# Bioenergy and Food Security: Indian Context

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## ABSTRACT

Bioenergy is the subject of increasing attention around the world and represents a controversial issue. The rise of commodities prices, the negative impact on food security, and climate change represent different challenges to be overcome before the full potential of bioenergy can be realized. In the context of the development of bioenergy, issues relating to agriculture need special attention. Bioenergy development is always linked with food security. Farmers, having the choice to convert their food crops to fuels crops, naturally expect a high return from their farmland, thereby generating a scenario where food production gets depleted. The case study reported in this article is of a typical district from India (Tumkur) and shows that optimal production of bioenergy can be generated by using the wasteland present in the area. This way, food security for the future generation can be maintained along with optimal growth of bioenergy.

**Keywords**: bioenergy; decentralized energy planning; food security

## INTRODUCTION

Adequate and reliable access to food and fuel energy is essential for societal development and the alleviation of poverty through provision of sufficient nutrition and income to satisfy health and other needs (1, 2). In India, approximately 70 percent of the population, over 700 million people, depends on agriculture, which can thus be considered one of the main economic drivers (3-5).

The report of the Intergovernmental Panel on Climate Change (IPCC) and several expositions concurring with its findings, such as the Stern Review on the Economics of Climate Change, led to a search for substitutes for fossil fuels (6). Bioenergy constitutes one of the major substitutes for fossil fuels. The term refers to the energy of biological systems such as wood and wastes. It is an indirect form of solar energy, because it arises due to photosynthesis. Bioenergy is the subject of increasing attention around the world and represents a controversial issue, since it may offer new opportunities for sustainable development but, on the other hand, also carries significant risks.

The driving forces behind bioenergy development include not only its ability to compete with petroleum prices but also its potential capacity to reduce global green house gas emissions and to enhance farmers' income. Therefore, biofuels may have potential benefits, such as diversification of agriculture output and domestic energy supply, development of infrastructures and job creation in rural areas, and generation of new revenues from the use of wood and agriculture residues and from carbon credits.

Energy economists the world over agree that the potential of biofuels is indeed high; in the future mix, biofuels will play a major role. The economic and social issues relating to the development of biofuels are also important.

The experience of Brazil is indeed impressive. Following the oil crisis in the 1970s, the Brazilians undertook a broad initiative; they shifted a major portion of their petroleum use to bioethanol and thus saved a large amount in their oil bills (7), besides creating numerous jobs.

A large, populous, and developing country such as India must adopt an integrated strategy to meet the growing energy need, because Indian national economics suffer much on account of increasing oil prices. In the semi-arid regions of India (8), a large chunk of the population of 400 million people is dependent on low-producing, dry land agriculture for food, fodder, and fuel (9). A 2001 survey on the diet and nutritional status of these rural populations indicated that, across all age and physiological groups, the consumption of almost all foods was below the recommended daily intake as set out by the government of India (10). This suggests that inadequate production and/or retention of food within the villages may be occurring (11). This problem is compounded by a parallel requirement to produce additional biomass as a source of fodder for livestock and the energy used primarily for preparation of food. The prevailing form of agriculture in India involves complex, mixed cropping/livestock systems, and this integration of crop and livestock production is particularly common in small-scale farming in rain-fed areas of rural India (12-14). The main concern is that these dominant biomass needs should not compete for land, given the high human and livestock population densities in India. The present work analyzes the question as to whether there is any negative impact from bioenergy generation in rural India. A decentralized energy-planning model is developed for Tumkur district to implement optimal bioenergy production and thereby predict the impact of bioenergy generation on food security.

## DECENTRALIZED ENERGY PLANNING FOR BIOENERGY

The current pattern of commercial, energy-oriented development, particularly focused on fossil fuels and centralized electricity, has resulted in inequities, external debt, and environmental degradation. For example, large proportions of the rural population and urban poor continue to depend on low-quality energy sources and inefficient devices, leading to a low quality of life. The current status is largely a result of the adoption of centralized energy planning, which ignores the energy needs of rural and poor areas and has led to environmental degradation, due to fossil fuel consumption, forest degradation, and large hydroelectric projects. Thus, there is a need for:

- An alternate approach to planning, i.e. a decentralized planning approach (DEP)

- A shift to renewable energy sources to sustain economic development

Decentralized planning involves scaling down energy planning to sub-national or regional scales. Energy planning at the village level is the lowest level of application of a decentralized planning principle, and district planning is considered the uppermost level.

