

Article

Indian Farmers' Perceptions and Willingness to Supply Surplus Biomass to an Envisioned Biomass-Based Power Plant

Anas Zyadin ^{1,*}, Karthikeyan Natarajan ^{1,*}, Suresh Chauhan ², Harminder Singh ², Kamrul Hassan ¹, Ari Pappinen ¹ and Paavo Pelkonen ¹

¹ School of Forest Sciences, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland; E-Mails: kamrul.hassan@uef.fi (K.H.); ari.pappinen@uef.fi (A.P.); paavo.pelkonen@uef.fi (P.P.)

² The Energy and Resources Institute (TERI), Darbari Seth Block, IHC Complex, Lodhi Road, 110003 New Delhi, India; E-Mails: sureshc@teri.res.in (S.C.); hsingh@teri.res.in (H.S.)

* Authors to whom correspondence should be addressed; E-Mails: anas.zyadin@uef.fi (A.Z.); karthikeyan.natarajan@uef.fi (K.N.); Tel.: +358-504-424-554 (A.Z.); +358-504-423-033 (K.N.).

Academic Editor: Andreas Manz

Received: 3 February 2015 / Accepted: 7 April 2015 / Published: 10 April 2015

Abstract: The main objectives of this socio-technical study are to investigate the Indian farmers' biomass production capacities and their perceptions and willingness to supply their surplus biomass to fuel an envisioned biomass-based power plant in three selected Indian states: Maharashtra, Madhya Pradesh and Tamil Nadu. For doing so, 471 farmers (about one-third from each state) have been interviewed in the field with info-sheet filled in by the field investigators. The farmers from all of the states appeared very much willing to sell their surplus biomass directly to a power plant. The farmers seem to depreciate the involvement of a middleman in the biomass procurement process. The farmers, however, appeared to highly appreciate a community-based association to regulate the biomass prices, with varying perceptions regarding government intervention. The majority of the farmers perceived the establishment of a biomass-based power plant in their region with positive economic outcomes. The farmers identified several barriers to supply biomass to a power plant where transportation logistics appeared to be the main barrier. The study recommends considering biomass collection, storage and transportation logistics as a fundamental segment of any envisioned investment in a biomass-based power plant. Biomass processing, such as pelletization or briquetting is recommended for efficient transportation of biomass at longer distances to reduce the transportation costs. The study further encourages the

establishment of a farmers' association aimed at collecting and selling biomass in agriculture areas predominant for small land holdings.

Keywords: perceptions; Indian farmers; biomass; power plant; willingness

1. Introduction

India currently faces a number of pressing socio-demographic and economic challenges that need to be proactively and unequivocally addressed by following trajectories toward energy independence and diversifying energy supply from local and, particularly, renewable sources. India has the world's second largest population of approximately 1.28 billion, and the population of India is estimated to be growing 18 million every year (1.3% each year), which will surpass China's population with a record of 1.5 billion by 2028 [1].

The economy of India has experienced a resurgence in the past few decades due to the country's dynamic economic growth and modernization, becoming the ninth largest economy in the world, driven by a real gross domestic product (GDP) growth of 7% since 2000 (in 2010, the real GDP growth of India was the fifth highest in the world [2]), and it proved relatively resilient following the 2008 global financial crisis [2]. Overall, the country ranked the fourth-largest consumer of crude oil, and its 249-gigawatt (GW) electricity generation capacity is heavily reliant on coal-based power plants [2].

The country imports the majority of its crude oil needs from the Middle East. Due to industrial expansion and population growth, the demand for crude oil is expected to double by 2040 compared to the present 3.7 million barrels per day (mbl/d) [2]. Because of insufficient fuel supply and power generation and transmission capacity, the country suffers from a severe electricity shortage, leading to rolling blackouts and brownouts [2]. Besides the population boom and energy crisis, rural electrification remains a key challenge for the Indian government together with the post-harvest losses in the agriculture sector, particularly in rural India. The agriculture sector in India is considered the backbone of the country, contributing approximately 17% of the country's total GDP and providing subsistence for approximately 60% of the rural population [3].

