Challenges **2015**, *6*, 158-172; doi:10.3390/challe6010158

OPEN ACCESS

challenges

ISSN 2078-1547

www.mdpi.com/journal/challenges

Article

Biomass Resource Assessment and Existing Biomass Use in the Madhya Pradesh, Maharashtra, and Tamil Nadu States of India

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Academic Editor: Andreas Manz

Received: 13 March 2015 / Accepted: 21 May 2015 / Published: 27 May 2015

Abstract: India is experiencing energy crisis and a widening gap between energy supply and demand. The country is, however, endowed with considerable, commercially and technically available renewable resources, from which surplus agro-biomass is of great importance and a relatively untapped resource. In the policy making process, knowledge of existing biomass use, degree of social reliance, and degree of biomass availability for energy production is unequivocal and pre-conditional. Field observations, documentation, and fill-in sheet tools were used to investigate the potential of biomass resources and the existing domestic, commercial, and industrial uses of biomass in selected Indian states. To do so, a team of field observers/supervisors visited three Indian states namely: Maharashtra (MH), Madhya Pradesh (MP), and Tamil Nadu (TN). Two districts from each state were selected to collect data regarding the use of biomass and the extent of biomass availability for energy production. In total, 471 farmers were interviewed, and approximately 75 farmers with various land holdings have been interviewed in each district. The existing uses of biomass have been documented in this survey study and the results show that the majority of biomass is used as *fodder* for domestic livestock followed by in-site ploughing, leaving trivial surplus quantities for other productive uses. Biomass for cooking appeared to be insignificant due to the availability and access to Liquefied Petroleum Gas (LPG) cylinders in the surveyed districts. Opportunities exist to utilize roadside-dumped biomass, in-site burnt biomass, and a share of biomass used for ploughing. The GIS-based maps show that biomass availability varies considerably across the Taluks of the surveyed districts, and is highly dependent on a number of enviromental and socio-cultural factors. Developing competitive bioenergy market and enhancing and promoting access to more LPG fuel connections seem an appropriate socio-economic and environmental approach to reduce the use of biomass for indoor cooking and increasing the share of surplus biomass for energy production.

Keywords: India; biomass resources; biomass uses; GIS applications

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1. Introduction

Globally, it is estimated that approximately 2.7 billion people are heavily reliant on traditional biomass as the main fuel for cooking and heating, and approximately 1.5 billion people do not have access to electricity [1]. According to a report by the International Finance Corporation (IFC), the poor globally spend US$37 billion on low-quality energy solutions for lighting and cooking [2]. That means the poor spend three to ten times more of their disposable income on energy than the rich [3]. In India, for instance, the lowest income group spends as high as 8% of their monthly expenditure on cooking energy.

India, the world's second highest populated country after China, accounts for 17.5% of the world's population. Besides the high urbanization rate, high population growth rate, and declining opportunities in the rural areas and a low paying agriculture sector [4], the country's energy [power] sector is confronted with a plethora of impairments and challenges to the ballooning demand for energy and power, particularly in rural India. Rural India is of particular interest because it accommodates almost 70% of the Indian population. It is where the majority of socio-agricultural activities are taking place and where modern energy supply facilities and apparatuses are unequivocally needed to elevate the rural residents' living standards. Due to low household incomes, lack of adequate and reliable electricity supply, the absence of efficient energy options, and the thin markets for commercial fuels and equipment, about 64% and 26% of rural households rely on firewood, crop residues and animal wastes for cooking, respectively [5–7]. Due to incomplete fuel combustion in the commonly-used traditional cooking stoves, indoor air pollution has severe health implications on both mothers and their children including acute and/or chronic respiratory diseases [6–9]. Therefore, political will and determination accompanied by socially oriented public policies aiming at e.g., empowering rural areas with modern energy systems that ultimately helps in "fuel switching" or "transition" may lay the concrete foundation towards rural areas' sustainable development.

In rural areas, there exists a unique opportunity to utilize the surplus agricultural crop residues, forest residues, biomass-based industrial by-products, and the vast set-aside wastelands. If intelligently assessed and, thereafter, effectively harnessed to produce energy, it would undoubtedly improve the indoor living environment, optimize and generate other productive uses of biomass, and certainly improve the socio-economic features of rural people. In this regard, agro-biomass resource assessment and the embedded sociocultural uses must be identified and thoroughly assessed for potential energy production on mini, meso, or macro scales. In India, several studies have quantified the potentials of biomass resources available for energy production [7,10,11]. Despite slight differences in agro-biomass resources quantifications, these studies assert the potentials and availability of agro-biomass for energy production using various biomass conversion technologies mainly gasification and anaerobic digestion processes [10]. These technical studies, however, paid little attention to the existing and competing uses of biomass at e.g., household level. Furthermore, more studies are needed to investigate the nature and degree of social reliance on biomass for household use in areas where biomass-based power plants deemed projects feasible. Moreover, effective public policy in developing countries requires analysis of the factors that affect energy demand at the household level [6]. Moreover, social sustainability and corporate social responsibility are robust components of the overall energy project planning and development which, if achieved, may lead to competitive advantage, improving firm reputation, and increasing customer satisfaction [12]. Identifying the existing practices and the degree of social reliance helps quantify the biomass-based social needs thus avoid future societal conflict or grievances. In a recent study by George and Stern [6] on energy choices in two tribal villages in Maharashtra, they found that higher income is associated with the use of higher quality energy sources, which reduces the overall energy use. Additionally, they found that household size, stove ownership, and seasons influence energy choices. Fuel prices, family size, education level, and cultural factors such as religion or caste can also have pronounced influence on energy choices [6,13].

