption (LRF)

Fig. 4 shows the food intake, energy intake and the LRF of a rural food diet for all the six regions of India. The food consumption pattern shows large variations between the regions. In almost all the cases, cereals and millets (particularly rice and wheat) are the most consumed food items. Wheat is the staple crop of Northern India, however, moving towards East and North-East, rice becomes the staple food. The wheat intake in the North region is almost 90% higher than the North-East region (refer Annexure C (Fig. C.1)), but the rice intake is as low as 71%. Other regions (i.e. West, East, South and Central) have more a mix of rice and wheat in their diets. Cereals and millets constitute about 50% of the total food intake except in North India. It is quite interesting that 34% of total food items are animal products for North India, mainly milk and its by-products. Green leafy vegetable consumption stays almost the same for all the regions, and the same goes for pulses and legumes. Even spice consumption remains consistent for all the regional diets. The average food intake of a rural Indian is about 320 kg/cap/yr.

We found that the variation in energy intake is much less than in food intake. More than 50% of the energy comes from cereals and millets. Even though 20–30% of animal products and vegetables are consumed, the energy intake is almost negligible, since the calorie content of such foodstuffs is almost 3-fold less than cereals and millets. The average energy intake is about 1918 kcal/cap/day, but it ranges from 1768-2026 kcal/cap/day.

LRF is a combination of yield and individual food consumption. Since the consumption of cereals and millets was high, more than 50% of the land demand was due to cereals and millets. In some regions, it reached as high as 75%. Rice and wheat play an important role in the LRF of food diet across all the zones (Annexure C). Comparing, the food intake and LRF graph of Fig. C.1 (from Annexure C), it is quite interesting to find that South India has a much lower wheat intake, however, the LRF is still quite high. One of the reasons for this high LRF is very low wheat yields (0.32 t/ha) in South India (Annexure B, Table B.1). The relative LRF for pulses & legumes lies between 5-13%. However, the LRF for pulses & legumes in the North-East zone is 41 m^2/cap/yr, which is almost half that of the other zones. The total share of other food categories (i.e. green leafy vegetables, spices, roots & tubers, fruits, oil & fats and sugar & jaggery) is less than the animal products for all the zones. The absolute LRF for animal products in North India is 202 m^2/cap/yr, which is more than double the LRF for the other regions. The very high consumption of milk and its products in North India ultimately increases its LRF. The overall average LRF is about 1000 m^2/cap/yr.

4.2. Land required for cooking fuel (LRC)

Fig. 5 shows the biomass yield from forest and TOF, and the fuelwood demand of individuals from different regions of India. There is considerable variation in the biomass yield from TOF and forests between all the regions. The biomass yield depends on the MAI of the forest or TOF. We found that the biomass yield from forests is much higher than the TOF. It ranges between 30 and 80%. The reason that TOF has such a low biomass yield is because the area available for TOF is much higher with respect to the growing stock density. In the case of TOF, trees are scattered in an open area however, in forests trees are grown densely, so in a smaller area they have more biomass. The biomass yield from TOF in the North-East region is higher than the other regions.

The individual consumption of fuelwood is almost double in the North-East with respect to other regions. One of the reasons for this large amount of fuelwood use is the lack of a market for other cooking fuels like kerosene and LPG. It is interesting that the pattern in the percentage of households using fuelwood (Fig. 1) is different from the individual consumption (Fig. 5) pattern. From Fig. 1, households in Central India use more fuelwood, but the per capita consumption is highest in North-East region.

Fig. 6, shows the LRC of the different regions; when fuelwood is harvested from forests and TOF. The average LRC for an individual when fuelwood is harvested from forests (LRC−F) is about 2500 m^2/cap/yr. The LRC-TOF increases by 3-fold, when an individual opts to harvest his or her fuelwood from TOF. However, in case of North-East region the LRC-F is almost equivalent to the LRC-TOF. The biomass yield for the West and North-East regions is the same, i.e. 1.2 t/ha/yr. However, Fig. 6 shows that the LRC for North-East region is twice that of the West region. The reason behind the 2-fold increase is due to the higher fuelwood use. From Eq. (4), we can find that LRC is indirectly proportional to the biomass yield. Fig. 5, shows that biomass yield is less in the case of TOF, thus there is an increase in land requirement with the same fuelwood demand.

4.3. Total land required for food and cooking fuel

The total land required, by combining for both food and fuelwood, is shown in Fig. 7. It is comparatively high for fuelwood harvested from TOF than from forests. However, the final outcome is, whether the fuelwood is harvested from forests or TOF, fuelwood consumption leads to higher land requirements.

5. Discussion

This study provides a comparison of the land required for food and cooking fuel in rural India. It gives an insight to the magnitude of amount of land required from a consumption perspective.