An integrated four-level (village-panchayat-block-district) computer model for rural energy planning was developed for Tumkur district, located in the eastern belt of the eastern half of the Karnataka state; the district has ten blocks (talukas) and has an area of 10,598 $km^2$. The satellite survey results of the National Remote Sensing Agency, Hyderabad, show that Tumkur's area under wasteland is 2,227,000 ha, which accounts for 26 percent of the district's area, highlighting the importance for initiating a planned program to reclaim the degraded lands. Wasteland is described as degraded land that is currently underutilized and deteriorating for lack of appropriate water and land management systems. Wasteland can result from inherent/imposed disabilities such as location, environment, chemical and physical properties of the soil, or financial and management constraints. Such land can be brought under vegetative cover with reasonable effort over a period of time. The guiding principles for wasteland development are biomass production and reduced soil erosion, as well as soil and moisture conservation for sustained productive uses. The scale of analysis included village level, Ungra; panchayat (local council) level, Yedavani; block level, Kunigal; and district level, Tumkur. The objective of these models was to explore an optimal mix to match the demand and supply for energy. The approach adopted was bottom-up (village to district) rather than top-down, to allow a detailed description of energy services and the resulting demand for energy forms and supply technologies. The time horizon included medium-term energy planning for the year 2020.

A business as usual scenario (BAU), economic objective scenario (EOS), renewable energy scenario (RES), and sustainable development scenario (SDS) were each developed and analyzed for the year 2020 in DEP modeling. The BAU scenario is based on the direction in which the selected location is headed. Assuming continued moderate economic growth, an energy consumption pattern, and modest technological improvement, this scenario leads to adverse environmental impacts ranging from regional acidification to climate change. Thus, this scenario leads to a higher dependence on carbon-intensive fossil fuels, resulting in high energy-related emissions, and falls short of achieving a transition towards sustainable development. Energy cost objective is given the highest priority in the EOS scenario. Employment, efficiency, and reliability objectives are given low priority. Government subsidy for agricultural water pumping and grid electricity for rural households is assumed to continue in the year 2020. The RES scenario is characterized by sustainable development and a shift towards environmentally benign energy technologies, with a significant role for renewables. Renewable system efficiency is assumed to increase by 25 percent by 2020; this scenario highlights the implication of renewable energy for future energy supply trends. The SDS scenario includes services that promote equity and quality of life, based on locally available, convenient, safe, environmentally sound, and sustainable technologies. Energy demand for 2020 is projected based on base year consumption data. The population for the year 2020 is estimated directly from the population growth rate. Livestock population is calculated based on the cattle to human population ratio.

DEP modeling included 56 energy end-use combinations covering all energy needs, all technological options, and different numbers of end-use combinations to optimally meet the energy needs of Tumkur district. Decentralized bioenergy systems for producing biogas and electricity, using local biomass resources, are shown to promote development, compared to other renewables. This is because, apart from meeting energy needs, multiple goals could be achieved, such as self-reliance, local employment, and land reclamation—apart from $CO_2$ emissions reduction. Analysis of the bioenergy potential shows that it is possible to meet cooking energy needs using biogas from cattle dung and leaflitter, and electricity needs of lighting and shaft power using the "energy forest/producer gas" option. The potential for biomass based kW/MW scale power generating systems was explored, and the feasibility and large potential is shown, especially for electricity generation.

## RESULTS AND DISCUSSION

Tumkur district was selected for a detailed analysis with an objective of meeting the energy needs at four different scales: Ungra (village), Yedavani (panchayat), Kunigal (block), and Tumkur (district) by adopting multiple scenarios.

The results of DEP analysis presented in the previous sections show that under RES and SDS scenarios, locally available and sustainable biomass (wood, leaflitter, and cattle waste) is the dominant source of energy. The bioenergy technology options considered were biomass gasification and biogas for meeting electricity and heat energy requirements. This section explains different bioenergy options for cooking and for biomass powered electricity generation to meet the energy needs from village to district level.