1.1. Status of Biomass-Based Industry in the Selected States

By 2013, the installed power capacity of 14 operating biomass-based power plants in Madhya Pradesh was around 59 MW_e [14]. The state aims to achieve the target of 300 MW_e biomass power by 2014. As it stands today, the registered biomass capacity in the pipeline has surpassed the target (314 MW_e), however, and due to unfavourable market conditions for biomass power production, many of the registered plants have not yet begin the construction process. Furthermore, out of 314 MWe registered capacity, about 184 MW_e of biomass power capacity had already been de-registered [14]. Maharashtra state aims to achieve 400 MW_e of biomass-based power capacity. The state has already issued all the licences to achieve the target. The licence for plant commissioning is issued under the assumption that five taluks would be able to support one 10 MW_e biomass power plant. As of 2013, the total installed biomass power capacity is around 180 MW_e (18 plants) [15]. Out of 18 power plants, 11 plants have been temporarily or permanently shut down [15]. The southernmost state of India, Tamil Nadu, is crippled by a severe shortfall of power production up to 4000 MW_e from its total demand of 13,500 MW_e. The present installed total biomass plant capacity is around 177 MW_e (19 plants—each plant capacity not greater than 15 MW_e) [16]. Most of the plants are distributed to the south of Tamil Nadu where there is an adequate supply of biomass from agriculture and wastelands. Among the existing biomass power plants, more than half of the numbers of plants (120 MWe with 80% plant load factor) have been struggling due to various reasons like unviable tariffs, restrictions on open access, rise in biomass cost, and reliable biomass supply [17,18].

This study has employed survey-based and GIS-based tools to assess the biomass resources in three different states, namely Maharashtra (MH), Madhya Pradesh (MP), and Tamil Nadu (TN). These states are selected because they produce considerable quantities of agriculture crop residues, accommodate considerable potentials of renewables, and biomass-based energy generation is one of the major focus areas of renewable energy programs in India and particularly in these states (Figure 1).

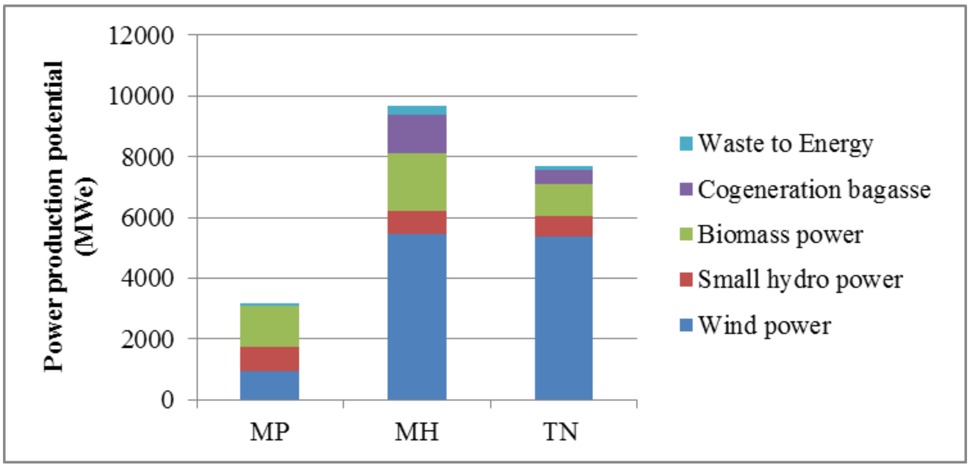

Figure 1. Source-wise renewable power production potential in the three states [19].

The main objectives of this study are to examine and document the existing biomass use practices in rural India and, based on the household biomass consumption, quantify the surplus biomass availability that can be utilized for energy production without jeopardizing the livelihood of the rural families. The implications of this study would assist in developing a new *modus operandi* and a modern biomass value-chain accompanied by technological solutions to help leapfrog the existing technical and social barriers in harnessing and utilizing surplus biomass in power sector. From a policymaking point of view, the study will assist policymakers to better understand the current social uses of biomass in the x-rayed states, thus assisting in crafting transparent and socially-friendly public policies. For investors and business makers, the study will help to identify biomass rich-zones and also poor zones where biomass utilization is socially sensitive. The study will further provide some logistical recommendations for economically reliable biomass utilization.

2. Methodology

The study area was narrowed down to three states of interest. The selected states were Madhya Pradesh (MP), Maharashtra (MH) and Tamil Nadu (TN). Both Madhya Pradesh and Maharashtra have areas of more than 300,000 km^2 and Tamil Nadu more than 130,000 km^2. The study areas cover nearly a quarter of the whole country's area and more than one fifth of the total population live in the aforementioned states. Two districts have been selected from each state (Figure 2). The selected cities were Bhopal and Indore (Maharashtra), Thane and Pune (Madhya Pradesh), and Kanchipuram and Coimbatore (Tamil Nadu). The selected cities were all the largest cities in each state. The full pilot area covered the city and the surrounding rural area. The actual border for the pilot areas were determined by the Landsat 8 image border, as each of the cities were used as the center point when looking for satellite images.

