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# Perspectives of Feedstock Supply for Biomass-Based Energy Plant Development in India: Views from an Expert Survey

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**Abstract:** Utilization of renewable energy resources is imperative due to energy access, energy security, and energy sustainability coupled with the rising environmental concern. India is one of the largest land mass countries in the world and amply bestowed with biomass resources. Investigations on biomass supply potential, socio-economic challenges, local people attitudes, current bioenergy markets, and technologies are prerequisite while seeking to develop sustainable energy plants. The study aimed to assess expert attitudes on wood-based energy development in India. This assessment was based on the opinions of Indian Forest Service (IFS) officers who are involved in managing wood-based biomass resources in different parts of the country. The study gave emphasis to the advantages, problems, and directions of the biomass based energy development in the country. The results showed that the development of biomass-based energy plants involves a number of challenges both locally and nationally. In addition, the study also highlighted the possible benefits of developing biomass based energy plants at local and national levels. The outcomes of this study provide useful information to the policy decision makers, energy entrepreneurs, and other stakeholders in the development of biomass based energy in India.

**Keywords:** Indian forest service (IFS) officer; perception; bioenergy; supply potential; challenges; India

## 1. Introduction

India has the world's second largest population of 1.24 billion in 2011 and the world's seventh largest landmass spanning over 328 million hectares [1]. The country has achieved rapid and remarkable economic development in the past two decades and in 2011 became the world's tenth largest economy. India is expected to take over China as the world's most populous nation by 2025 [2]. The consequence of both economic and population growth is expected to increase energy demand by about 3.9% annually until the year 2025 [3].

Presently, about 95% of India's current commercial energy demand is met by domestic production of coal (51%), natural gas (9%), and imported oil (35%), while the rest is satisfied by hydropower and nuclear energy. Although the Indian economy has grown at 7% annually since 2000, it has failed to achieve a balanced economic growth between urban and rural areas [2]. For instance, 37% of the national population and 42% of the rural population live below the poverty line. The fast economic growth did not remarkably improve the energy sector and India remains energy poor in many parts of the country [4]. Nearly one-quarter of the national population and 44% of the rural population do not have access to grid electricity [5,6]. Per capita electricity consumption is only 814 kWh, which is only 24% of the world average [6]. In India, biomass still constitutes the predominant sources of energy and it contributes to about 30% of the total primary energy supply [7]. Nearly 70% of the country's population lives in rural areas where they mostly use biomass for cooking and space heating applications.

Several policies had been formulated by the Government of India aimed to increase domestic production of biomass fuels. Biomass fuel has been recognized as a local, widely accessible and renewable resource, and potentially the most suitable to alleviate the macro and micro level energy crisis [8,9]. It has been considered one of the most promising resources for achieving the national energy target [7]. However, lack of information related to the opportunities and challenges associated with the promotion of bioenergy in the perspective of environmental and socio-economic concerns has been identified as the major challenge to modernize biomass based energy in India [7–10]. In addition, various challenges associated with the development of large-scale bioenergy projects are recognized as: lack of available land for energy crop plantations; lack of information on the impacts of bioenergy production on food security; and lack of institutional, financial, and initiatives in promotion of bioenergy marketing [11]. A recent study revealed that lack of public acceptance, political support, available technology, and infrastructure are the major hindrances in the development of forest-based bioenergy projects in India [12].

However, the above bottlenecks are very common in the promotion of bioenergy, not only in India but also in other developed and developing countries. Studies from the United States of America [13], United Kingdom [14], Ireland [15], Sweden [16] and Finland [17,18], and developing countries such as China [19], Jordan [20], India [21], Nepal [22], and Bangladesh [23] recognized that public attitudes and perceptions are important elements in the development of bioenergy. Moreover, the gap in scientific knowledge and understanding of bioenergy among different stakeholders was identified as the major cause of failure in innovative renewable energy projects [24]. Expert knowledge and perceptions is therefore paramount from the everyday user's perspective in establishing a trust between stakeholders.

In the context of India, the Indian Forest Service (IFS) officers can be considered as one of the most important stakeholders in bioenergy related projects, since they are involved in implementation of forest,

environment, climate, rural development strategies, and policy frameworks. They are recruited by the Central Government through civil service examination and trained in forestry education. However, their services are placed under different state cadres and they are duly liable to both state and central governments. Information from the IFS officers is extremely useful for gathering first-level background information on the development of biomass-based energy projects in the country. The study was based on a questionnaire survey among the IFS officers, since they were involved in the implementation of national policies on forest, agriculture, energy, climate change, rural development, and other national agenda. The study aims to explore the IFS officers' perceptions towards various aspects of development of biomass-based energy projects in India and to identify the hindrances to its promotion. This study can be regarded as first-level background information for developing biomass-based energy projects in different parts of the country.