**Biogas options**

The two biogas end-use options considered for meeting the energy needs are cooking and power generation. Both these technologies have been developed indigenously and are available off the shelf. Biogas dual-fuel systems based on dung as the feedstock for power generation, as well as biogas plants for cooking, have already been implemented in villages (15, 16).

*Cattle Dung Biogas Electricity*

Biogas is a clean fuel and can be used in internal combustion engines directly or used to generate electricity by coupling a dual-fuel engine to a generator. Over 90 percent diesel substitution is possible; even full operation on biogas is also feasible. Community biogas is the only technically feasible option for power generation in villages. Pura village in Tumkur district showed that it is not feasible to have several biogas-based power generation systems attached to several small biogas plants (15). Based on the cattle dung available at the community level, the electricity generated is adequate for meeting the energy needs of lighting in Ungra village when the efficient scenario is adopted. However, the power generated using biogas is only adequate for meeting the minimal baseload requirements. Biogas available based on dung resource is not feasible at the panchayat level, block level, or district level, due to limited dung resource and complexities involved in transporting dung and piping biogas across villages.

*Installed Capacity for Biogas Power*

First, biogas potentially available from the quantity of dung and leaflitter feedstock (barring minor seasonal variations) is calculated. Second, the power generation capacity, as well as the number of hours of power generation, is determined by using the quantity of biogas production/day. Scheduling of the baseload activities, as shown in Table 1, may be necessary to minimize the installed capacity by distributing the activities at different periods in the day.

Ungra village would require an electricity supply for a minimum period of 10 hours/day for the critical baseload activities. The potential for installed capacity, assuming 10 hours of electricity supply per day, is 13-42 kW (as seen in Table 1). Thus, the electricity requirement for appliances, irrigation water pumping, and rural industries cannot be met from a biogas electricity option. This option is not considered, since the dung resource available is limited. The biogas option considered is largely for cooking, which is the dominant energy-consuming activity, even if alternate feedstocks are available.

**Table 1. Biogas for power generation at Ungra village scale, assuming a community biogas system with cattle dung plus leaflitter**

| Scenarios | Electricity generation potential[a] | | Installed capacity at 10h/day of operation (kW) from biogas power option | Installed capacity to meet all energy needs (kW)[d] |
|---|---|---|---|---|
| | Biogas(cubic meter/day) | Biogas(kWh/day) | | |
| BAU[b] | 95 | 127 | 13 | 85 |
| SDS[c] | 316 | 421 | 42 | 60 |

[a]Electricity generation potential is estimated by using the biogas production/day and 0.75 $m^3$ of biogas/kWh.
[b]Biogas production only from cattle dung
[c]This scenario considers biogas production from cattle dung plus leaflitter available from energy plantation; biogas production from fresh leaf biomass =60 l/kg fresh leaves (20).
[d]Based on calculations made for the year 2020

*Biogas Potential for Meeting Cooking and Water-heating Energy Requirements*

Biogas can be used as a convenient cooking and even water-heating fuel. Since cooking is the dominant energy-using activity in rural areas, there is a need to meet its energy requirements on a priority basis. Though the biogas-generation potential from available dung is inadequate to meet all the cooking fuel needs of a village, a large potential exists for increasing biogas generation using alternative feedstock (such as leaflitter or crop residue not used as cattle fodder) and by increasing gas yields per kg of dung by technological developments (such as increasing the temperature of the slurry in the digester). Thus, all the biogas potential could be used for meeting the energy requirement of cooking first, with any surplus for water heating. This fuel option improves the quality of life of rural women, as gaseous fuel is convenient for cooking. Table 2 presents the biogas potential available at the village, panchayat, block, and district level for the year 2020.