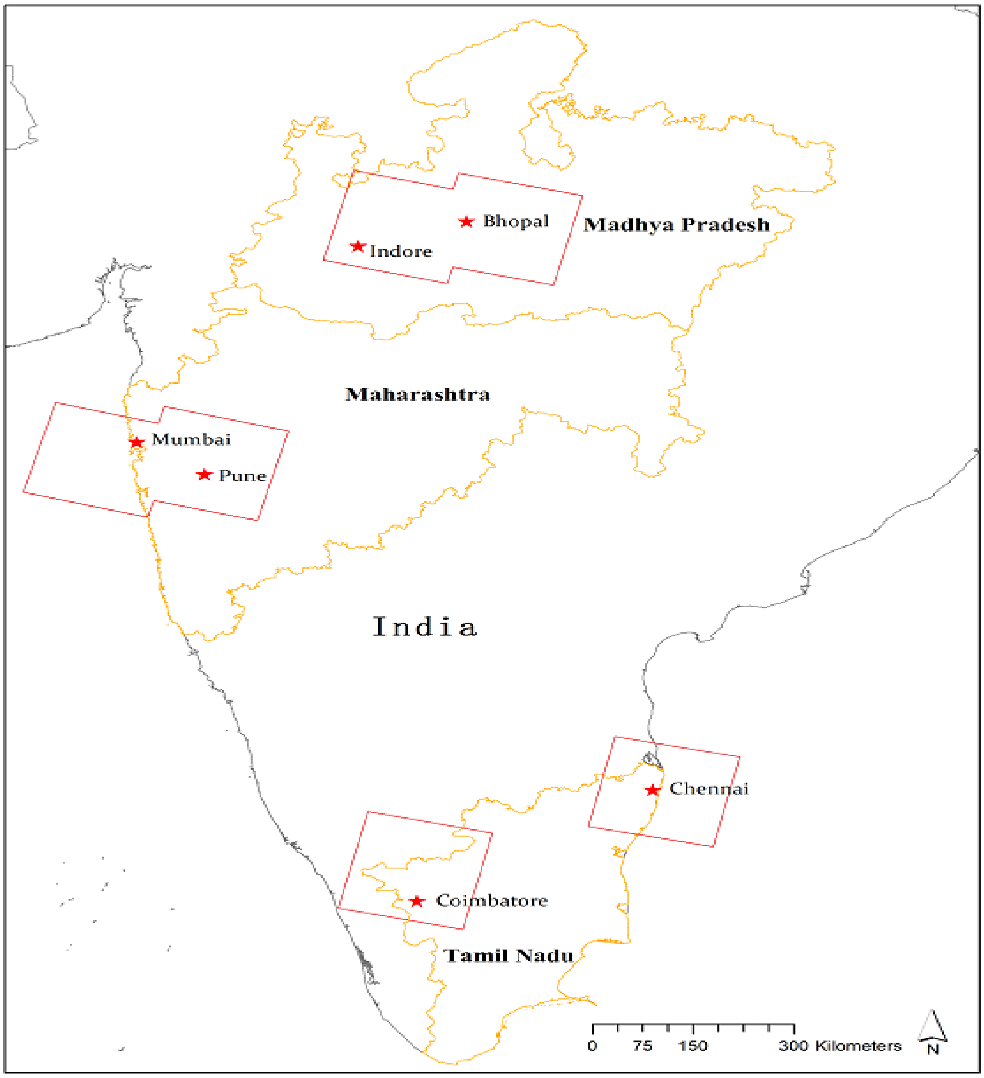

Figure 2. State-level study regions and selected pilot cities including the mapped pilot region.

For mapping the available biomass resources in pilot areas, results from field data were used. The questionnaire study was conducted in the rural parts of each pilot area. Tools were translated into Hindi, Marathi and Tamil to conduct the pen-and-paper based survey. After having consultations with various stakeholders and based on previous experience, a sample size of 75 was selected for household surveys from each selected district with approximately 150 farmers from each state. During preliminary discussions with the stakeholders, it was realized that farmers across different socioeconomic categories could have different production, use and supply patterns. Hence, farmers were divided into three categories of small (less than 5 acres), medium (5–10 acres) and large farmers (more than 10 acres). Due to limited research resources and time constraints, a sample of 25 farmers was drawn from all three categories. In addition, the sample size of 25 was considered to be representative sample size for each category, since the agricultural cropping pattern in a given area (village or taluk) does not vary greatly as most farmers would cultivate one similar crop during that season. Moreover, one can think that the biomass generated from one particular crop does not vary according to the land holding category. After this stratification, households were randomly surveyed from the villages.

The participants answered questions on their annual biomass production, yield, and residue production and the consumption of that residue biomass. To retrieve clearer insights of the biomass resource availability and distribution, literature sources and biomass databanks were also explored. For Madhya Pradesh and Maharashtra, the Biomass Resource Atlas of India was used to acquire the biomass values for agriculture and forest classes [20]. The district-wise biomass information for Tamil Nadu was acquired from a study conducted by Tamil Nadu Energy Development Agency (TEDA) and the Institute for Energy Studies (IES) [16]. Secondary data was also explored from various state reports, policy briefs from international organizations, and peer-reviewed articles. The questionnaire data was transferred from paper forms to digital format and further analyzed to calculate per hectare production and consumption of agro residue and horticulture residue biomass and eventually the total surplus biomass for agriculture land use. These surplus biomass figures were used as the amount of surplus biomass in the biomass mapping stage. To generate biomass-related maps, the GIS Arc Maps was used.

The land use mapping on the state-level was done at the National Remote Sensing Centre (NRSC). However, due to restriction on use of the data, the original land use map is not shown on this paper. The original Land Use Land Cover (LULC) map had 19 classes, and it was reclassified into five classes. It can be assumed that the reclassified map has better overall accuracy because there are fewer classes. However, the classification accuracy of the original map was not calculated. On the other hand, the overall accuracy of the reclassified map in Madhya Pradesh, Maharashtra and Tamil Nadu is 78%, 55% and 53%, respectively. The overall accuracy was relatively low, especially in Maharashtra and Tamil Nadu, at only about 50%. The corresponding kappa values were also quite low—0.55, 0.37 and 0.32, respectively. One reason why the figures are so low can be that the LULC map itself had a slight misalignment when compared to the satellite imagery. The reason for that misalignment was unclear, though, the NRSC does mention that the thematic accuracy is within one to three pixels. Because the accuracy assessment was done on a pixel-by-pixel basis; therefore, the misalignment of even one pixel can cause a specific area to have incorrect class corresponding to it.

