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Techno-economic Assessment of Biomass Pellets for Power Generation in India

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About the Authors

DR PALLAV PUROHIT

Dr Pallav Purohit joined the Air Quality & Greenhouse Gases (AIR) Program as a Research Scholar in September 2007. He has developed and implemented the global F-gas (HFC, PFC and SF6 emissions) module in the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model and coordinating various policy applications involving GAINS model in developing countries. Before joining IIASA, Dr. Purohit worked as a Postdoctoral Research Fellow at the Research Program on International Climate Policy, Hamburg Institute of International Economics (HWWI), Germany where his focus was on a detailed technical evaluation of renewable energy options towards a more policy oriented analysis of the chances and risks of such technologies under the Clean Development Mechanism of the Kyoto Protocol. He was also a visiting faculty member to the Institute of Political Science at the University of Zurich, Switzerland and visiting fellow at the School of International Development, University of East Anglia, UK.

He is an Associate Editor for the International Journal of Global Energy Issues (IJGEI) and editorial board member of Sustainability, Innovative Energy Policies, Journal of Environment & Agricultural Studies, Journal of Renewable Energy, American Journal of Electrical Power & Energy Systems (EPES), International Journal of Sustainable and Green Energy, and The Open Renewable Energy Journal (TOREJ).

Dr. Purohit received his MSc in Physics from the H.N.B. Garhwal University, India in 1998 and his PhD in Energy Policy and Planning from the Indian Institute of Technology (IIT) Delhi in 2005. Between 1999 and 2005, Dr. Purohit worked at several institutions in India with a particular focus on energy, economic and environmental interactions.

DR VAIBHAV CHATURVEDI

Dr Vaibhav Chaturvedi is a Research Fellow at Council on Energy, Environment and Water (CEEW).
Prior to CEEW, Vaibhav worked as a Post Doctoral Research Associate at the Joint Global Change Research Institute (JGCRI), collaboration between the Pacific Northwest National Laboratory, USA and the University of Maryland, College Park, USA. He holds a PhD in Economics from the Indian Institute of Management Ahmedabad, India and Masters in Forest Management from the Indian Institute of Forest Management Bhopal, India.

His research is focused on Indian and global energy and climate change mitigation policy issues-carbon dioxide emission stabilization pathways, low carbon and sustainable energy policies, modelling energy demand, and water-energy nexus within the integrated assessment modelling framework of the Global Change Assessment Model (GCAM). Vaibhav's recent work includes analysing nuclear energy scenarios for India, Indian HFC emission scenarios, climate policy-agriculture water interactions, transportation energy scenarios, model evaluation, investment implications for the global electricity sector, and modelling the building sector energy demand scenarios for India. Vaibhav has been actively involved in global model comparison exercises like Asian Modelling Exercise (AME) and Energy Modelling Forum (EMF).

At CEEW, Vaibhav's research focuses on India within the domain of energy and climate policy, mid-range and long-range energy scenarios, HFC emission scenarios, urban energy demand pathways, and energy-water inter relationship. He has been actively publishing in leading international energy and climate policy journals.

Abstract

Biomass pellet production has increased considerably in recent years, mainly due to the demand created by policies and bioenergy-use targets in the European Union (EU). Global biomass pellet production was 24.1 million tonne (Mt) in 2014. In this study, a preliminary attempt has been made to assess the techno-economic feasibility of biomass pellets for electricity generation in India produced from biomass surplus available from agriculture and forestry/wasteland. Biomass surplus availability from agriculture and forestry/wasteland for biomass pellet production is estimated at 242 Mt for 2010–11, and is expected to rise to 281 Mt in 2030–31 due to increased crop production and associated waste/residue availability. The surplus biomass availability from the agricultural sector (123 Mt in 2010–11) alone is sufficient to substitute 25% of the current coal consumption in the power sector (through co-firing of coal with biomass pellets).