## 2. Materials and Methods

The study involved a questionnaire-based survey method of a group of IFS officers who participated in the 'Mid-Career Training' program at the University of Eastern Finland during autumn 2013. There were 31 IFS officers participating in the survey: one each from Assam, Himachal, Haryana, Jammu and Kashmir, Punjab, Sikkim, and Tamil Nadu states; two each from Arunachal Pradesh-Goa-Mizoram Union Territories, Kerala, Karnataka, Maharashtra, Rajasthan, and Uttarakhand; three each from Andhra Pradesh and West Bengal; and the remaining six from Madhya Pradesh. The officers participating in the survey were from the Indian Forest Service cadre of which seven were from 1995 batch, 22 from 1996 batch, and the remaining two from 1997 batch. All the IFS officers had more than 15 years governmental job experience in the field of forestry and related fields. The survey was based on IFS officers' knowledge and understanding of the relevant issue. The questionnaire applied in the survey consisted of both open and closed-ended items. The questionnaire consisted of three sections. In the first section, the questions were designed to assess the available and surplus forest and agriculture biomass feedstocks that have potential for bioenergy production. The second section consisted of wasteland issues related to the current utilization and prospects of energy wood plantation. The third section mainly focused on the socio-economic aspects of bioenergy development. Altogether about 30 (dichotomous, multiple choice, and Likert-type scale) questions were developed for this survey, of which 18 were open-ended and 12 were closed-ended. The open-ended questions mostly consisted of respondents' perceptions relating to items which were categorized into low, medium and high, so that the respondents could be able to express their cognitive knowledge on particular item. However, the closed-ended questions mainly consisted of the dichotomous type where the respondents had two options (Yes or No). A similar scaling frame was also adopted in analyzing public knowledge and perception in other studies [18–23]. The information obtained from the IFS officers was processed and analyzed with the statistical package SPSS version 19.0. Simple descriptive statistics such as frequencies and cross-tabs were applied to compare the average rating for different statements of the IFS officers. Moreover, the respondents' answers from open-ended questions were skimmed and consolidated statements. A copy of the full-form questionnaire is available from the corresponding author upon request.

## 3. Results and Discussion

### *3.1. Respondents' Perceptions on Biomass Supply Potential from Forest Resources*

#### 3.1.1. Biomass Supply Potential from Forests

Forest is the second largest land-use in India after agriculture, covering 22% of the total land of the country. It has been known that two to three million people are engaged in woodfuel collection, making it the largest source of employment in the energy sector of the country. The estimated amount of harvested woodfuel from the forests, and trees growing on homestead, farmlands, and common lands was 139 million tons in 2006 [25].

Woodfuel forms the main available forest-based biomass resource in the country. To know the IFS officers' perception on supply potential of forest-based biomass for bioenergy production in their respective states, about 60% of the respondents stated that the potential of such biomass from forests was quite low. However, about 25% of the respondents viewed that the potential of forest-based biomass was medium; while only about 15% of survey respondents informed that the potential was high. The results revealed that in most of the states the forest biomass potential was low, with the exception of the states of Andhra Pradesh, Kerala, Madhya Pradesh, and Uttarakhand, where the potential varied between medium to high. Subsequently, the respondents were asked whether there was a possibility of increasing the potential of forest biomass in their jurisdictions or not. In this regard, about 60% of survey respondents informed that the biomass potential could be increased in the future. At the same time they also identified the main driving factors, which could be the raising of new plantations with fast growing tree species and intensifying the collection of logging residues during forest harvesting. However, about 40% of the respondents considered that the potential of forest biomass would not be increased, mainly due to the shrinkage of the governmental forest resources, lack of suitable land for afforestation, fewer tree resources on privately owned land, and imposed government regulations (e.g., felling ban in natural forests). In fact, the dense forests are degrading into scrub or sparsely covered forest areas, and/or conversion into secondary plantation areas, in many states. For instance, in the northeastern region, which holds one-fourth of the country's forest, cover has declined by 627 $km^2$ since 1991.