*Community and Individual Biogas Systems for Cooking and Water Heating*

To estimate the potential of biogas, community level systems are considered rather than individual family or family-scale systems for the following reasons:

**Table 2. Biogas potential from cattle dung and leaflitter (from energy plantation) for meeting the cooking energy requirements for the year 2020 (land area under energy plantation estimated assuming a wood productivity of 8 t/ha/year)**

| | Ungra village | Yedavani panchayat | Kunigal block | Tumkur district |
|---|---|---|---|---|
| Human Population (2020) | 1353 | 9230 | 316,949 | 2,782,900 |
| Biogas potential of cattle dung ($m^3$/day) | 95 | 882 | 45,370 | 272,361 |
| Land proposed for energy forest for producer gas electricity (@8 t/ha/year) ha | 20 | 727 | 8261 | 138,713 |
| Leaf harvest potential of land under energy forest [a] in t/year(fresh) | 640 | 19,400 | 220,291 | 3,699,020 |
| Biogas from leaflitter [a] ($m^3$/day) | 220 | 1375 | 36,018 | 1,120,966 |
| Total biogas from leaf biomass from energy forest +dung ($m^3$/day)[b] | 315 | 2257 | 81,388 | 1,393,326 |
| Saving in biomass (mainly wood) if all the biogas potential is used for cooking and water heating (t/yr) | 457 | 6480 | 220,000 | 1,950,000 |
| % population whose cooking energy needs can be met from biogas from dung + leaf biomass[c] | 100 | 100 | 100 | 100 |

[a]Leaflitter productivity dry t/ha/year, leaf biomass harvest potential = mean yield of 8 dry t/ha/year or 30 fresh t/ha/year. Two-thirds of 8 dry t/ha/year (= 5.3 t/ha/year) is taken as available for biogasification (21). This scenario considers biogas production from cattle dung and leaflitter; 32 ha of wasteland is used for energy plantation; biogas production from fresh leaf biomass = 60 l/kg fresh leaves (20).

[b]Total biogas for SDS (example: Ungra village is 95 $m^3$/day from dung + 220 $m^3$/day from leaf and litter = 315$m^3$/day).

[c]Biogas requirement = 200 l/capita/day for cooking.

- To obtain economy of scale
- To share facilities such as a biogas digester, storage drums, sheds, civil structures, etc.
- Many households may have fewer cattle than required for individual systems.

It can be observed that 100 percent of energy needs for cooking can be met by biogas from cattle dung plus leaflitter. It is important to note that biogas systems are feasible at the village scale only, at best, with an adjacent village. Panchayat, block, or district-scale biogas systems are not feasible, due to problems associated with transporting dung, low density leaflitter, storing a large volume of gas, and transporting gas across villages.

**Biomass Required for Power Generation**

A biomass gasifier-based power generation system is one of the feasible options. The technology is readily available and has already been field tested (17, 18). Biomass gasifier systems are available in India as biomass + diesel dual-fuel systems and pure-producer gas engines. Gasifiers are available at a few kW to a few MW scales. The wood required per kWh of electricity ranges from 1.0 to 1.30 kg.

*Producer Gas Electricity Option*

The dominant power-requiring service in villages is pumping of irrigation water. The producer gas electricity option could be considered at two levels:

- Use of biogas electricity for meeting the baseload requirement of services such as lighting, domestic water pumping, and (in some villages) flour milling, while the power requirement of the remaining services could be met from producer gas.
- Producer gas electricity alone could be considered for meeting all the electricity requirements of all the services, thereby keeping the biogas option for other services, particularly cooking.

**Biomass Production/Availability**

In countries with high population densities such as India, the argument against biomass gasifiers is that land may not be available for biomass production. Thus, in this section the potential for the conservation of currently used biomass for cooking through biogas and improved stoves, as well as land availability for sustainable biomass feedstock production, is presented.

*Land Required for Wood Production*

Wood from growing trees in dedicated energy forests is considered the feedstock for the gasifier in the estimation of the land area required for the year 2020 at Ungra village, Yedavani panchayat, Kunigal block, and Tumkur district.

*Ungra Village*

Total woody biomass required for meeting all the projected electricity needs through biomass gasification is 162 (SDS) to 291 (BAU) t/year. The potential for biomass conservation is 457 tons, using the biogas and efficient stove options given in the Table 3. Thus, the savings that could be achieved is more than adequate to supply wood for decentralized power generation at the Ungra village level. However, if all the 162 tons of wood required under SDS has to be grown separately, the land required is 40 ha, at a productivity of 4 t/ha/year, and 14 ha at a productivity of 12t/ha/year, as shown in Table 3.