3. Results

3.1. The Existing Competing Uses of Biomass in the Selected States

Throughout the field excursions, the various uses of biomass have been documented and presented in Figure 3 below. India is a land of physical, climatic, geographic, ecological, social, cultural and linguistic diversity [4]. Therefore, the uses of biomass vary considerably across the states and are based on a plethora of socio-economic, enviromental, and cultural factors such as level of income, education level, family size, and caste and religious orientation [6,7,11,21]. Other factors such as access to LPG gas cylinders, biomass prices and availability, and availability and access to forest biomass resources are of direct influence on household demand [7,11]. In the surveyed states, the agro-biomasses are widely used for domestic cooking, livestock fodder, thatching, fodder manure, and commercial uses (*i.e.*, sold to third parties, e.g., hotels, bakeries, potteries, restaurants). In some states, field burning is traditionally practiced with respect to crop types. Apart from household and commercial use, biomass is also used in various small-scale industrial rural enterprises such as brick making, rice par-boiling, and charcoal making [21]. In the six surveyed districts, the survey of biomass uses are featured in Figure 4. In Indore and Bhopal, almost half of biomass is used as a feed for domestic livestock and a considerable share of biomass is burnt on site. In Thane and Pune, the use of biomass as a fodder for livestock accounts for almost two-thirds of the available biomass. In the Tamil Nadu state, and in the surveyed districts, the biomass resources are mainly used for animal fodder (46%) and organic fertilizer (33%), such as in Kanchipuram district where 73% is used as organic fertilizer and in Coimbatore district, where 19% is used as fodder for animals. The share of biomass being sold out to third parties varies among the surveyed districts where the highest share is being sold in Thane (30%) to zero percent share sold in Coimbatore district.

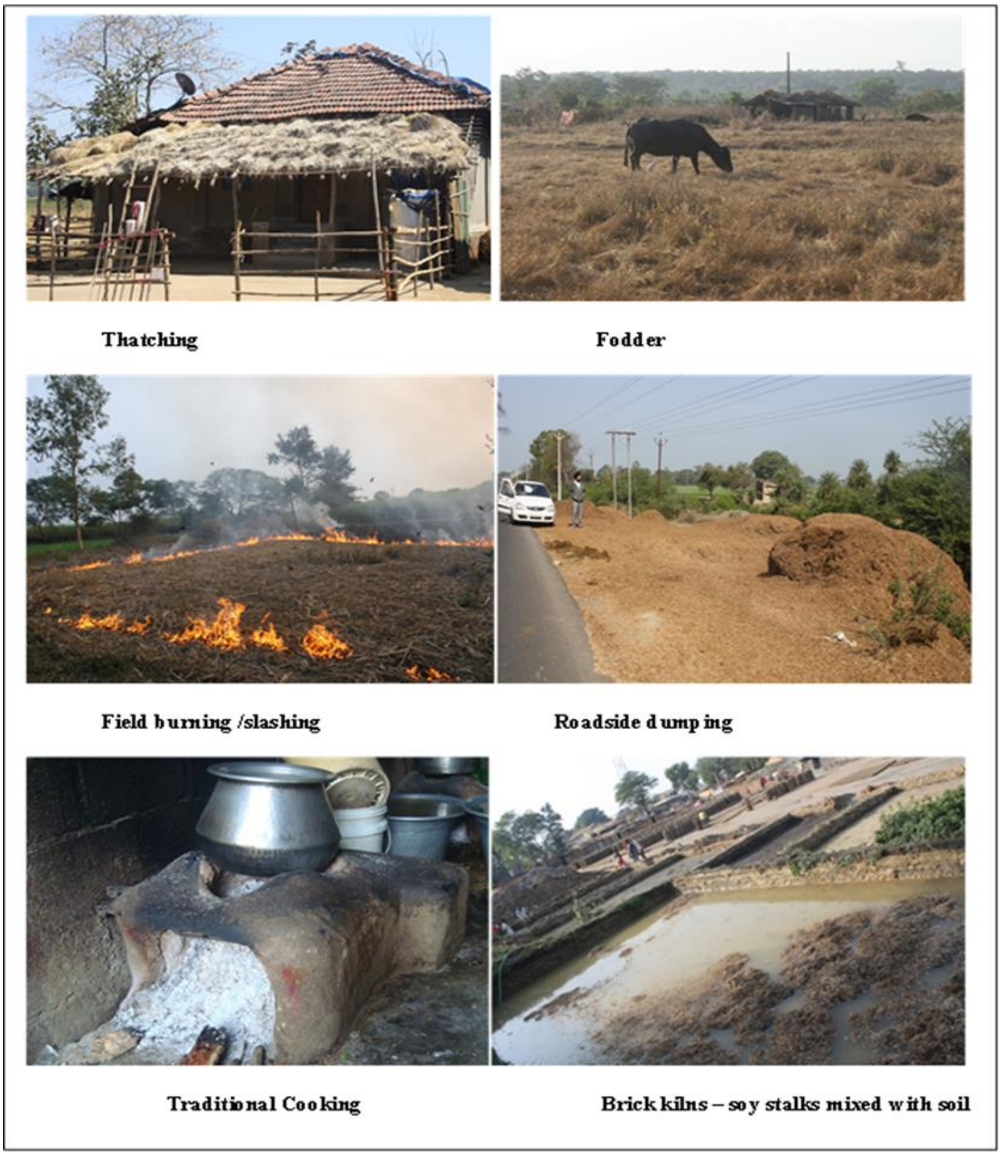

Figure 3. Field-documentation of the various biomass uses in the surveyed states.

The traditional practice of field burning is common in Madhya Pradesh state in order to prepare the field for the next sowing season in a quick span of time. This is because the collection window for biomass is rather short between two seasons. Besides field burning, the soybean residuals are also dumped out on the roadside in MP. Moreover, all the selected six districts have minimal use of biomass for cooking, as the farmers have access to modern LPG cooking stoves. Overall, the results indicate that agro-biomass for fodder is the predominant use of agricultural residues in all the selected study sites except Coimbatore, where only a small share is being sold. This because in Coimbatore, the major agricultural crop residuals are from groundnut, tapioca, and cotton, where they are usually ploughed in the field to maintain and enhance the soil fertility as manure. The agricultural residuals such as sorghum stalks, paddy straws, and maize stalks are collected and used as fodder. The major buyers for agro-biomass are dairy farms and small industries like brick kilns. Furthermore, the share of surplus biomass available for other uses is rather trivial. A revisit to biomass on-site burning, roadside dumping, and ploughing is needed to explore opportunities in diverting part of such waste biomass into energy production facility.