India is endowed with a considerable potential of renewable resources and surplus biomass potentials that may assist the country in addressing the growing energy needs, while maintaining a healthy economy able to provide socio-economic welfare to its poor population. In this regard, the Ministry of New and Renewable Energy (MNRE) made estimates of the wind, solar and small hydropower capacity that would largely enable the transition to a more clean energy production, encourage energy independence and navigate the pathway towards rural electrification. In 2013, India invested approximately US\$ 6 billion in renewable energy, of which US\$ 600 million were new investment in biomass and waste-to-energy projects [4]. According to MNRE's annual report, a total of 288 biomass power and cogeneration projects aggregating to a 2665 Megawatt Electricity (MWe) capacity have been installed in the country for feeding power to the grid [3]. Of great importance are the surplus crop residue potentials readily accessible for small-scale or family-size biogas installation, large-scale cogeneration and considerable potentials for second generation biofuel production, particularly from agriculture and forestry wastes, municipal solid and liquid wastes and industrial by-products, such as molasses from

sugar industry. For instance, India is the second largest sugarcane producer, with 17% of the world production in the last decade. A number of studies have estimated the gross biomass potentials and the respective surplus potentials in India, however with variations due to state-wise variations in cropping areas, productivity and also the competing uses of biomasses [3].

Overall, India produces 565–686 million tons (MT) of gross crop residue biomass on an annual basis, of which 234 MT (34% of gross) are estimated as surplus for bioenergy generation, which is equivalent to 17% of India's total primary energy consumption [3]. Globally, bioenergy is receiving robust policy momentum to mainly revalorize the underutilized biomass/biowastes resources to deliver energy services to poor people, not only for domestic use, but also to generate income, also known as productive uses of energy [5]. In rural India, agricultural biowastes serve as cleaner cooking facilities, lightening and better livelihoods for millions [6,7]. This of particular importance in the Indian context, since 33% of India's population has no access to grid-based electricity [3,7].

Approximately 70% of India's population (nearly 830 million) lives in rural areas. Over 85% of rural households use cattle dung, agricultural waste and fuel wood as the primary cooking fuel. Indian farmers have enjoyed heavily subsidized (almost free) electricity through their organized lobbying and emerging regional political parties who responded favorably to the farmers' wishes and maintained and fuelled intensification of subsidies over time [8–10]. While the agriculture sector consumes about one quarter of total electricity production, its revenue contribution is as low as 7%, leaving the utilities in financial distress [11,12].

Indian farmers today are seeking continuous, reliable and quality electricity supply to maintain their agricultural activities, especially those who use groundwater electric pumps for irrigating their seasonal crops [11]. Moreover, providing access to electricity for 400 million rural Indian citizens remain a quintessential policy endeavor for the Indian government. On this pretext, the MNRE has initiated a number of programs for promoting biomass use for energy. However, the logistics of biomass transportation, handling and storing the bulky biomass materials are indispensable, yet overlooked issues in the biomass supply chain [13]. Other logistical challenges related to biomass stem from its thin spread over vast fields, intermittent (seasonal) availability, middleman or trader involvement, price fluctuations, competing industries (such as brick kilns) and the poor road conditions [13]. These issues are largely encompassed within the economic and, to lesser extent, environmental sustainability frameworks.

One key pillar of sustainability in any energy-related project is social sustainability. For instance, previous experiences in renewable (clean) energy projects showed that public acceptance and support is a unequivocal and quintessential pre-requisite to tackle and overcome society-related barriers in project development and implementation phases [14,15]. In the vein of bioenergy commercial development, issues, such as supply chain development, the biomass physical characteristics, technology choice, environmental consequences and potential volume of biomass, have received ample research efforts [3,16]. While research investigating the surplus quantity of biomass available and technological feasibility, economic aspects remain quintessential; however topics, such as the producer's (or farmer's) "*ability*" and "*willingness to supply*" biomass and/or "*willingness to grow alternative biofuel feedstocks*", remain largely under-researched; not only in India, but also where the provision and outlook for bioenergy development are high [16–22]. In this regard, Altman *et al.* [16] argue that "*willingness to supply research is critical in the early stages of commercialization of new technologies, feasibility of industry, and ultimately industry development*". Therefore, research aiming at understanding farmers'

perceptions is vital to successfully design and present economic incentives and policy initiatives [17,22]. Recent research results based on data from two biomass producer surveys collected from the United States' mid-Missouri and southern-Illinois showed that producers will supply slightly more than 2% of their biomass production for each one dollar increase in price and that the supply of agriculture by-products is elastic [16]. They further suggest that Illinois and Missouri producers would potentially supply about 40% and 32% of their corn stover to biomass processors, under ideal conditions (price and market) [18]. In a survey-based study in western Kansas, the results show that a farmer who farms to maximize profit is 14% more willing to plant annual bioenergy crop [19], and the study found that female farm operators in central and western Kansas were 17% less likely to harvest crop residues [19]. In a case study from the Cumbria region, the United Kingdom, farmers, particularly the old ones, were reluctant to change the traditional and the heritage of stock production and dairying into feedstock for bioenergy production [20]. The authors also suggest that the decision to grow bioenergy crops will not be based solely on economic terms, and that farmers' management decisions are largely influenced by prior values, beliefs and experiences [20]. In the EU, particularly Poland, the results of multiple survey-based studies on biomass co-firing revealed, as indicated by the respondents, problems such as high investment costs, "overgrown bureaucracy", the high prices of commercial biomass, and the lack of biomass suppliers and the lack of local expertise [22].