In terms of related capacity, the potential of biomass pellet-based power (BPBP) projects is estimated at 30 GW for 2010–11 and 35 GW for 2030–31. The associated CO_2 mitigation potential resulting from the substitution of coal is estimated at 192 and 205 Mt CO_2eq in 2020–21 and 2030–31 respectively if the entire biomass surplus available from the agricultural and forestry/wasteland sectors were to be diverted for power generation. Using a simple framework for determining the techno-economic feasibility of biomass pellets, the pellet production cost is estimated at INR 4,473/ tonne for a 1,500 kg/hr capacity biomass pellet unit. The levelised cost of electricity is estimated at INR 8.35/kWh for BPBP as compared to the INR 6.92/kWh for imported coal. For states with lower tariff for biomass power, the break-even price of carbon for BPBP projects is estimated at 18 Euros. Our preliminary estimates indicate that BPBP projects will currently generate employment of more than 5 million person-months in the construction of biomass power plants and over 200,000 full-time employments in the operation of biomass power plants and in the production of biomass pellets.

Keywords: biomass pellet, agricultural residue, biomass co-firing, levelised cost of electricity

1 Introduction

The depletion of fossil fuels (i.e. natural gas and oil) and the need to reduce greenhouse gas (GHG) emissions to levels that will avoid dangerous levels of human-induced climate change have resulted in the increasing use of biomass for heat and power production. Bioenergy accounts for roughly 10% (50 EJ) of the world's total primary energy supply today [1]. Most of this is consumed in developing countries for cooking and heating, using very inefficient open fires or simple cook stoves, with considerable impact on health (indoor air pollution) and on the environment [2–3]. Attempts to overcome the poor handling properties of biomass, i.e. its low bulk density and inhomogeneous structure, have led to increasing interest in the development of biomass densification technologies, such as pelletisation and briquetting [4–8]. When compared to other types of bioenergy, the pellet sector is one of the fastest growing. In 2013, 22 million tonnes (Mt) of pellets were produced worldwide in approximately 800 plants with individual capacity of over 10,000 tonne [9]. The annual growth of biomass pellet production has been close to 20% over the last decade [10], and has increased dramatically in recent years, mainly due to the demand created by policies and bioenergy-use targets in Europe [11]. The need for mitigating carbon dioxide (CO_2) emissions is an important reason behind the policies in Europe. Bioenergy is also being discussed as an important technology in the de-carbonisation of future global electricity production. Global bioenergy production could increase to 180 EJ in 2050 (compared to 50 EJ under BAU) under a 2.6 W/m^2 climate-policy scenario with the imposition of a carbon tax on both the fossil-fuel and land-use sectors [12].

The decreasing availability of fuelwood in most developing countries has necessitated efforts for more efficient utilisation of agricultural residues. In India, about 25% of total energy consumption is estimated to be met from various biomass resources, i.e. agricultural residues, animal dung, forest waste, firewood, etc. [13]. India produces a huge quantity of agricultural and forestry residues, a major part of which is used for domestic, commercial, and industrial activities, viz. fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc. [14–15]. Biomass constituted more than 85% of India's rural energy fuel consumption in 2005, the bulk of it being used for meeting cooking energy needs [16]. Raw agricultural residues have many disadvantages as an energy feedstock. These include (i) relatively low calorific value; (ii) variability of quality and calorific value; (iii) difficulty in controlling the rate of burning; (iv) rapid burning, necessitating frequent refuelling; (v) difficulty in mechanising continuous feeding; (vi) large volume or area required for storage; and (vii) problems in transportation and distribution [17]. Several of these disadvantages may be attributed to the low bulk density of agricultural residues. To improve the characteristics of agricultural residues for transportation, storage, and combustion (e.g., feeding into furnaces), it is necessary to upgrade the raw agricultural residues by increasing their bulk density.

An approach being actively pursued worldwide for the improved and efficient utilisation of agricultural and other biomass residues is their densification to produce pellets or briquettes. The advantages of briquetting or pelletisation of agricultural residues for boiler applications are that (i) the rate of combustion is comparable to that of coal; (ii) burning in grate-fired boilers is possible; (iii) uniform combustion can be achieved; (iv) particulate emissions can be reduced; (v) the possibility of spontaneous combustion in storage is reduced; and (vi) transportation, storage, and feeding are made more efficient. Other possible areas of application of briquetted or pelletised agricultural residues include firing in residential, commercial, and industrial heating systems [4]. They can also be used as fuel in wood stoves and external combustion engines, and as raw material for pyrolysis and gasification. Wood pellets in India are mostly used for residential cooking and heating (with pellet stoves) and/or commercial purposes [18–20]. For example, over 400,000 Oorja stoves (a combination of a uniquely designed 'micro-gasification' device or stove and a biomass-based pellet fuel) were sold between 2006 and 2010 in the Indian market [19]. In contrast, biomass pellets are being increasingly used for power generation in many countries. In Europe, North America and Asia (viz. China, Japan, and South Korea), wood pellets are mostly used for co-firing at coal-fired power plants [21–25]. It will be interesting to see how this application of biomass pellets has evolved in India.