Land required for food (LRF) and land required for cooking fuel (LRC)

The methods used in this study for both food and fuelwood followed the same procedure. We combined the yield and the individual consumption values to assess the land requirement. The average LRF of a rural Indian is about 985 m^2/cap/yr (≈1000 m^2/cap/yr). The results

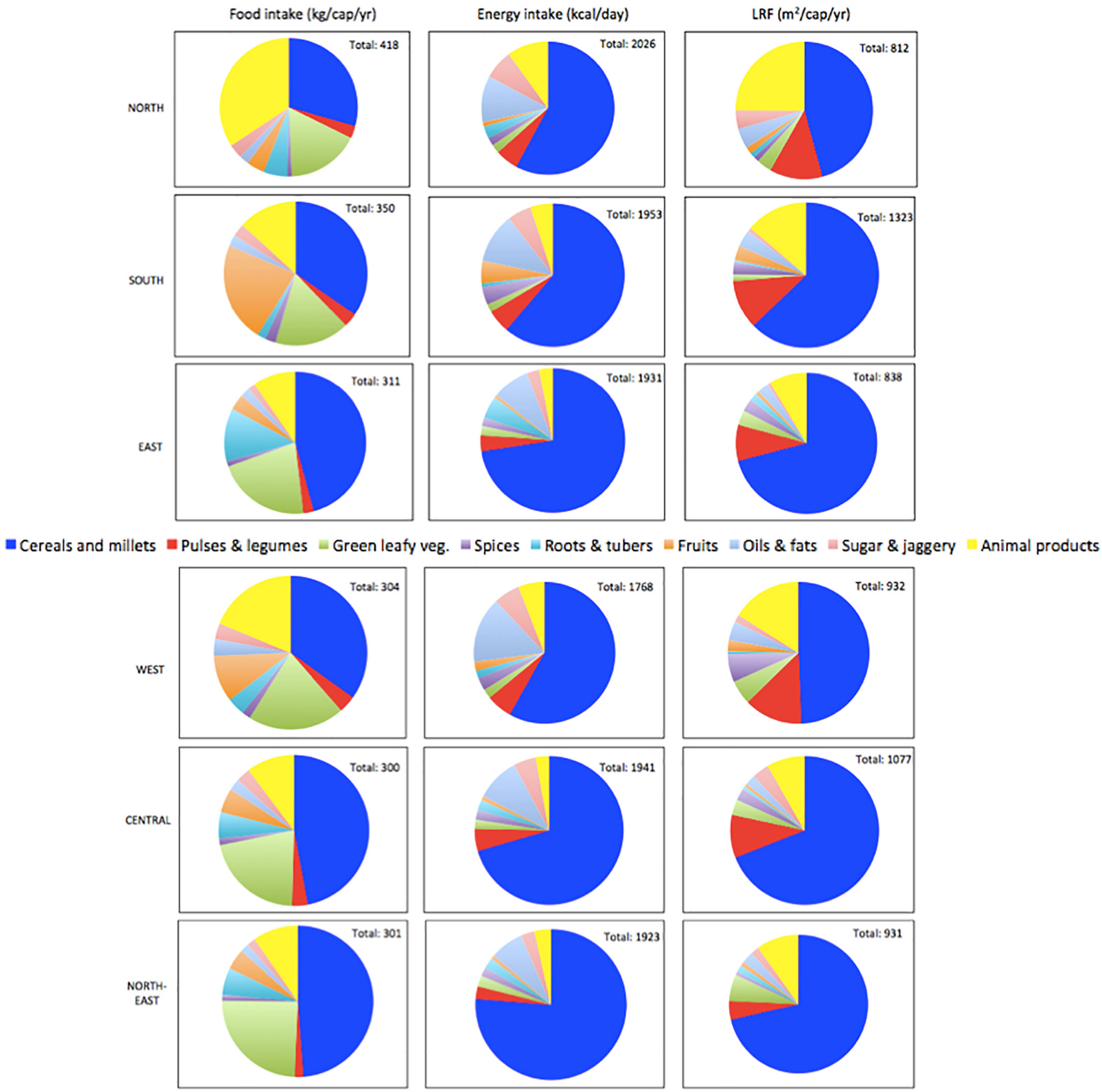

Fig. 4. Relative representation of food intake, energy intake and the land requirement for the different groups of food items consumed by a rural person from six zones of India.

also show variation among the regions. The 1000 m^2 for food that was calculated in this study is significantly (about 40%) lower than other studies for this region. The explanation for this can be found in the very low food consumption (1918 kcal/cap/day) that was found in the survey. Other studies used food consumption values of 2500 kcal/cap/day. Further, in such studies the consumption of animal products was far higher than in the survey used here. So, our value of 1000 m^2/cap/yr can be considered as the minimum area needed to feed one person (food at the starvation level). It is worrying that the arable land available per person in India is only 1200 m^2, so there is not much room for improvement of the food supply.