In India, much of the research efforts focus on transforming the agriculture sector into a modern and more sustainable practice and improving farmers' skills and capabilities to meet new challenges in the agricultural sector, such as endemic diseases, salinity and excessive use of synthetic fertilizers and pesticides. To our knowledge, no region-wise studies were conducted to reveal farmers' ability and willingness to supply surplus biomass to an energy producer. Moreover, Indian farmers' knowledge and experiences may help reveal strengths, weakness and opportunities during the initial bioenergy project planning process, of which project planners or investors may be unaware.

1.1. The Aim of the Study

The key and overall objective of this survey study is to primarily investigate the perceptions of local farmers and their willingness to participate in a new business model for utilizing surplus biomass to generate power and heat for residential and industrial uses. The study further investigates the possible benefits, potential impacts and any sort of barriers to the establishment of a biomass-based power plant in the nearby area from the farmers' point of view. The study also aims at providing policy insights for policymakers in India for the sake of crafting new bioenergy policies or reassessing the current policies and amending them to accommodate the criteria for social sustainability.

1.2. The Study Areas

Three Indian states were selected for this survey-based study, namely: Maharashtra, Madhya Pradesh and Tamil Nadu. These agricultural states have high biomass potential [3] and high interest in biomass-based power plants (national and international). Furthermore, the study areas (states) were selected to investigate the degree of socio-economic reliance on agriculture biomass and the farmers' ability and willingness to supply surplus biomass for potential biomass-fired power plants (Figure 1). Maharashtra state is the wealthiest state in India, contributing 15% of the country's industrial

output and 13% of its GDP. It has a population of 112 million, and more than 60% of the people are employed in the agriculture sector and associated activities [23]. In Maharashtra, rice is the second most important crop of the people, which is grown over an area of 15,000 hectares with an annual rough rice production of roughly 33,000 tons [23]. According to Hiloidhari *et al.* [3], Maharashtra has an annual surplus biomass potential of 31 million tons equivalent to 563 PJ. Regarding Madhya Pradesh, the economy of the state mainly depends on agriculture, with more than 70% of the population involved in agricultural activities. Madhya Pradesh has an annual surplus biomass potential equivalent to 207 PJ [3]. The Tamil Nadu state is India's second most industrialized state. The economy of the state is dominated by the service sector and manufacturing. Agriculture has been the mainstay of the state's economy since independence, with more than 65% of the population relying on this sector for a living. The agriculture sector of the state contributes about 21% of the state GDP [24]. In the selected states, there is a lot of biomass potential, a lot of industry and a lot of interest in bioenergy. There are about 20 major types of agro-biomass residues available in India.