**Table 3. Combined wood and land required for energy forest at village, panchayat, block, and district levels under BAU and SDS scenarios for biomass power generation**

| Requirements | Ungra | | Yedavani | | Kunigal | | Tumkur | |
|---|---|---|---|---|---|---|---|---|
| | BAU | SDS | BAU | SDS | BAU | SDS | BAU | SDS |
| Electricity power requirement in MWh | 224 | 125 | 5380 | 4476 | 111,400 | 66,000 | 1,150,000 | 1,109,000 |
| Capacity to be installed (kW)[a] | 70 | 50 | 955 | 766 | 19,000 | 11,300 | 197,000 | 190,000 |
| Installed Capacity required with power factor of 80% load (kW)[b] | 85 | 60 | 1150 | 920 | 23,000 | 13,500 | 236,000 | 228,000 |
| Wood and Land required (ha) at productivity | | | | | | | | |
| Wood required at 1.3 kg/kWh at 18% efficiency (t/year) | 291 | 162 | 6994 | 5819 | 111,476 | 66,087 | 1,565,350 | 1,109,706 |
| Biomass conservation potential by adopting SDS scenarios for Ungra village , Yedavani panchayat, Kunigal block and Tumkur district are 457t, 6480 t , 250,000 t and 1,950,000 t of fuelwood | | | | | | | | |
| Total geographical area for Ungra village, Yedavani panchayat, Kunigal block and Tumkur district are 362 ha, 3674 ha, 91266 ha and 1,180,000 M ha<br>Total wasteland area for Ungra village, Yedavani panchayat, Kunigal block and Tumkur district are 89 ha, 1354 ha, 30599 ha and 300,000 Mha. | | | | | | | | |
| Biomass productivity | Land area required | | | | | | | |
| 4 t/ha/year | 73 | 41 | 1749 | 1455 | 27869 | 16522 | 391,338 | 277,426 |
| 6 t/ha/year | 49 | 32 | 1166 | 970 | 18579 | 11015 | 260,892 | 184,951 |
| 8 t/ha/year | 36 | 20 | 874 | 727 | 13935 | 8261 | 195,669 | 138,713 |
| 12 t/ha/year | 24 | 14 | 583 | 485 | 9290 | 5507 | 130,446 | 92,475 |

[a]It depends on the number of irrigation pumps and capacity of the pumps (5 kW) and assuming only one fourth of the pumps have to be operational simultaneously. (Example: in Ungra, assuming the total requirements of 56 pumps in the year 2020, the installed power generation required would be 70 kW).

[b]Installed capacity consisting of a power factor of (0.8); for Ungra the actual capacity is 85 kW assuming 80 percent of rated capacity° (70kW + 20 percent of 70kW – rounded to 85 kW).

*Yedavani Panchayat*

The biomass fuel conservation potential through the adoption of biogas and efficient stove options ranges from 5819 (SDS) to 6,994 (BAU) tons/year (Table 3), compared to 5,819 tons of wood fuel required per year for the projected power generation. Thus, the biomass fuel that could be conserved is more than adequate to meet the wood requirement for power generation. However, as shown in Table 3, the land required if all the wood required has to be grown at a productivity of 4t/ha/year is 1455 ha, compared to the wasteland area of 1354 ha.

*Kunigal Block*

Under SDS, the wood requirement of 66,089 t/year required for gasification to meet all the projected electricity needs (66 GWh) of the rural population of Kunigal block could be compared with the likely biomass fuel conservation potential of 0.22 Mt/year (Table 3). However, to grow wood in dedicated plantation for power generation, the land required would be 16,522 ha, at a conservative wood productivity of 4t/ha/year, compared to wasteland area of 30599 ha. The analysis in Table 3 clearly shows that by adopting biomass conservation technologies such as biogas and improved stoves, adequate biomass could be saved to meet the biomass feedstock requirement for power generation and meet all the energy needs of Kunigal block level. Thus, there may not be any need to dedicate land for production of wood for electricity generation.