In India, Section 86(1)(e) of the Electricity Act, 2003 requires the State Electricity Regulatory Commissions (SERCs) to determine and implement Renewable Purchase Obligations (RPOs). Subsequent to the Electricity Act, 2003, the National Action Plan on Climate Change (NAPCC) was adopted. It aims to derive 15% of India's energy requirements from renewable energy sources (non-solar) by 2020. The Jawaharlal Nehru National Solar Mission, launched in 2010, requires SERCs to set solar RPO targets starting from 0.25% by 2012–13 to 3% by 2022. To achieve the target set by NAPCC, India's Ministry of Power (MoP) launched the Renewable Energy Certificate (REC) mechanism in November 2010 [26]. Electricity generation through biomass pellets and/or co-firing of biomass pellets with coal can help to meet the RPO targets of SERCs in states with low solar/wind resources (and limited wasteland availability) and with extensive availability of agricultural and forestry residues, or these states can attract investment through REC mechanism. India's Intended Nationally Determined Contributions (INDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) before the 21st Conference of the Parties (COP21), also states that it is 'envisaged to increase biomass installed capacity to 10 GW by 2022 from the current capacity of 4.4 GW' as part of the overall goal of increasing the share of non-fossil fuel electricity generation capacity to 40% in the country's electricity mix by 2030 [27].

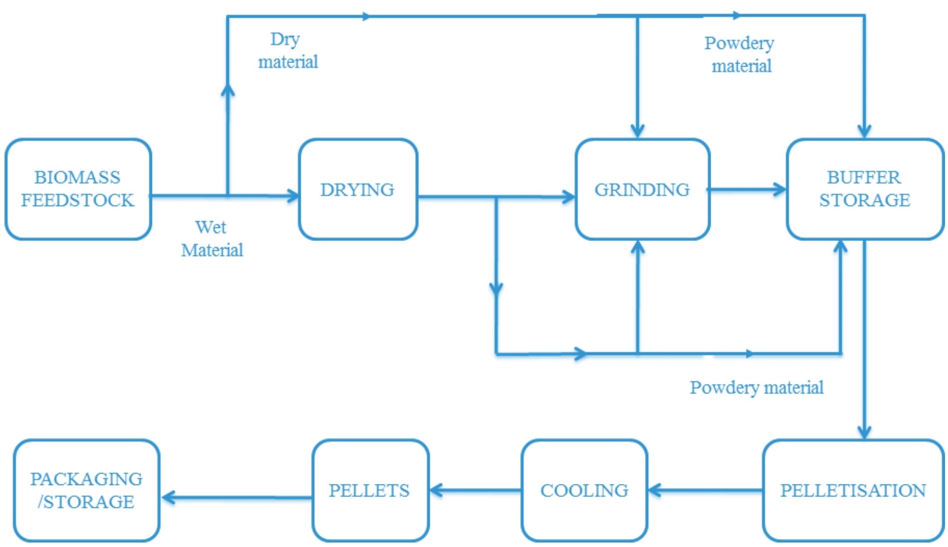
It is in this context that we will address the following research questions here: (a) What is the potential for the production of biomass pellets and corresponding generation of electricity in India up to 2030? (b) What is the production cost of biomass pellets? (c) What is the cost of electricity production from BPBP projects? and (d) Is a carbon price required for enhancing the financial viability of BPBP generation?