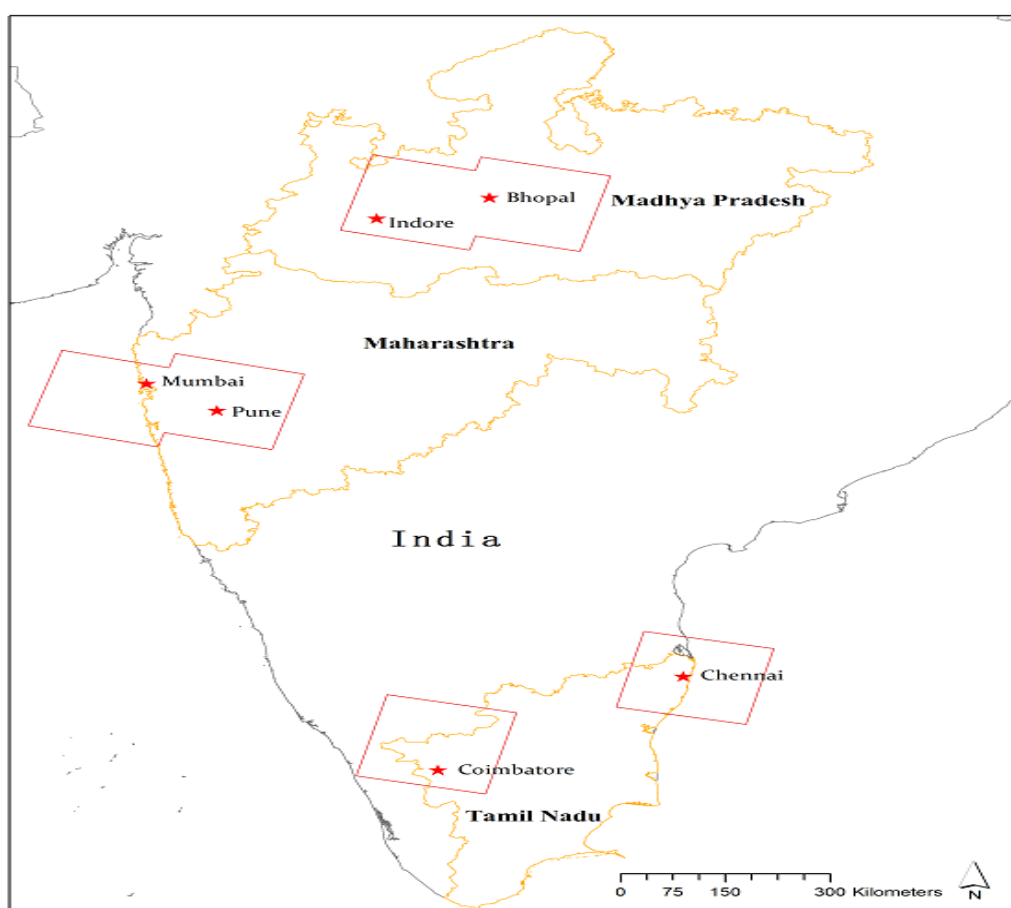


Figure 1. Geographical distribution of the state-level study regions and the selected surveyed cities.

2. Study Methodology

The targeted population was rural farmers who cultivate various types of crops on varying sizes of rainfed/irrigated lands. Two districts were selected from each state. In Maharashtra, Pune and Thane districts were selected for the survey study; Bhopal and Indore districts were selected in Madhya Pradesh

and Coimbatore and Kanchipuram districts from Tamil Nadu. These districts were selected due to the high agricultural activities, hence high biomass potential, and the high number of biomass-based and/or co-firing power plants either in the construction phase or in the pipeline. In each district, a number of villages were selected and visited: 11 and 21 villages in Pune and Thane, respectively; 9 and 12 villages in Indore and Bhopal, respectively; and 5 villages in Coimbatore and Kanchipuram districts.

The authors have developed a semi-structured questionnaires and later translated it into Hindi, Marathi and Tamil languages to conduct the pen and paper survey. In each state, bilingual tools were used for the survey. Field teams consisting of six members each were constituted to visit the villages and to meet and discuss with the local farmers. Each field team consisted of five investigators and one supervisor in each village; farmers operate in juxtaposition and with various land sizes. In some cases, a group of farmers gathered for the interview and were surveyed individually.

The first part of the survey is a census-like info sheet. It consisted of questions related to the farm size (rain-fed, irrigated), crops planted, number and types of livestock, uses of biomass, fuels used for cooking, shares of biomass used in various activities and, finally, the perceptions and willingness part. First, the census-like parts were scheduled to be published in a consecutive article in the special issue “*Bioenergy in BRIC countries*”.

The farmers’ ability, perceptions and willingness to supply surplus biomass were investigated by 10 statements with 4 possible answers (yes, no, don not know and remarks). The final section of this study consisted of 3 open-ended questions. The first question aimed at identifying the major obstacles the farmers might experience during the supply of biomass to an energy company; the second question addressed the benefits the farmers might get from selling biomass to an energy company and, finally, the possible impacts of a nearby biomass-based power plants on the famer’s livelihood and his community. Non-parametric tests, such as cross-tabulation and Kruskal–Wallis, were used to reveal any statistical differences among the three selected states. A copy of the English version questionnaire is available from the corresponding author via email. SIGMA India has been assigned to collect data from the field and data coding and entry, while the University of Eastern Finland (UEF) team and The Energy and Resources Institute (TERI) colleagues helped develop the survey tools, data analysis and results reporting.