*Tumkur District*

The wood requirement of 1.55 Mt/year for biomass power generation to meet all the projected power needs of the rural population in Tumkur district should be compared with the likely biomass fuel conservation potential of 1.95 Mt/year. However, if there is a need to grow wood separately for power generation, the land required would be 277,426 ha, at a conservative wood productivity of 4t/ha/year. There is no need to depend only on the conservation route, as the land required for growing biomass feedstock is available.

The analysis presented in Table 3 clearly shows that, firstly, all the biomass feedstock required at all the four scales, from village to district, can be obtained from biomass conserved by shifting to biogas. Further, if all or part of the woody biomass has to be produced from dedicated energy forests, adequate wastelands are available at moderate biomass productivity (6 to 8 t/ha/year). Thus, there is no need to convert cropland to energy forests and no competition between food and fuel.

Assuming a conservative conversion efficiency of 18 percent and 1.3 t (wood)/MWh, the wood required for operating 1MW unit for 16 h/day or 5840 hr/year would be 7592 t/year. The land required per megawatt would be in the range of 1000-2000 ha (rounded from 949-1898 ha), at productivities of 8 to 4 t/ha/year, respectively. If the conversion efficiency is doubled to, say 35-40 percent using advance systems, the land required would be halved to 500 and 1000ha/MW at productivities of 8 to 4 t/ha/year, respectively. A higher biomass productivity of 8t/ha/year could be considered, since the power generation utility managing the multi-megawatt scale system is expected to provide technology packages for higher woody biomass productivity.

Thus, large extents of degraded land, or wastelands, are available for raising energy plantations. These lands are generally subjected to overgrazing, and soil erosion, thus needing to be protected from further degradation. Only 6 to 12 percent of such available degraded lands in Kunigal and Tumkur are adequate for growing the biomass feedstock needs of decentralized power generation systems in a sustainable way. Investment required for raising biomass energy plantations could be obtained from biomass power utilities. Farmers could also be given incentives to dedicate a fraction of their land (mainly degraded patches) to tree culture for biomass power to meet their water pumping requirements. A farmer needs to dedicate 2400 $m^2$ of land at a productivity of 6t/ha/year to operate 3.7 kW biomass gasifier systems for 300 h/year. Even the land area under the cropland boundary (occupying an area of 3 to 10 percent of the holding) could be used for growing trees (19). The land area to be dedicated for energy plantation could be reduced by further increasing the wood productivity, as wel1 as using many woody crop residues to substitute for fuel wood. Only a fraction of degraded cropland and non-cropland owned by farmers needs to be used for growing wood for power generation. Thus, individuals could also grow the biomass feedstock required.

Rural communities have diverse biomass needs—firewood for cooking, grass or leaves for fodder, leaves for manure, trunk for timber, etc. However, only small branches or sticks are required for the gasifier. Large tree trunks cannot be used in gasifiers. The leaves, fruits, seeds, and large tree trunk would be available for meeting other community biomass needs. The total land required for Kunigal block and Tumkur district for biomass power generation to meet rural energy needs requires only 27 to 45 percent of total wasteland area. A shift to biogas and efficient stoves for cooking could lead to a large reduction in demand for biomass fuel, further reducing the area required to be dedicated for power generation. Grass production from the energy forest would be available as fodder. Thus, there need not be any competition for land for growing wood for power generation and for meeting other rural biomass or food grain needs.

## CONCLUSION

A large, populous, and developing country such as India must adopt an integrated strategy to meet the growing food, fodder, fuel, and timber requirement. When the wastelands are used for energy forests, carbon sequestration will occur in soil, as well as in standing trees, and sustainable harvesting will ensure a constant stock of biomass in the forests. Thus, raising energy forests on wasteland could be an attractive carbon sequestration project with potential for carbon revenue. Further, a shift from fuel wood to biogas would lead to a reduction in pressure on trees and forests, thereby reducing emission of $CO_2$ from burning wood from a non-sustainable source.