#### 3.1.2. Biomass Supply Potential from Forest-Based Industries

Saw mills represent one of the main wood-based industries in India. Various wood residues such as bark, off cuts, and saw dust are produced in saw mills while processing round wood into primary wood products. The respondents were asked to provide information about the existence of saw mills and the supply potential of saw mill residues in their respective jurisdictions. About 55% of the respondents' stated that the supply potential of saw mill residues was between medium to high while about 40% of the respondents informed that the potential was low because of the low volume of raw materials processed and intensified use of saw mill residues for cooking fuel. About 5% of the respondents did not provide any answer since they were not sure about the potential supply of such biomasses. The respondents viewed that biomass potential varies for each state. For instance, the survey revealed that the supply potential of sawmill residues was high in the states of Andhra Pradesh, Karnataka, Kerala, and Uttarakhand.

3.1.3. Biomass Supply Potential from Crop Residues

India has about 140 million hectares of arable and permanent crop land, which constitutes about 43% of the total geographical area of the country [26]. The main crops are rice, wheat, pulses, oil seeds, and other commercial crops including sugarcane, cotton, coconut, jute, mulberry *etc.* Cereals dominate the agricultural crops followed by pulses, cotton, and sugarcane. Several studies have revealed that the residues produced from agricultural crops are promising sources for bioenergy generation in India [27]. The estimated potential of crop residues during 2005–2006 was about 317 million tons [25]. To know the extent of biomass supply potential from crop residues the respondents were asked to provide their opinions. About 60% of the respondents speculated that the supply potential was high to medium, while 35% viewed that it was low. Another 5% did not provide any answer. The results also revealed that the supply potential of crop residues varies for each state and each region depending on cropping patterns and use of agro residues for various domestic purposes such as cooking fuel, animal feed, thatching, mulching, and fencing. The respondents were asked to provide three most promising crops whose residues could be available for bioenergy production. The respondents selected a total of 18 promising crops of which the top 10 crops are shown in Table 1.

**Table 1.** Promising crops and their residue for bioenergy production ($N = 31$).

| No. | Crop | Type of Residue | Response (%) |
|---|---|---|---|
| 1 | Paddy | Straw, husk | 80 |
| 2 | Sugarcane | Baggasse, tops, leaves | 48 |
| 3 | Wheat | Sraw, husk | 43 |
| 4 | Maize | Stalks, cobs, | 38 |
| 5 | Ground nut | Shell | 34 |
| 6 | Pulses | Stalks, husk | 31 |
| 7 | Jute and mesta | Stalks | 28 |
| 8 | Mustard seeds | Stalks, husk | 16 |
| 9 | Cotton | Stalk, husk | 15 |
| 10 | Coconut | Frond, husk, shell | 14 |

*3.2. Respondents' Perceptions on Energy Wood Plantation on Government and Privately Owned Lands*

3.2.1. Aspects of Energy Wood Plantation on Government Lands (Other than Waste Lands) and Privately Owned Lands

It has been reported that more than 55 million hectares of wastelands are available countrywide, of which nearly 20 million hectares of lands are designated as barren and uncultivated [10]. The barren and uncultivated lands are not generally suitable (due to low soil nutrients, low soil moisture, steep or terrain landscape *etc.*) for agricultural practice, since it involves high investment cost and low economic output. Part of these lands and degraded forest lands can be exploited for energy wood plantation through afforestation/reforestation and forest enrichment programs. In this regard, the respondents were asked to provide three suitable tree species that can be promising for energy wood plantation on different types of uncultivated lands, such as: marginal lands of roadsides, railway tracks, and embankments; forest

lands; fallow lands; and lands belonging to the local body. The respondents provided some 30 suitable tree species. The top 10 preferred tree species for wood energy plantation on government and private owned lands are shown in Table 2.

**Table 2.** Suitable tree species for energy wood plantation on government and private uncultivated lands ($N = 31$).

| No. | Tree Species | Response (%) |
|---|---|---|
| 1 | *Acacia spp.* | 77 |
| 2 | *Eucalyptus spp.* | 58 |
| 3 | *Prosopis juliflora* | 50 |
| 4 | *Leucaena leucocephala* | 26 |
| 5 | *Populus spp.* | 24 |
| 6 | *Pongamia pinnata* | 20 |
| 7 | *Casuarina spp.* | 14 |
| 8 | *Shorea robusta* | 12 |
| 9 | *Quercus spp.* | 11 |
| 10 | *Melia azedarach* | 9 |

Tree planting on both governmental and privately owned lands is considered an emerging potential tool for halting misuse and over-exploitation of the lands and environmental degradation in India [28]. Planting trees eventually helps in forest restoration and increases forest biomass resources. However, wood-based biomass development on both government and privately owned lands involves a number of institutional and policy barriers. In this regard, the respondents were asked to provide three main challenges related to the development of wood-based biomass resources on both government-owned and private-owned lands. It appeared that most of the challenges were considered to be lack of societal knowledge and awareness of future biomass fuel supply and lack of adequate governmental policy on land management, followed by small land holdings by the farmers (Table 3).