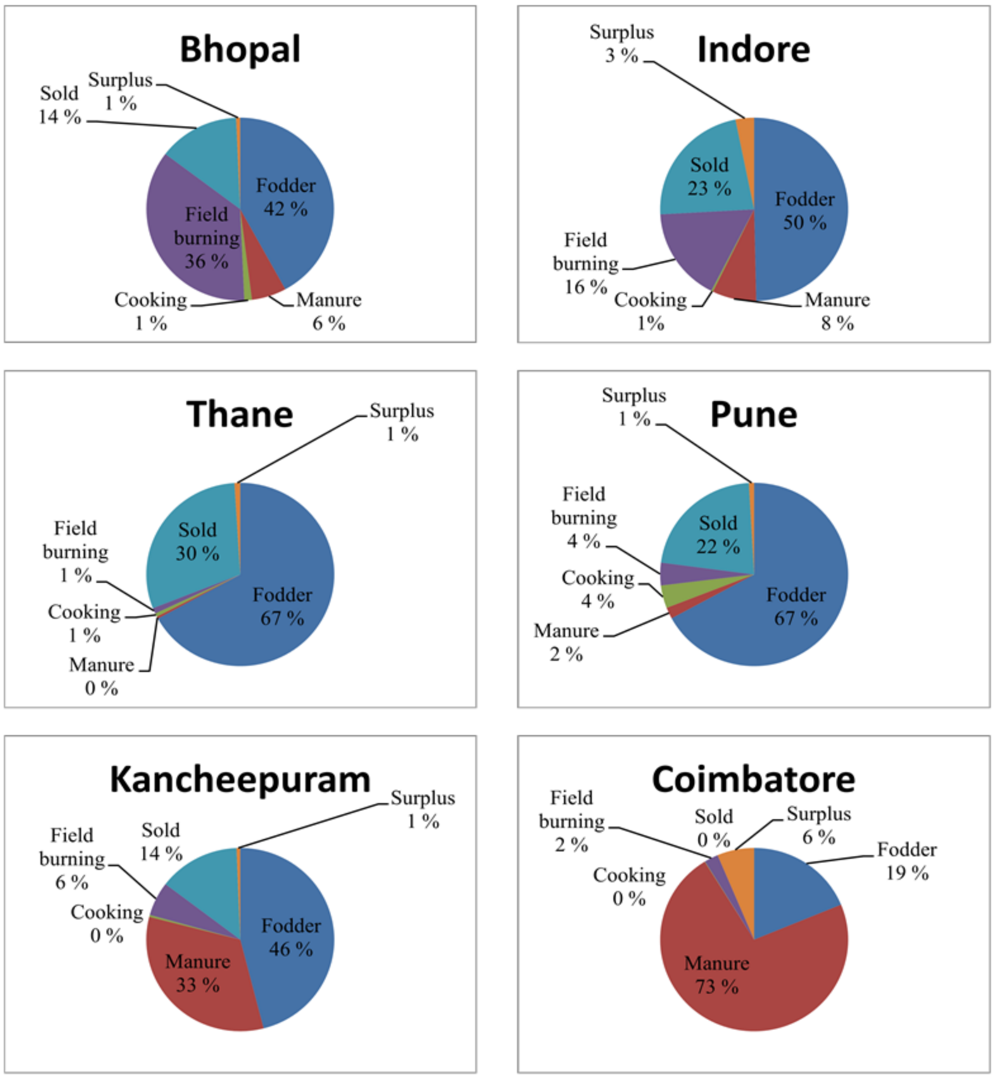

Figure 4. Share of biomass consumption and surplus availability in six pilot districts.

3.2. Mapping the Agro-Biomass and Forest Resource Potentials for Energy Production

The Biomass Resource Atlas of India (2000–2004) estimates the theoretical potential of surplus agro-biomass available for supply at 10.32 million tons in the state of Madhya Pradesh. Similarly, for Maharashtra and Tamil Nadu, the theoretical potential of surplus agro-biomass available for supply was around 14.78 million tons and 8.9 million tons, respectively [20]. For the state-level, biomass mapping (Figure 5) and for covering other land use classes than agriculture in the pilot-level mapping, literature sources were used to search the best possible biomass surplus estimates. For Madhya Pradesh and Maharashtra, the Biomass Resource Atlas of India [20] was used to acquire the biomass values for agriculture, forest and wasteland classes. The biomass figures were for the years 2000–2004 and the biomass information was listed separately for states, districts and taluks. Biomass information for the Atlas was acquired using data from multiple sources including remote sensing data and field data. The Atlas gives area of production per specific location (state, district or taluk) and land use (Agro, forest or wasteland), and production of total biomass for all land uses as well as the crop biomass for agriculture. The surplus biomass is derived from the production and consumption of residue biomass, though consumption is not given in the table.