We found that the LRC is very high with respect to LRF. Due to the paucity of studies on LRC, in order to validate our calculation we compared it with the biomass yield data from other studies. The average biomass yield for forests is about 1.32 t/ha/yr and for TOF is 0.47 t/ha/yr, which is similar to the biomass yield given by FAO for Asia (The Ministry of Environment and Forests, 2009). According to the World Bank, the per capita forest available in India is about 640 m^2/cap/yr (The World Bank, 2018a), and we found that a rural Indian requires about 2507 m^2/cap/yr to produce fuelwood for cooking. This study indicates that there is already demand for more forested land. Other studies revealed that rural populations would still depend on biomass for cooking (Arnold et al., 2003). FAO has indicated that there is an ongoing competition for land and food security (FAO, 2008). Thus, with rising population and demand, there is a possibility that, to meet cooking fuel demands, rural households could convert agricultural land

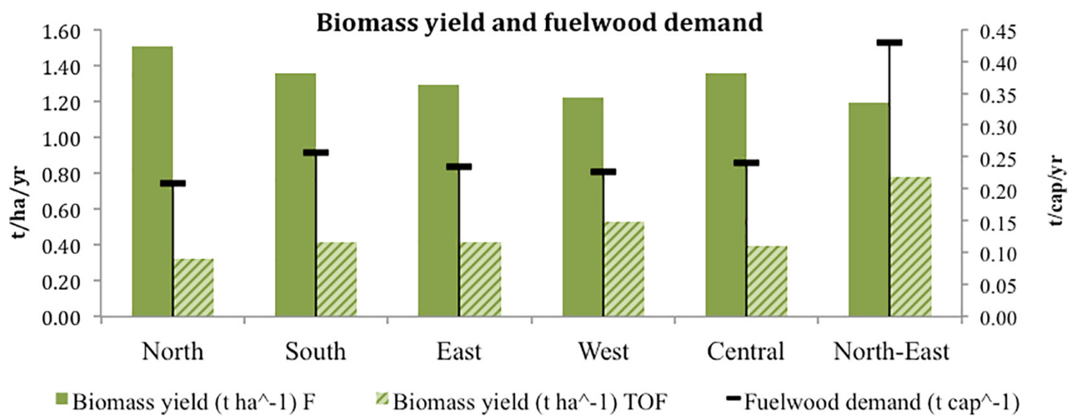

Fig. 5. Biomass yield from TOF and forest (in t/ha/yr) and individual fuelwood demand region-wise (in t/cap/yr).

to forested land (The World Bank, 2018b; Aayog, 2017; The World Bank, 2018c). Our estimate for LRC-F and LRC-TOF are based on the annual growth of the forest or TOF (i.e. MAI). The main reason behind using MAI is to avoid deforestation. Otherwise, complete harvests of roundwood from forests or TOF could eventually decrease the LRC. The TOF are considered naturally grown for this study, i.e. there is no plantation method. However, for Indian forests and TOF, there is a scope of plantation for higher yield of wood (FSI, India State of Forest Report, 2013). A Eucalyptus can produce biomass of about 2.5 t/ha/yr (i.e. more yield). So, if we chose to use all the TOF area available for wood production, then the average LRC will be 1100 m^2/cap/yr, which almost 6 times less than LRC-TOF.

We know that this is an exploratory study comparing the land requirement for food and cooking fuel for a rural diet. We have excluded some factors like the type of land used for producing animal feed, different post-harvest loss and small shrubs in TOF areas. Even if we had opted to include these factors, there would still have been more input assumptions, making the study more complex and yet negligibly affecting the results. This is because our study area, the rural Indian population, has a low animal product intake and they mostly do subsistence farming, which minimizes their post-harvest loss.

Our findings should be read as an insight into the magnitude of land required for food and cooking fuel for a rural diet and not reduced to its absolute values. Fig. 1 showed that, other than fuelwood, there are other cooking fuels (like cow dung etc.) which are being used in very small quantities (about 4–10%). There might be situations where households use fuelwood for heating, however in the survey data they used it for cooking. Moreover, in most cases households uses heating as a side activity, whilst cooking. However, after fuelwood, households mostly use kerosene and LPG. They are energy intensive as well as having a lower land footprint than biomass. Global Land Outlook suggested in their study that other efficient cooking fuel, normally non-renewable energy (i.e. kerosene and LPG), has a land footprint of 0.1–1 m^2/MWh, but the biomass land footprint can be as high as 1000 m^2/MWh (Global Land Outlook, 2017).