3. Results and Discussion

In total, 471 farmers from the three surveyed states participated in this survey study. Roughly, one-third of the participants came from each state and its surveyed districts and villages. The agriculture economics of the participating farmers showed that around one-third of the farmers from Maharashtra state possess up to five acres of cropland, and some 38% hold from 5–10 acres. Up to 80% of the farmers in Maharashtra state produce up to five tons of non-food biomass annually, and about 62% of the farmers wish to sell their surplus biomass in a price range of 3000–6000 Rupees per ton (36–73 Euros/ton, 1 Euro = 70 Rupees, on 2 January 2015). In Madhya Pradesh state, about one-third of the farmers possess up to five acres of cropland, and 32% hold between five to 10 acres. Almost 75% of the farmers produce from one ton up to five tons of non-food biomass annually, and half of the farmers wish to sell their surplus biomass in a price range from 1000–3000 Rupees per ton (12–37 Euros/ton). In Tamil Nadu state, over half of the farmers (53%) possess from one up to five acres of land and 33% from five to

10 acres. Over 60% of the farmers in the surveyed districts in Tamil Nadu produce from one to five tons of biomass annually, and over 60% of the farmers in the surveyed districts in Tamil Nadu state wish to sell their surplus biomass in a price range of 1000–3000 Rupees per ton (12–37 Euros/ton). Differences in biomass prices among the states are a reflection of the biomass supply and demand nexus in varying climate conditions that, to a large extent, determine the scale of biomass availability and the degree of local consumption at the farm and household level [3,7].

3.1. The Farmer's Willingness to Supply Surplus Biomass to a Power Plant

The farmers' response frequencies to the willingness and perceptions statements are shown in Table 1. As indicated, the farmers from all states showed high willingness to supply surplus biomass to an energy producer (Item 1). The farmers' capability to supply biomass throughout the year (Item 2) showed that while around 85% of the farmers in Maharashtra and Tamil Nadu feel able to do so, only about half of the farmers in Madhya Pradesh are able to do so. The reason might be the agriculture outlook in Madhya Pradesh and the seasonal availability of biomass, besides the degree of reliance on biomass for other competing uses [3]. The farmers from all of the states largely agree that other farmers in their locality are also able to supply biomass for energy production, and they strongly believe that this process will generate extra income (Items 3 and 4). One of the key issues directly and critically involved in the biomass business-as-usual is the seasonal expenses associated with collecting crop residues from the field and storing them (Item 5). The other key issue is middleman involvement in the biomass procurement process from farmers (Item 6). For the former issue, only the farmers from Madhya Pradesh seem unwilling to spend resources in collecting biomass; farmers use their domestic animals to graze the crop fields, and in some cases, they burn the leftovers. Regarding the middleman concept, about two-thirds of the surveyed farmers in Maharashtra and Tamil Nadu appeared unwilling to have a middleman involved in the biomass purchasing process. In Madhya Pradesh, 79% of the farmers appeared also unwilling to have middlemen involved in their biomass selling process. During the field interviews, some farmers alluded to the middleman's unreliability and delay in paying the money to the farmers (see also Section 3.2 below). Other farmers talked about the middleman's subjugation and price control. The aforementioned issues might be common in Madhya Pradesh. On the other hand, and as a reflection of the middleman concern, the farmers showed explicit and high willingness to directly sell their surplus biomass to an energy firm (Item 7), particularly through contractual obligation (Item 8), clearly in Maharashtra state (97%) and to a lesser extent in Madhya Pradesh (79%) and Tamil Nadu (69%). In Maharashtra, a number of biomass-based power plants have been commissioned, which may explain the farmers' confidence in pursuing contracts, whilst a number of power plants have been shut down in other states due to increasing raw material prices; thus, this may have rendered the farmers ambivalent. Studies show that after power plant commission, the biomass price starts to increase very rapidly. An example is Transtech Green Power Ltd. in Jaipur in Rajasthan [13].

State interventions, subsidies and incentivization policies are crucial to any market-driven business model; therefore, it is imperative to explore how the farmer's perceive this issue (Item 9). In this regard, slightly over 50% of the surveyed farmers in Maharashtra and Tamil Nadu states agree to have a governmental regulation over biomass prices. A rather high willingness from the farmers in Madhya Pradesh state for governmental intervention has been found. The degree of political trust in Madhya

Pradesh for the ruling party might have an influence on the farmer's perceptions. Previous experiences in India have shown that political parties that tend to publically support and favor the farmers' needs will harvest the majority of the farmers' votes, while a candidate with other intentions loses the election battle [11,25]. Bottom-up community-based renewable energy projects accompanied by high public participation and support are deemed more publically accepted, thus more successful than top-down development of large-scale schemes. They may also bring additional benefits, such as increased engagement with sustainable energy issues [26]. Moreover, milestone community-based initiatives in clean energy mini-scale projects have been documented in many European towns, such as Germany, Denmark and Austria [27]. In this study, almost all of the farmers from the surveyed states showed high willingness to participate in a village (community)-level association or society to regulate the biomass procurement method for an energy firm. In this context, the farmers may have perceived the association as another means for socialization, thus increasing the social cohesion of their society, but also as a tool to avert the negative influences of unanticipated market distortions and/or price fluctuations of biomass and other biomass-based fuels for domestic use.