The present work concludes that use of biomass-based energy systems is proposed to meet all the energy needs from village to district level. Biogas and biomass power systems reduce the drudgery and increase the productivity of human labor. The additional biomass required for the new systems, such as biogasifier and biogas generation, is already available in the form of savings resulting from shifting to the more efficient devices. This is more than adequate to meet the growing demand. It is also possible to augment biomass production by (a) growing fuel-fodder-fertilizer plantations in the wastelands, which comprise about 12 percent of ecosystem land (for Tumkur district at productivity of 8t/ha/year), for the present as well as future energy needs, and (b) increasing cropping intensity and productivity, a potential which is already possible. A large potential exists for generating biogas by using the presently unutilized leaflitter and other plant wastes. Biomass-based energy options also lead to self reliance, local participation, local control, and creation of skills in rural areas. A detailed analysis of strategies for food, fodder, fuel, and timber for India is beyond the scope of this research work. However based on the analysis made by Ravindranath and Chanakya (20), TERI (http://www.teriin.org/), and the Planning Commission Report (http://planningcommission.nic.in/reports/genrep/ar0405.pdf), we summarize the arguments to show that land is not a constraint for bio-energy options. The area under crops has stabilized at around 140-143 Mha from 1970 to 2001 (shown in Figure 1), and the degraded land estimates vary from 66 Mha to 130 Mha.

According to a projection by a working group set up by the planning commission of India, the demand for food grains for a population of 1.3 billion is projected to be 270 Mt by 2020 (http://www.vision-2020india.org/). The projected food grain requirement of 270-300 Mt can be achieved by increasing the food grain yield from the current 1.64 t/ha in 2000-2001 to 2.3 t/ha, using the 127.5 Mha (2001) of land currently under food grains. In fact, there is potential to at least double food grain productivity to the range of 3-4 t/ha with expansion of irrigation, multiple cropping, and modern cultivation practices. Thus, it is possible to meet the food grain requirement of the growing population without increasing the cropped area. Increased irrigation and cropping intensity, leading to an increased area under cereals, will lead to a corresponding increase in fodder production as a by-product. The grass productivity of pasture or village commons or degraded forest lands is very low. Sudha et al. (19) have shown that through mixed forestry of appropriate density, for bioenergy, the grass production from the cur-

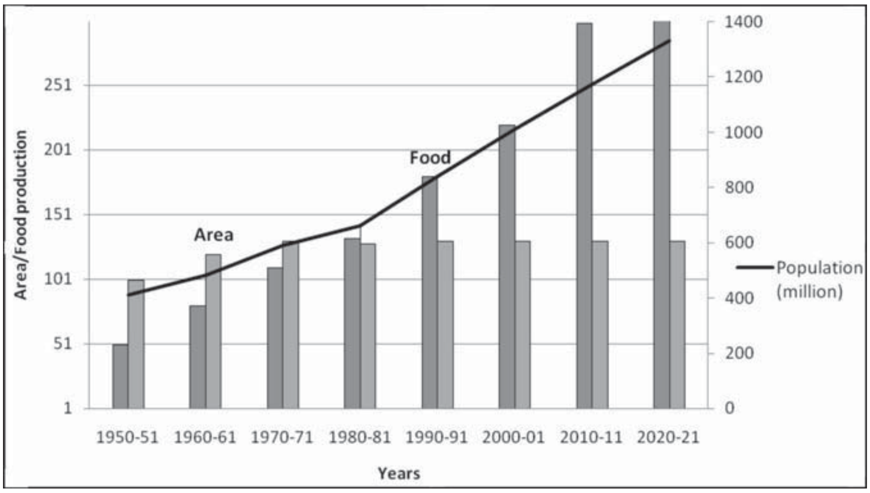


**Figure 1. Growth in population, area under crops and food production, area in Mha, food production in Mt [Source: 20 and http://www.teriin.org/]**

rently degraded lands could be increased. Taking the lowest estimate of degraded land, 66 Mha (20), about two thirds of this is adequate for decentralized rural bioenergy centers for 0.5 million villages, as well as for 16,000-32,000 MW of megawatt-scale biomass electricity (depending on woody biomass productivity and efficiency of conversion). Even after dedicating land for producing woody biomass for energy and timber, surplus degraded land would be available.

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