The paper is set out as follows: Sections 2 and 3 briefly describe the biomass pelletisation process and the status of the global trade in biomass pellets respectively. Section 4 describes the methodology of the paper. The results are presented in section 5, that is: (i) the estimates of the state-wise availability of agricultural and forestry residues for the production of biomass pellets; (ii) the potential of biomass pellets for electricity generation; and (iii) the techno-economic viability of biomass pellets for electricity generation and the associated carbon finance potential of biomass pellets. Section 6 briefly discusses the potential for employment generation in the biomass pellet-based electricity production value chain, the implications of the climate policy, and the international biomass pellet market. Finally, Section 7 presents the key findings and insights emerging from this study.

2 Biomass pelletisation process

The biomass pelletisation process consists of multiple steps, including pre-treatment of raw material, pelletisation, and post-treatment. Figure 1 presents the schematic of the pellet production process. The first step in the pelletisation process is the preparation of the biomass feedstock, which includes selecting a feedstock suitable for this process, and its filtration, storage, and protection. The raw materials used are sawdust, wood wastes, agricultural and forestry residues, etc. Filtration is done to remove unwanted materials like stone, metal, etc. The feedstock is stored in such a manner as to prevent contamination by impurities and moisture. In cases where there are different types of feedstock, a blending process is used to achieve consistency. The moisture content in biomass can be considerably high, and hence needs to be reduced to 10 to 15% [28]. Drying increases the efficiency of biomass, and it produces almost no smoke on combustion. However, the feedstock should not be over-dried, as a small amount of moisture helps in binding the biomass particles. The drying process is the most energy-intensive process and accounts for about 70% of the total energy used in the pelletisation process.

Figure 1. Flow diagram of pellet production process



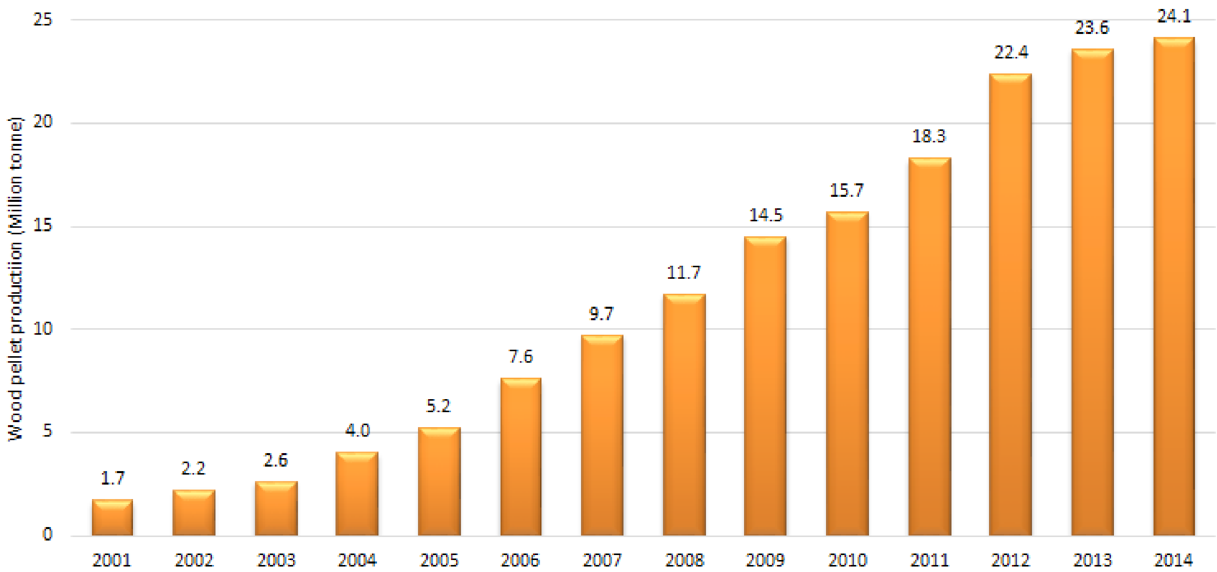
The biomass is reduced to small particles of not more than 3 mm before it is fed into the pellet mill. Size reduction is done by grinding, using a hammer mill equipped with a screen of size 3.2 to 6.4 mm. If the feedstock is quite large, it is put through a chipper before grinding. The next—and the most important—step is pelletisation where the biomass is compressed against a heated metal plate (known as a die) using a roller. The die has holes of fixed diameter through which the biomass is passed under high pressure. Due to the high pressure, frictional forces increase, leading to a considerable rise in temperature. The high temperature causes the lignin and resins present in the biomass to soften, which acts as a binding agent between the biomass fibres. In this way, the biomass particles fuse to form pellets. The rate of production and the amount of electrical energy used in the pelletisation of biomass are strongly correlated to the type of raw material used and to the processing conditions such as moisture content and feed size. The average amount of energy required to pelletise biomass is roughly 16 to 49 kWh/t [29]. During pelletisation, a large fraction of the process energy is used to make the biomass flow into the inlets of the press channels.