Table 1. Farmers' willingness to supply surplus biomass to potential energy producers: Descriptive.

No.	Statement	State								
		Maharashtra			Madhya Pradesh			Tamil Nadu		
		Yes	No	DK ¹	Yes	No	DK	Yes	No	DK
1	Are you willing to supply crop residues from your land to an energy producer?	100%	0	0	93%	6%	1%	97%	3%	0
2	Do you think you could supply crop residues from your land throughout the year?	86%	14%	0	48%	51%	1%	84%	16%	0
3	Do you think there are other farmers in your area who are willing to supply crop residues for energy production?	93%	2%	5%	88%	4%	8%	95%	5%	0
4	Do you think supplying crop residues from your land would give you an extra income?	99%	1%	0	94%	6%	0	99%	1%	0
5	Are you willing to spend money in mobilizing crop biomass /residues from your land to mitigate the demand of energy producers?	77%	23%	0	32%	68%	0	62%	38%	0
6	Are you willing to sell crop biomass residues to middle-men / supplier supplying biomass to energy producers?	42%	58%	0	18%	79%	3%	39%	61%	0
7	Are you willing to sell crop residues directly to energy producers?	92%	8%	0	94%	6%	0	97%	3%	0
8	Are you willing to go for a contractual obligation with energy producers for supplying the crop residues from your land?	97%	3%	0	79%	18%	2%	69%	31%	0
9	Do you want government to regulate the price of crop biomass residues for energy production?	53%	46%	0	89%	9%	2%	57%	43%	0
10	Are you in favor of a village-level cooperative body/ society that shall be involved in regulating the supply of crop biomass/ residues to the energy producers?	96%	4%	0	93%	5%	2%	97%	3%	0

¹ DK: I don't know.

A Kruskal–Wallis test has been used to reveal statistically significant differences among the three states. The test showed significant statistical differences between the states for all of the items, except for Items 3, 7 and 10 (see Table 1). Farmers in Maharashtra state appeared the most willing to supply surplus biomass to a power plant and throughout the year followed by farmers from Tamil Nadu, then Madhya Pradesh (Items 1 and 2, $p = 0.002$ and $p = 0.000$, respectively). However, farmers from Maharashtra state appeared the least willing to invest money in collecting and mobilizing crop residues and the least willing to have a middleman involved in the biomass procurement process (Items 5 and 6, $p = 0.000$ and $p = 0.000$, respectively), followed by farmers from Tamil Nadu and Madhya Pradesh. Furthermore, farmers from Maharashtra state appeared the most willing to sign a contractual obligation with an energy producer to sell their surplus biomass (Item 8, $p = 0.000$), and Tamil Nadu's farmer's appeared the most willing to sell their surplus biomass directly to an energy producer (Item 7). With no statistical difference, farmers from all of the states appeared in favor of a village-based association to sell their surplus biomass (Item 10). Another noteworthy statistical difference was found for the item related to the governmental intervention to control the biomass market and prices (Item 9). Farmers from Madhya Pradesh appeared largely approving of a governmental intervention followed by farmers from Tamil, with the least approval indicated by the farmers from Maharashtra state ($p = 0.000$). As stated earlier, these differences might have arisen from the nature of the political order and the degree of political trust in the surveyed state, as well as in the light of the current government's performance.