**Table 3.** Main challenges for production of wood biomass on government (other than waste lands) and private owned uncultivated lands ($N = 31$).

| No. | Type of Challenge | Response (%) |
|---|---|---|
| 1 | Lack of knowledge and awareness in society of future biomass fuel supply | 60 |
| 2 | Lack of adequate governmental policies on land management | 57 |
| 3 | Small land holdings by the farmers | 51 |
| 4 | Lack of management of existing forest resources | 42 |
| 5 | Lack of suitable land for afforestation | 33 |
| 6 | Biotic pressure on existing land and forests resources | 30 |
| 7 | Lack of motivation of farmers | 27 |

Further, the respondents were asked to provide their opinion on the severity of woodfuel collection from the existing forest resources. About 90% of the respondents considered that the present practices of woodfuel collection from the forests were not sustainable and putting negative impact on the health and vitality of the existing forest resources. They also considered that such practices were the major cause of concerns for forest deterioration and forest degradation in the country. About 10% of the

respondents stated that the impact of woodfuel collection on existing forests was low, but rather high for other causes, such as intensifying of forest land for agricultural activities, especially for cropping and grazing.

### 3.2.2. Aspects of Wood Energy Plantation on Government Owned Wastelands

Wasteland in India is described as "degraded land which can be brought under vegetative cover with reasonable effort (and cost), and which is currently under-utilized or land which is deteriorating for lack of appropriate water and soil management or on account of natural causes" [29]. Wastelands in India are mainly categorized into cultivable and non-cultivable. Cultivable wastelands such as degraded forestlands, degraded pasture lands, shifting cultivation areas, and mining wastelands can be brought under afforestation programs [30]. Due to differences in definitions of land categories, specifically identification of wastelands, however, there are many inconsistencies exist concerning the statistics of wastelands in India. For instance, the National Remote Sensing Agency (NRSA) has estimated that there are about 55.27 million ha of wastelands in India [29], whereas the National Wasteland Development Board has estimated an area of 123 million ha under wastelands [31]. Nevertheless, since the last couple of decades, there were many interventions taking place to halt further degradation and rejuvenate of these wastelands, particularly under the Joint Forest Management (JFM) program aiming to bring such land under tree cover [28].

In order to investigate the availability and status of the wastelands, about 60% ($N$ = 31) of the respondents stated that there are available wastelands in their respective states, whereas about 35% of them informed about non-availability of wasteland, and remaining 5% of the respondents did not give any answer and it was assumed that they were not sure about either the availability or non-availability of wastelands in their respective states. Subsequently, the respondents were asked to provide information about the current status of the available wastelands. Of the respondents who informed about the availability of wastelands in their respective states, about 89% ($N$ = 19) stated that most of the wastelands were occupied mainly for human settlement and crop fields and only 11% informed that the lands were vacant and ready for bioenergy plantation.

Further, the respondents were asked to provide the three suitable tree species for energy wood plantation on wastelands which are not suitable for cultivation. Based on their experiences, they selected some 25 tree species. *Acacia spp., Dalbergia sissoo, Prosopis juliflora* and *Eucalyptus spp.* were considered the top most promising tree species. However, according to the respondents' preferences, the top 10 most promising tree species for energy wood plantation on wasteland are given in Table 4.

The respondents were asked to provide their views on prospects for energy wood plantations on wastelands. About 95% of them viewed that energy wood plantations on wastelands have enormous prospects. At the same time they pointed out that raising energy wood plantations on such types of land requires a number of policy interventions, including political will and a long-term budget. They appraised that such afforestation programs could increase forest resources, improve supply of firewood, and eventually reduce the biotic pressure on the existing forest resources (Table 5). Moreover, they also emphasized that raising energy wood plantations on wastelands could help in improving environment and creating job opportunities for the local community. However, 5% of the respondents were not positive towards energy wood plantation in wastelands, as they considered that such afforestation

programs could affect existing livelihood systems (e.g., grazing and cropping practices) of the local communities. In fact, wood-energy production on wastelands in India involves a number of impediments, including land tenure barriers and low productivity of plantations [27,28].