Cheng et al. (Cheng and Urpelainen, 2014) established that, even though rural Indian households use LPG, they do not replace fuelwood. Therefore, the better option to decrease the LRC is by using an improved cookstove (ICS), which can decrease the fuelwood use by 3-fold (Das et al., 2018).

Finally, we can conclude that many studies have so far been completed on land required for food in all regions in the world. These studies mention that the availability of arable land in the world will become a major problem. In this paper, we show that in rural areas arable land is not the issue but the forested land that is needed for cooking fuel. The situation in India characterized here is typical for all rural areas where land required for cooking fuel is far larger than the land required for food.

6. Conclusions

This study gives an insight into the land requirement for food and cooking fuel from a consumption perspective and its variation among the regions. Even though there are various food items in an individual diet, the main component is the staple food (e.g. rice or wheat). It is the principal provider of energy intake in humans, as well as being a major contributor to the LRF. The average LRF for rural people in India is about 1000 m^2/cap/yr. However, the LRC is almost doubled if fuelwood is from forests, and almost 6 times when harvested from TOF. This study concludes that fuelwood requires far more land than that for

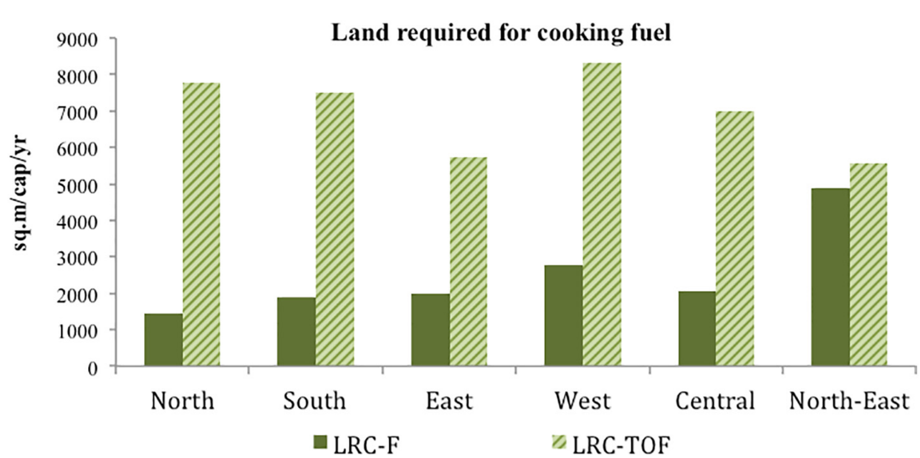

Fig. 6. Land required for cooking fuel (LRC) for all the five regions of India.

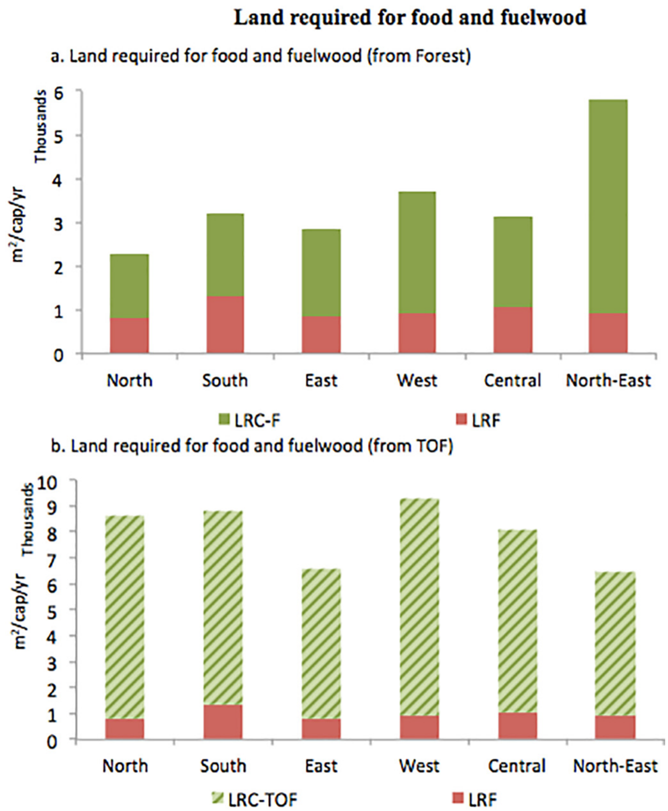

Fig. 7. Total land required for food and cooking fuel (a) Fuelwood from forest, and (b) Fuelwood from TOF.

food consumption. It implies that efficient cooking fuel, which requires less land, should be introduced to the rural population.

Declaration of Competing Interest

None

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2019.102682.

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