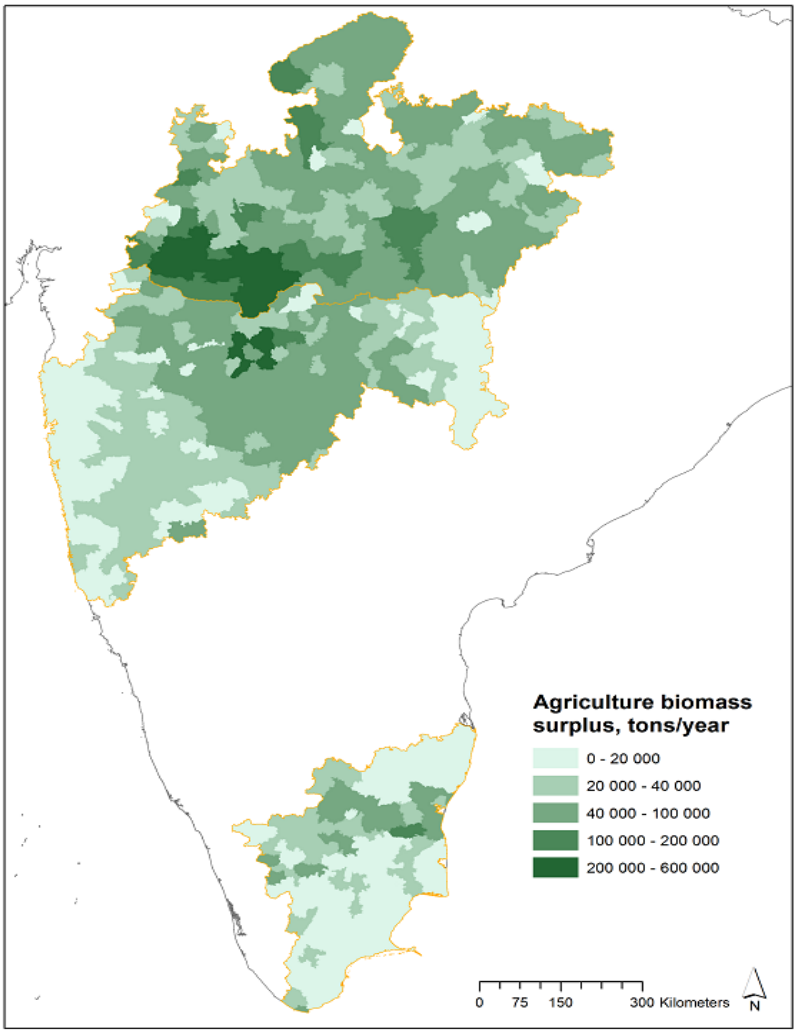

Figure 5. Surplus agro-biomass availability in MP, MH and TN.

It was decided to use the district-wise information, because it was the best combination of spatial detail and data reliability. The taluk-wise information was not used because there were many differences with the administrative taluk border layer used and the Atlas' taluk division. The district-wise biomass surplus and production figures were used for agriculture and forest land use classes. The biomass consumption was calculated based on the aforementioned figure. The values in the Atlas were given as kilotons of biomass per year. The area of specific land use within each district was used to calculate the tons of biomass per hectare figures, which were later used in map production. The district-wise biomass information for Tamil Nadu was acquired from a study conducted by the Tamil Nadu Energy Development Agency (TEDA) and the Institute for Energy Studies (IES). The District Wise Biomass Resource Assessment Study—Tamil Nadu was conducted in 2009–2010 [16].

The surplus biomass available for supply is calculated after taking into account the existing uses of biomass. In 2013, the annual biomass generation in six pilot areas were 387 thousand tonnes in Bhopal, 834 thousand in Indore, 572 thousand tonnes in Thane, 1.364 million tonnes in Pune, 160 thousand tonnes in Kanchipuram and 202 thousand tonnes in Coimbatore. The results show that the share of biomass consumption and surplus availability varied geographically which depends on many factors viz., crop production, crop types, seasonal variations, available infrastructure (e.g., access to LPG cylinders and/or forest wood resources), and socio-economic, cultural, and traditional practices. Another geographical presentation of surplus biomass availability can be found based on crop categories in Hiloidhari *et al.* [7].

The potential of utilizing forest biomass for energy generation exists; however, it is still underutilised. The degraded forest lands offer an excellent opportunity to develop energy plantations, which would also increase the livelihood opportunities for the local community through joint forest management practices. The challenges to harness the forest biomass for energy generation are manifold e.g., inaccurate data on forest land resources, encroachment, strong conservation acts and policies, wildlife, remote areas and poor infrastructure. The Biomass Resource Atlas of India (2000–2004) estimated that 59.7 million tons of surplus forest biomass can be generated annually [20]. The state-wide forest biomass generation potential was 5.4 million tonnes in MP, 5.1 million tonnes in MH, and 2.3 million tonnes in TN [20]. In our study, no field level forest inventory was conducted to study the surplus forest biomass availability; instead, the field level assumptions from [20] have been used to estimate the state-wide forest biomass distribution presented in Figure 6.

The final stage of this analysis was devoted to calculate the biomass power potentials (MW_e). In doing so, data resources from various sources such as state reports, the Biomass Atlas, peer-reviewed articles, and field data have been cross-checked to produce biomass power potentials in the three selected states. These power potential calculations took into account only surplus biomass after deducting the shares of other biomass uses. For power potential calculation, the plant parameter assumptions (average agro-biomass calorific value—3000 kcal/kg, Plant load factor—100%, specific fuel consumption—1.11 kg/kWh, station heat rate—3940 kcal/kWh) were obtained from Orient Green Power, Pollachi, Coimbatore district.

The calculated agro-biomass power potential is presented in Figure 7. The potential energy generation varies spatially explicitly as the share of biomass consumption and surplus availability varied geographically, which depends on many factors viz., crop production, crop types, seasonal variations, existing uses, and available transportation infrastructure. A study by Zyadin *et al.* [22] found that Indian farmers are very much willing to directly supply (sell) their surplus biomass quantities to a potential energy producer and that energy production is perceived to bring prosperity and wealth to their communities. However, the availability of transportation logistics, middleman reliability, and availability of seasonal workers are perceived as key obstacles to the biomass supply chain.