**Table 4.** Suitable tree species for energy wood plantation on wasteland ($N = 31$).

| No. | Tree Species | Response (%) |
|---|---|---|
| 1 | *Acacia spp.* | 65 |
| 2 | *Dalbergia sissoo* | 55 |
| 3 | *Prosopis juliflora* | 50 |
| 4 | *Eucalyptus spp.* | 31 |
| 5 | *Tectona grandis* | 25 |
| 6 | *Shorea robusta* | 20 |
| 7 | *Leucaena leucocephala* | 20 |
| 8 | *Azadirachta indica* | 15 |
| 9 | *Casuarina spp.* | 10 |
| 10 | *Pongamia spp.* | 10 |

**Table 5.** Respondents' answers on possible benefits derived from energy wood plantation on wastelands ($N = 29$).

| No. | Reason | Response (%) |
|---|---|---|
| 1 | Increase forest resources | 92 |
| 2 | Improve supply of firewood | 66 |
| 3 | Reduce pressure on existing forest resources | 43 |
| 4 | Proper utilization of land | 42 |
| 5 | Improve environment | 39 |
| 6 | Opportunities for employment and income | 18 |

The respondents were asked whether they consider that raising energy wood plantations on wastelands could be a challenging issue or not. About 83% of the respondents commented that such afforestation program on existing wastelands could be a challenging issue. They considered that the main challenge for implementation of such programs on wastelands could arise from the social perspectives: for instance, the need to evacuate the encroached wastelands from the local people since most of the wastelands are occupied by local people. In addition, they also considered other challenges, such as political influences, grazing, and controversy regarding land ownerships, which are underlying factors for implementation of energy wood plantation on wastelands. They considered that energy wood plantation on wastelands involves a great challenge since most of the wastelands had been illegally occupied by the local people. They expressed that political willingness, and support from local communities and local governmental agencies are essential to implement afforestation programs on wastelands, as are the increase of investment in the forestry sector, financial incentives for farm and community forestry, tuning of wastelands leasing procedure from captive plantation to forest-based industry, and reviewing of existing policies, laws and regulation related to forestry [28].

About 17% of the respondents were not in agreement with the proposition of energy wood plantation on wastelands. They considered that such programs could put negative impacts on agricultural practices,

such as the grazing of livestock, which is the main source of livelihood of many local communities. In addition, they also explained that the controversy of ownership of many wastelands was remained unsolved. The dispute on ownership of wasteland is reported to be a common phenomenon in many states of India, *i.e.*, Orissa and Madhya Pradesh [32], which is one of the major challenges for implementation of afforestation programs on such lands.

### *3.3. Respondents' Perceptions on Socio-Cultural Aspects of Bioenergy Promotion*

#### 3.3.1. Local People's Dependency on Biomass Resources

In this section, the survey was extended to explore the IFS officers' perceptions on various socio-cultural perspectives of bioenergy promotion in India. The first six questions mainly focused on knowing the local people's dependency on the existing biomass resources and their willingness in supplying biomass for bioenergy plants (Table 6). It appeared that the local inhabitants were highly dependent on existing forest for woodfuel, especially for cooking and heating purposes (Item 1), whereas the dependency on crop residues for the same purposes was medium (Item 2). It indicated that woodfuel dominated in overall biomass fuel consumption. The results revealed that the local people have had a high level of willingness to plant trees on wastelands (Item 5) rather than on other government (Item 4) and privately owned lands (Item 3). It also indicated that the local people were more interested in using their land for crop cultivation than for tree planting (Item 6).

**Table 6.** Respondents' perceptions on the dependency of local people on biomass resources and their willingness in planting trees.

| Item Question | Response (%) | | |
|---|---|---|---|
| | **High** | **Medium** | **Low** |
| 1. Extent of woodfuel dependency on existing forest resources among local people | 76 | 10 | 14 |
| 2. Extent of crop residues dependency among local people for cooking fuel | 31 | 36 | 33 |
| 3. Willingness of local people for planting trees on private lands for woodfuel supply | 14 | 19 | 67 |
| 4. Willingness of local people for planting trees on government lands for woodfuel supply | 20 | 50 | 30 |
| 5. Willingness of local people for planting trees on wastelands for woodfuel supply | 53 | 31 | 16 |
| 6. Willingness of local people's to cultivate energy crops for meeting cooking fuel supply | 11 | 11 | 78 |