Binders or lubricants may be added in some cases to produce higher quality pellets. Binders increase pellet density and durability. Wood contains natural resins which act as a binder. Similarly, sawdust contains lignin which holds the pellet together. However, agricultural residues do not contain much resins or lignin, and so a stabilising agent needs to be added in this case. Distillers dry grains or potato starch are some commonly used binders. The use of natural additives depends on the biomass composition and the mass proportion between cellulose, hemicelluloses, lignin, and inorganics. Excess heat is produced by the friction generated in the die. Thus, the pellets produced are very soft and hot (about 70 to 90^{o}C). They need to be cooled and dried before they are stored or packaged. After they have cooled, they are packaged in bags or stored in bulk. Pellets can be stored indefinitely, but they must be kept dry to prevent deterioration.

3 Global biomass trade

In 2014, global production of biomass pellets rose by 8% to just over 24 Mt (Figure 2) as compared to 2012, continuing a strong upwards trend. The main biomass pellet-producing regions continued to be Europe (roughly 62%) and North America (roughly 34%). The top producers were the United States (26%), Germany (10%), Canada (8%), Sweden (6%), and Latvia (5%). The United States had an estimated 184 plants producing biomass pellets in 2014 [30].

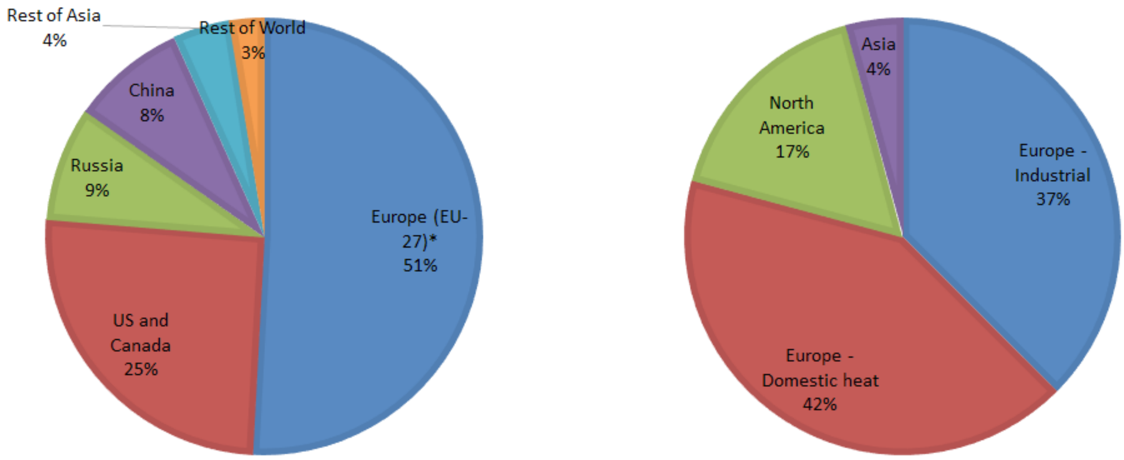
Figure 2. Biomass pellet global production



Source: [30–31]

In the global perspective, in 2013, the EU was the largest consumer and producer of wood pellets, manufacturing 12 Mt pellets, with Germany, Sweden, Latvia, and Portugal as the top producers (Figure 3a). Similarly, Europe ranked at the top in biomass pellet consumption in 2013, with a demand of 10 Mt of wood pellets for domestic heat production and 9 Mt of wood pellets for industrial use. Europe was followed by North America and Asia, with wood pellet consumption of 4 Mt and 1 Mt respectively (Figure 3b).