3.2. The Farmer's Perceptions of the Benefits, Impacts and Barriers in Establishing a Power Plant

The farmers' response to the open-ended questions have been categorized and coded in order to simplify the presentation of the results. These results will be presented hereinafter per state. In Maharashtra state, 55% of the farmers perceives the impacts of a nearby power plant positively in terms of employment opportunities for the local area and improving the biomass procurement process. Still, 39% of the farmers negatively perceives establishing a power plant, as they associate the power plant with air pollution (from burning the biomass), thus increasing the public health risks. The farmers experience on-site biomass burning or at home; therefore, they have developed such perceptions. In Madhya Pradesh, the farmers perceived the impacts of a nearby power plant only positively as it generates employment opportunities (58%), and 80% believed that the power plant may become a reliable and affordable source of electricity for them. The farmers in Tamil Nadu state perceived the impacts of establishing a power plant in their locality largely in a positive way. The main positive impact appearing, similar to Madhya Pradesh, is the ability to acquire reliable, stable and affordable electricity from the power plant. Some 10% of the farmers believed that a power plant might be a way to clean the environment. The farmers in Tamil Nadu, however, suggest establishing the power plant on wastelands, because they are not productive. A rather straightforward question the farmers were asked was to deliberately discuss the benefits of selling their surplus biomass to the energy producer. The farmers' answers centered on the extra income that they may get from the selling process (95% in Maharashtra, 90% in Tamil Nadu and 80% in Madhya Pradesh). The farmers also alluded to other benefits, such as seasonal working opportunities for locals, improved waste management and a cleaner environment. Of great importance are the barriers and challenges for supplying biomass to a biomass-based power plant.

Therefore, the farmers were asked to openly identify possible barriers to supplying biomass to a power plant. These barriers are presented in Figures 1–3 for the three surveyed states.

Regarding the farmers from Maharashtra state, the main barrier to supply biomass materials to fuel the power plant is the transportation costs and reliability (Figure 1). During the field excursions, the farmers discussed the logistical issues associated with biomass remobilization, where the existing transportation fleet is rather aging, unavailable, unreliable and sometimes costly. This is also accompanied by the poor road conditions in India in general. About 21% of the Marathi farmers alluded to the middleman's unreliability in terms of payment due time and the falling prices of biomass during the low-demand periods and good harvest seasons, and also the middleman's monopoly and hegemony over the biomass market in some villages or towns. In Madhya Pradesh (Figure 2), although 40% of the farmers indicated no barriers to supply biomass materials to a power plant, 16% discussed the transportation barriers and, equally important, the lack of seasonal workers to collect the crop residues from the field. It might be that such seasonal working opportunities are low paid, and therefore, it is difficult to find seasonal workers or the biomass is only collected free of charge by acquaintances to feed their domestic livestock. Furthermore, 12% of the farmers would not have financial resources to employ workers to collect the biomass materials.

In Tamil Nadu state, the majority of the farmers (90%) indicated no barriers to supply biomass to a power plant in their state. It might be that the biomass is very much available since this is a rice-oriented state, and that the biomass procurement chain and biomass market are rather mature in the light of the existing biomass-based industry, such as briquetting, and brick kilns. Only 10% of the Tamil farmers think that transportation logistics, the availability of feed for livestock and a lack of financial resources to collect the residues are barriers to supplying biomass materials for an envisioned power plant in their region.

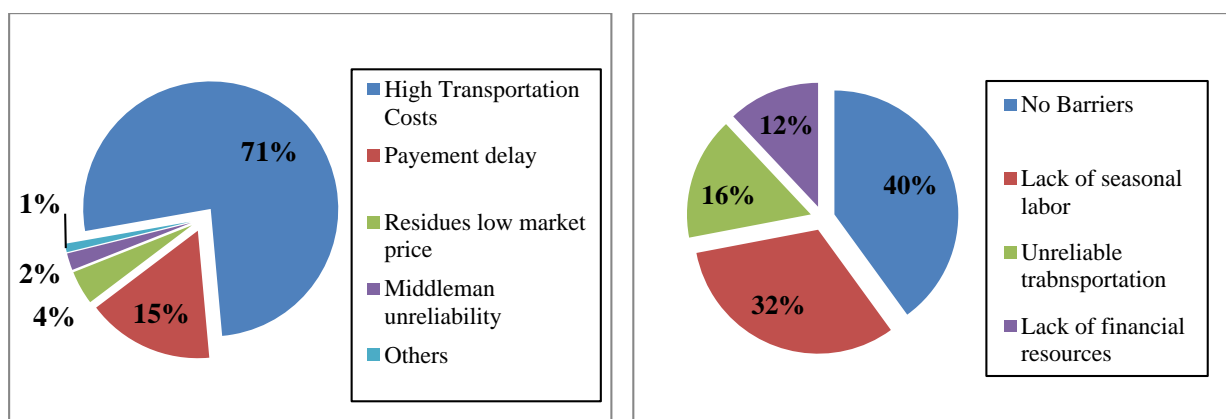


Figure 2. Barriers to biomass supply to a power plant in Maharashtra State (**left**) and Madhya Pradesh (**right**).