#### 3.3.2. Local People's Attitudes towards Bioenergy Promotion

Forestry experts' opinions are considered as an important element for bioenergy development in many developed and developing countries [17–22]. Hence, the IFS officers were asked a set of questions related to the local people's attitudes towards bioenergy promotion (Table 7). The results revealed that the existence of a bioenergy plant may influence the local people towards development of bioenergy resources and promotion of a bioenergy market. Nearly half of the respondents answered that the existence of a bioenergy plant could influence the local people to plant trees on their own lands (Item 1 in Table 7), although the local people would not be motivated enough to plant trees on their lands if there is no existence of a bioenergy plant (Item 3 in Table 6). It could be speculated that the existence of a bioenergy plant has had an influence on the local people in planting trees on their lands. Such attitudinal change could be due to the existence of a bioenergy plant which could also provide guarantees for

development of markets of local wood and other biomass products (*i.e.*, biomass fuel). It is obvious that farmers always look for competitive markets for selling their products; for biomass fuel is more significant since it is a non-food material, and selling of such biomass fuels always involves uncertainties. In this regard, the existence of farming contracts could help in reducing uncertainties and promoting trust between farmers and bioenergy plant operators. About three quarters of the respondents informed that there was no such contract existing in their region (Item 2 in Table 7), with the exception of the respondents from Karnataka and Kerala, where some contracts existed between farmers and biomass plant operators. Nevertheless, farmers' motivation towards tree planting on their lands and farming contracts are worth consideration in the sustainability aspects of a bioenergy plant.

**Table 7.** Respondents' views on local peoples' attitudes towards bioenergy promotion.

| Item Question | Response (%) | |
|---|---|---|
| | Yes | No |
| 1. Respondents' answer on whether the existence of a bioenergy plant could attract the local peoples' towards planting trees on their own lands | 62 | 38 |
| 2. Respondents' answer on whether there is presently any farming contract existed between farmers and biomass-based companies (e.g., pulp and paper mills, biopower) | 27 | 73 |
| 3. Respondents' answer on whether introducing of farming contract could enhance and ensure supplying feedstock for bioenergy plant | 76 | 24 |
| 4.Respondents' answer on introducing of public-private forest management (e.g., JFM for instance) can be useful for motivating local people for energy wood plantations on public and private lands | 91 | 9 |
| 5. Respondents' answer on the influences of a bioenergy plant (if exist) to the local peoples' willingness for selling their forest products | 70 | 30 |
| 6. Respondents' answer on the influences of a bioenergy plant (if exist) to the local peoples' willingness for selling their crop residues | 75 | 25 |

The majority of the respondents suggested that the introduction of farming contracts could enhance and ensure the supply of feedstock to the bioenergy plants (Item 3 in Table 7). One of the mechanisms of such farming contracts could be the JFM, which is commonly practiced in many parts of India for enhancing tree resources in degraded forest lands through "co-management" between the local people and the forest department [31]. Over 90% of the respondents considered that such a mechanism could be a useful tool for motivating farmers for energy wood plantation on public forest lands (Item 4 in Table 7). Nonetheless, the majority of the respondents viewed that the existence of bioenergy plants could also influence the local farmers to sell their wood products and crop residues to the bioenergy plants (Items 5 and 6, in Table 7, respectively). However, the results indicated that the existence of bioenergy plants could have immense impact on changing the local farmers' attitudes towards production and supply of both wood and agricultural based biomasses.

### 3.3.3. Local Bioenergy Market Dynamics

Development of a market is considered an important element for promoting bioenergy [33,34]. The IFS officers were asked whether there were markets in their area where local people could have

opportunity to sell their forest products and crop residues. About 62% of the respondents stated that there were markets in their respective states where the local people sell their forest products, *i.e.*, woodfuels. Woodfuels markets seemed to be well developed in most of the States, particularly in Kerala, Karnataka, Tamil Nadu, and Uttarakhand. About 60% of the respondents informed that there were no markets in their respective states for selling crop residues. This indicated that crop residues based markets had not yet been developed well in most of the States, particularly in Madhya Pradesh, Maharashtra, and West Bengal, where vast amount of lands are utilized for crop cultivation. The small-scale commercial enterprises (mostly restaurants, bakeries, brickfields) are the main buyers, followed by households, for both wood and non-wood biomass fuels (mainly crop stalk and animal dung). About two-thirds of the respondents informed that mainly women brought biomass fuels to the local markets for selling.