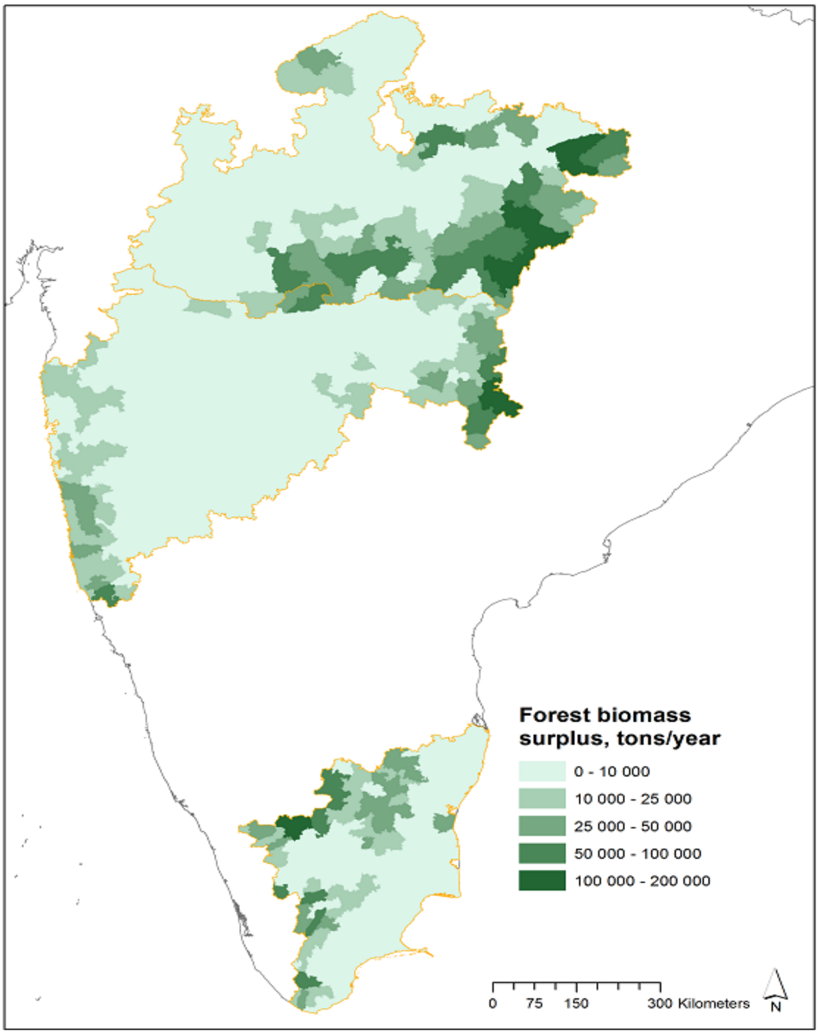

Figure 6. Surplus forest-biomass availability in MP, MH and TN.

4. Discussion and Conclusions

The unprecedented economic growth in India has created a stampede to increase energy demand. Most Indian cities face rolling power cuts which are exacerbated by fluctuating fossil fuel costs and growing demand for more power due to rapid urbanization. The biomass-based power production holds great potential to meet India's growing energy demand, but it is not being entirely utilised. Constraints related to resource availability and seasonality, supply chain logistics and infrastructure, technological modifications, lack of strong legislative and financial measures/incentives, and policy uncertainties have resulted in the poor attraction of biomass power investments or even the shutdown of some existing biomass-powered plants.

The current traditional and cultural practices with various uses of biomass have limited the availability of biomass supply to energy generation. However, it will be unrealistic to collect the biomass for energy generation without embracing the existing particular sociocultural uses of biomass; biomass as a fodder is of critical importance in India. Therefore, it is imperative to utilise non-fodder crops (e.g., soybean husks, cotton stalks, coconut fronds) for energy generation. On the other hand, the biomass dependency for domestic purposes (cooking, thatching) could be reduced through modern cooking stoves (improved cooking stoves, subsidised LPG) and government housing programmes.

Switching from traditional energy use would not only reduce the dependency on biomass but also improve the living standards of poor people. In this pretext, during Census 2010–2011, less than 50% of urban households and only 6% of rural households use LPG [23]. The remaining 80% of rural Indian households continue to use traditional fuels for cooking due to affordability, access and awareness limitations [23]. Therefore, the current LPG subsidy mechanism is heavily skewed in the favour of higher income groups and the urban areas of country [23]. Although The *Rajiv Gandhi Gramin LPG Vitaran Yojana* (RGGLVY) has increased the LPG availability in rural areas, sparsely populated and/or remote agglomerations are still underserved due to the "high cost of delivery and financial unviability of conventional distributor models" [23] (p. 10). The report [23] proposes improving LPG availability in rural areas by raising the awareness of the benefits of LPG consumption together with re-rationalizing the subsidies scheme.