In the U.S., the farmer's age, gender, land leasing and nature of supply contracts appeared a noteworthy barriers to bioenergy development [16,18,19]. For instance, older farmers, female farm operators and those renting more land are less willing to supply straw to a biomass feedstock source [16]. The reason, as suggested by the authors, is that older farmers may not be willing to engage in uncertain business enterprises and appear unwilling to change their current production system. Moreover, the size of the

land, owning a baler, off-farm income, having experience with selling biomass and tillage practices are a number of factors affecting the farmers' willingness to supply biomass in Illinois, Missouri and Kansas of the U.S. [16,18,19]. In the U.K., similarly, older farmers appeared critical and more reluctant to change their current practices [20]. The reluctance to change, according to the authors, is largely due to farmers' confidence in the market and policies, lack of knowledge and that farming is not a purely economic occupation, but rather experiencing non-economic rewards, such as autonomy, outdoor activities and doing "interesting work" [20]. To conclude, studies have stressed the need to elevate the farmers' awareness and knowledge of bioenergy through outreach and training campaigns and clearly and appropriately designed support and incentivizing mechanisms for both farmers and investors to restore or increase the confidence in the bioenergy market.

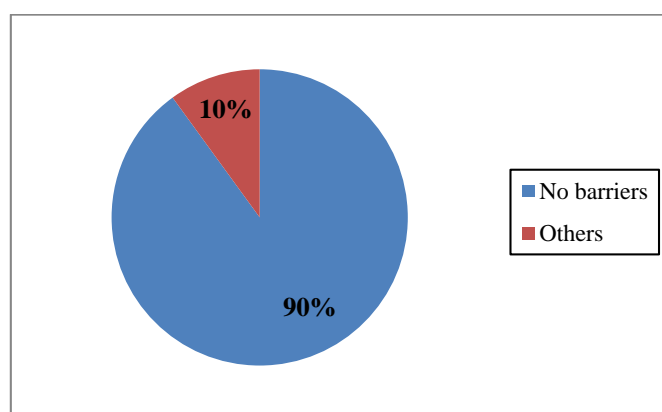


Figure 3. Barriers to biomass supply to a power plant in Tamil Nadu state.

4. Conclusions

This study revealed that Indian farmers from all of the states are willing to sell their surplus biomass directly, preferably without middleman involvement, to an energy producer. The majority of the farmers perceived the establishment of a biomass-based power plant in their region with positive economic outcomes. The farmers identified several barriers to supplying biomass to a power plant, with transportation logistics as a key barrier. From a technical point of view, the study recommends considering the biomass collection, processing (briquetting or pelleting), developing central biomass terminals and transportation logistics as a fundamental segment of any envisioned investment in a biomass-based power plant. The farmers may also benefit from the by-products, such as the ashes-as a mineral fertilizer for their agriculture fields. Public policies aimed at increasing the use of biomass for energy production purposes must be dynamic, aim at elevating the farmers' socio-economic status and crafted in a broader framework that accommodates socially-driven factors in biomass use for household activities (caste, education, religion, income, *etc.*) [7,11,13]. The government of India can itself play the role of the middleman by setting fair biomass prices on annual/seasonal bases and purchasing biomass from farmers in a district-wise terminal setup. These purchased quantities can be processed, stored or resold to private energy production facilities. In long-term strategic development actions, educating the poor farmers and housewives and elevating their cognitive knowledge of "fuel switching" options would lay the foundation toward more sustainable, socio-economically and environmentally-resilient rural Indian communities.

Acknowledgment

This study was conducted by the School of Forest Sciences, University of Eastern Finland (UEF), under the research project titled “*Sustainable Bioenergy Solutions for Tomorrow*” Working Package 2 Task 2.3 Case India (BEST-SHOK project), jointly coordinated by the Finnish Bioeconomy Cluster (FIBIC) and the Cluster for Energy and Environment (CLEEN), with funding from the Finnish Funding Agency for Innovation (TEKES).

Author Contributions

Anas Zyadin and Karthikeyan Natarajan wrote the manuscript. Suresh Chauhan and Singh Harminder helped in developing the survey tools, assisted in data collection in the field and commented on earlier versions of the manuscript. Kamrul Hassan helped in developing the survey tool and commented on earlier versions of this manuscript. Ari Pappinen and Paavo Pelkonen supervised the process of setting the research outline, creating survey tools and providing assistance on the structure of and commenting on the earlier versions of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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