The respondents were asked whether middlemen were involved in the local trade of woodfuel and crop residues or not. About half of the respondents stated that there were middlemen involved in the trade of both woodfuel and crop residues in their areas, whereas about 30% of them informed that there were no middlemen involved in the local trade of biomass fuels, as the farmers would sell their products directly to the buyers. However, 20% of the respondents did not give any answer about the involvement of middlemen in the trade of biomass fuels. The reason might be that the respondents were not aware of the trade of local biomass fuels in their area. Nevertheless, the respondents pointed that the market price of (air dried basis; moisture content ~20%–30%) woodfuel and crop residues depended on the dynamics of demand and supply. Based on the data the average price of woodfuel was about Rs. 4300 ($73) per ton and for crop residues (residues from cereals) it was about Rs. 3300 ($55) per ton.

#### 3.3.4. Aspects of Municipal Waste to Energy

Municipal Solid Waste (MSW) is used for power generation in many developing countries like India. Over 90 million tons of MSW is generated annually by Indian cities as by-products of industrial, municipal, agricultural and other processing [35]. The Ministry of Non-Conventional Energy Sources, Govt. of India, launched several projects under “National Programme on Energy Recovery from Urban, Municipal & Industrial Waste”. Concerning the potential of MSW for energy, the IFS officers were asked about the availability of MSW in their area. About two-thirds of the respondents informed that there was unutilized MSW available in the municipalities, which could be utilized as feedstock for bioenergy plants. However, about 20% of them informed that the amount of generated waste was not enough to produce energy which is economically viable from it. Regarding the current practice of waste disposal, about 78% of the respondents informed that MSW were mainly dumped in the designated dumping sites. Other significant practices of waste disposal were for landfills (12%) and open burning (10%). The majority of the respondents stated that a number of waste pickers are involved in picking valuable recycling materials (*i.e.*, plastic, rubber, and metal) before final disposal of MSW. The pickers mainly collect recyclable materials from the dumping sites and sell them to the local markets. The collection of recyclables forms the main source of their livelihoods. Such types of waste-based livelihood dependency were reported in most of the cities in India and many other Asian countries [35].

### 3.3.5. Technological Development Aspects of Bioenergy

In order to recover energy from biomass, there are several national policies on fiscal and financial incentives that have been launched to attract private and public sector entrepreneurs and investors in the development of biomass-based power projects in India. There are several biomass-based energy technological options, such as combined heat and power (CHP), biogas, and bioliquid available, which are supported by the policy. With regard to the suitable technological options, about 46% of the respondents suggested that biogas would be the most suitable for promotion of bioenergy in an Indian context, while about 27% supported CHP, and about 14% suggested bioliquid (*i.e.*, bioethanol, bio-diesel). About 73% of the respondents viewed that the installation of biomass-based energy plants would be possible in their area. However, only 9% of them did not consider the possibility of such installations in their area due to insufficient supply of biomass feedstock. Nonetheless, the respondents were asked to select the most promising biomass that is ready for energy production. They considered that the most readily available biomass for a bioenergy plant could be municipal wastes (52% of the respondents ranked 1st), crop residues (23% ranked 1st), forest biomass (14% ranked 1st), and agro-industrial residues (11% ranked 1st).

Nevertheless, the modernization of biomass for energy use in India involves a number of challenges from technological, environmental, and socio-economic aspects [8]. Considering these issues, the respondents were asked to provide the most challenging issues which were underlying bioenergy promotion in India. From a feedstock supply point of view, the majority of the respondents identified that lack of harvesting technology as the main challenge, followed by lack of suitable terminals for storage of biomass feedstock (Table 8). Although modern bioenergy technologies offer a number of biomass conversion pathways, such as gaseous (*i.e.*, biogas), liquid (*i.e.*, bioethanol, biomethanol), and solid (*i.e.*, briquette, pellets), the wide application of such technologies in India has not been well developed yet. Lack of research and development on biomass energy and lack of modern bioenergy technologies have also been considered as significant challenges for bioenergy promotion in India. Moreover, lack of initiatives for bioenergy market development and lack of logistics related to bioenergy transportation and distribution were also considered as the major issues regarding the entrance of this modern form of bioenergy into the society. It has been quite evident that due to institutional, technical, informational, market, and financial barriers, the rate of dissemination of bioenergy technologies was rather low [36,37].