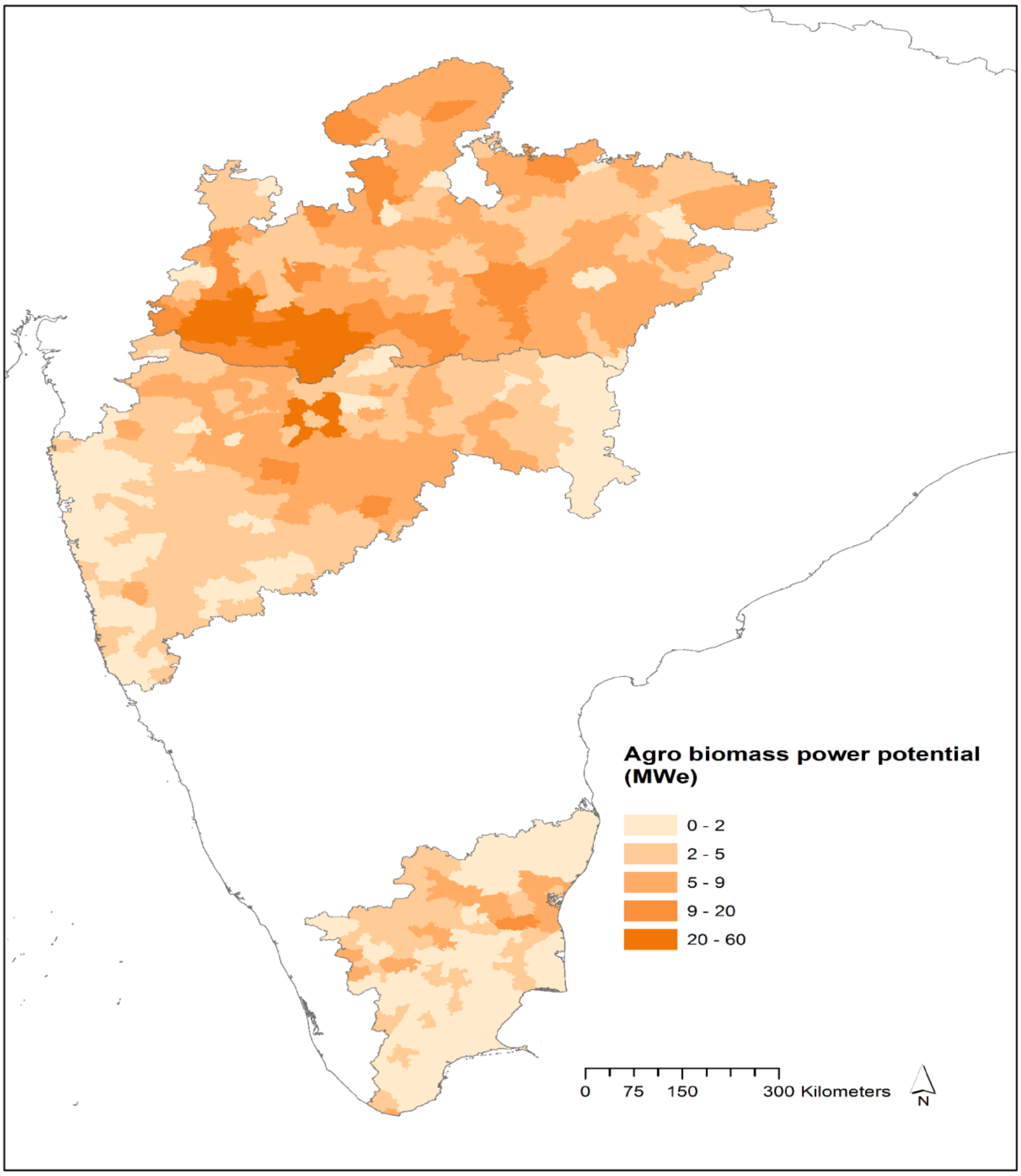

Figure 7. District wide biomass power production potential (MWe) in MP, TN and MH.

An organized biomass market is another key for successful development of the biomass industry in India. New market policies and regulations must accompany the biomass market development to avoid price fluctuations that may harm the economics of the existing or envisioned biomass-based power plants. However, paying extra attention to the sociocultural ties and uses of biomass in rural India is very crucial from a social sustainability point of view.

The present biomass industry lacks successful stakeholder models for sustainable utilisation of biomass for energy generation. For example, a biomass power plant "X" located at "Y" depends on many geographically dependent factors, e.g., continuous biomass supply, quality and mix of biomass, water resources, biomass price, power evacuation infrastructure, labour availability, public acceptance, industrial competition, and co-operation between governmental departments. The variations in any one of the factor would greatly affect the plant production. Besides these factors, commercial installations of renewable energy is very high compared to financial risks involved in other purchase options such as that of conventional non-renewable power projects. In this regard, hybrid energy systems or co-firing biomass in coal-fired power plants accompanied by green certificates-assuming biomass is carbon-neutral, would reduce emissions, and create a somewhat balanced energy production for the time being.

The organized biomass supply chain is crucial to secure and maintain reliable and stable biomass supply. The agricultural biomasses are bulky in nature and, therefore, an efficient supply chain is needed to increase the cost competiveness and energy efficiency. One could select appropriate fuel collection methods like bundling (paddy straw, sugarcane tops), chipping (e.g., eucalyptus, casuarina) with respect to fuel type, which eventually allows more biomass to be transported in a single truck. Subsequently, the biomass could be further processed using fuel processing technologies like pelleting or briquetting to increase the energy efficiency of the fuel. In addition to its increased energy value, the fuel handling becomes easier, and then the biomass can be efficiently transported to longer distances. The sustainability of biomass for energy must be evaluated in detail with respect to food security, environmental performance, and energy efficiency. Importantly, a country like India cannot afford to have pure energy plantations in agricultural lands which would eventually increase the food competition and food prices. On the other hand, agro-forestry practices (where agriculture and energy crops are cultivated together) could be adapted to meet both the agricultural and biomass needs for various food and non-food uses.

Acknowledgments

The authors wish to thank the anonymous reviewers for devoting their time to comment and improve earlier versions of this article. The authors are indebted to the Indian farmers who participated in this study and provided insightful thoughts regarding biomass distribution and domestic uses. The study was supported by the School of Forest Sciences, University of Eastern Finland under BEST-SHOK project (Project: Sustainable Bioenergy Solution for Tomorrow—WP 2 Task 2.3 Case India) jointly coordinated by the Finnish Bioeconomy Cluster (FIBIC Oy) and the Cluster for Energy and Environment (CLEEN OY) with funding from the Finnish Funding Agency for Innovation (TEKES).

Author Contributions

The authors wish to thank TEKES for providing generous financial support to conduct this research project in India. Anas Zyadin and Karthikeyan Natarajan wrote the manuscript, Karthikeyan Natarajan helped in data collection, photos, and developing resources maps, Petri Latva-Käyrä developed the GIS maps, Suresh Chauhan and Singh Harminder helped in data collection and field excursions, and Paavo Pelkonen supervised the process of setting the research outline, creating survey tools, and providing assistance and commenting on earlier drafts of this manuscript. *Photos courtesy of*: Karthikeyan Natarajan.

Conflicts of Interest

The authors declare no conflict of interest.

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