### 3.3.6. Prospects of Biomass-Based Energy Development in India

Biomass is playing a significant role in energy dynamics and sustainable development in India [7]. The instant benefits of biomass fuels include local energy supply and poverty reduction in the rural areas of the country. In this regard, the respondents were asked to provide possible benefits of a biomass-based energy plant that could be received by the local people. Almost all respondents viewed that providing clean fuel would be the most significant benefit that could be derived from a biomass-based energy plant. In addition, about half of the respondents considered that an attractive benefit from a bioenergy plant could be the improvement of the local environment, as well as reducing biotic pressure on existing biomass

resources, while 45% of survey respondents emphasized that such a plant could eventually generate income for the local people, and only 5% supported economic development.

**Table 8.** Respondents' perception on challenges involved in modernization of bioenergy technologies in India.

| **A. Challenges Related to Feedstock Supply** | **Response (%)** |
|---|---|
| Lack of harvesting technology | 62 |
| Lack of terminals for storing biomass | 12 |
| Lack of suitable railway network for transportation | 7 |
| Lack of appropriate road network *i.e.*, short distance, cost-effective | 5 |
| Lack of cross-country highways for carry heavy load biomass | 5 |
| Lack of logistics for transporting of biomass *i.e.*, railcar, heavy truck | 5 |
| No answer | 5 |
| **B. Challenges Related to Technological Options** | **Response (%)** |
| Lack of biomass conversion technologies | 43 |
| Lack of related research and development | 29 |
| Lack of industrial-scale bioenergy plants | 14 |
| Lack of small-scale bioenergy plants | 5 |
| Other | 5 |
| No answer | 5 |
| **C. Challenges Related to Bioenergy Marketing** | **Response (%)** |
| Lack of initiatives for bioenergy market development | 48 |
| Lack of bioenergy transportation and distribution logistics | 33 |
| Lack of grid connection in rural area | 5 |
| Maintenance of existing power grids | 5 |
| Motor engines not ready for using biofuels | 5 |
| No answer | 5 |

India has a high potential for developing biomass-based energy program interventions [25]. The potential of biomass-based power generation installation capacity is estimated at about 16,000 MWe [5,7]. Until June 2011, there were only 2788 MWe biomass-based power plants commissioned, which was only 17.5% of the total biomass-based power installation capacity of the country [6]. However, the respondents were asked to give their views on the prospects of biomass-based energy plants in India. About 76% of the respondents viewed that biomass-based small-scale power generation plants would have enormous prospects while only 19% suggested this for large-scale biomass-based power plants. Biomass-based power has been recognized as an attractive industrial investment in India. The annual investment is estimated at over $130 million, harnessing about 5000 million kWh of electricity and providing employment about 10 million man-days [38].

## 4. Conclusions

The study focused on wood, crop, and MSW-based biomass feedstock supply potential in India to utilize them for bioenergy plants. The country has opportunities for promoting sustainable bioenergy by enhancing afforestation programs and intensifying other non-wood biomass resources. For instance,

bioenergy potential from forests is currently seen to be quite low, but can be substantially increased by the adoption of several interventions, such as implementation of afforestation programs in both private and public lands. Utilization of wastelands for energy plantation, selection of suitable tree species, intensifying the existing forest resources management, and reformation of policies related to forest, energy, and wasteland are critical interventions in the promotion of future forest-based bioenergy development in the country.

The potential for supplying biomass feedstocks from crops, especially residues from paddy, wheat, sugarcane, and maize, is promising. The availability of forest residues, wood processing residues, crop residues, and MSW, as well as animal dung, could make them potential feedstock for bioenergy plants. In this regard, it is imperative to undertake a detailed study of the investigation of promising crop areas, suitable cropping patterns, current utilization of crop residues, and farmers' willingness to sell their crop residues for bioenergy production. In addition, it is also important to conduct research on the sustainability aspects of supplying biomass feedstock, utilization of the resources, land-use policies, and livelihood of the local communities. There is also need to pay attention to land utilization for large-scale plantation programs and other biomass feedstock production in order to ensure that such practices will not bring negative impacts on food production systems, livelihood, and biodiversity.

However, lack of societal awareness of bioenergy promotion, lack of appropriate bioenergy technologies, and lack of policy directives for good practice could be limiting factors in promoting biomass-based energy development in the country. In addition, lack of infrastructure for bioenergy could also become a challenge for the penetration of modern biomass technologies into India. The government, private, and international investors should take steps towards investing in agriculture and forestry for the production of biomass feedstock and the establishment of biomass-based energy plants in India.

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## Author Contributions

The first author involved in designing the questionnaire, analyzing the data and preparing the manuscript. The co-authors were involved in designing of the questionnaire and improving the text of the manuscript. All authors have read and approved the final manuscript.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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