Figure 3. Global regional pellet production and consumption in 2013



a) Global regional pellet production b) Global regional pellet consumption

Source: [32]

A dramatic shift in the trading patterns and export routes for biomass pellets was observed in 2014. The largest international trade flows are from North America (the United States and Canada) to the EU. In 2014, shipments of biomass pellets from Canada to Europe declined to 2011 volumes, whereas Canadian shipments to Asia (notably South Korea) increased significantly. While the volume of biomass pellets shipped to Asia is increasing, the primary supplies for Asian markets continue to be sourced either domestically or from within the region—for example, South Korea imports from Vietnam.

In the wood pellets global trade, Europe met its growing demand mostly through imports. In 2013, Europe imported about 6.4 Mt of biomass pellets, with around 75% of total imports from North America, a 55% increase compared with 2012, and the rest was almost all from Russia and Eastern Europe. Table 1 presents statistics of the biomass pellet global trade.

Table 1. Biomass pellets global trade

Exporter	Importer	Volume (kt)	
		2013	2014
United States	EU-27	2,776	3,924
Canada	EU-27	1,963	1,166
Russia	EU-27	702	821
Ukraine	EU-27	165	137
Belarus	EU-27	116	126
Bosnia and Herzegovina	EU-27	171	178
Serbia	EU-27	70	71
Australia	EU-27	31	0
Norway	EU-27	48	18
Egypt	EU-27	17	20
Other	EU-27	23	33
EU-27	Switzerland	87	59
EU-27	Norway	30	27
EU-27	Japan	6	6
Canada	South Korea, Japan	250	503

Source: [30–32]

4 Methodology:
Estimating surplus biomass availability, electricity generation potential, and levelised costs

The rise in pellet consumption has resulted in a wider variety of materials used for pellet manufacture. Thus, the pellet industry has started looking for a broad range of alternative materials, such as wastes from agricultural activities, forestry, and related industries, along with the combination thereof. In the results section, we present our estimates for the biomass surplus from agriculture, forestry, and wasteland, the potential for biomass pellet-based electricity generation, and its financial viability. This section lays out the methodology for the same.

4.1 Availability of agricultural residue for biomass pellets

Agricultural residues are the most commonly used biomass feedstock for the production of biomass pellets in India. Availability of agricultural residues as energy feedstock essentially depends on the total amount of the crop produced, the residue-to-grain ratio for the crop, the collection efficiency (which includes storage-related considerations), and the amount used in other competing applications. The effective crop residue availability for ith crop (CRAeff,i) per unit crop produced can therefore be expressed as [33]

$$CRA_{eff,i} = RC_i\left(1-CR_{cts,i}\right)\left(1-CR_{fodder,i}\right)\left(1-CR_{oth,i}\right) \tag{1}$$

where RC_i represents the residue-to-grain ratio for ith crop; CR_{cts} is the fraction of the total crop residue lost in collection, transportation, storage, etc.; CR_{fodder} is the fraction of the crop residue used for fodder; and $CR_{oth,}$ is the fraction of the crop residue employed in other competing uses.

Therefore, the effective net annual crop residues availability, NRA_{eff}, for biomass pellets in India can be estimated as

$$NRA_{eff} = \sum_{i=j=1}^{m,n} A_{i,j} Y_{i,j} RC_i\left(1-CR_{cts,i}\right)\left(1-CR_{fodder,i}\right)\left(1-CR_{oth,i}\right) \tag{2}$$

where $A_{i,j}$ and $Y_{i,j}$ respectively represent the area and the yield of i^{th} crop (i = 1, 2, 3, . . . m crop) in the j^{th} state (j = 1, 2, 3, . . . n state).

For estimating residues from forests and wastelands, a similar approach is followed. Data sources for various variables in equations 1 and 2 are given in section 5.

4.2 Unit cost of biomass pellets

The unit cost of biomass pellet production, UC_{bp}, can be obtained as the ratio of the total annualised cost of the biomass pellet unit to the annual production of pellets. The annual production of biomass pellets, $AP_{bp,}$ can be expressed as:

$$AP_{bp} = 8760CUF_{bp}P_{bp} \tag{3}$$

where CUF_{bp} represents the capacity utilisation factor of the biomass pellet unit and P_{bp} is the rated production capacity (kg/hour) of the biomass pellet unit.

The total annualised cost would comprise the annualised capital cost, the annual operation cost (including cost of fuel), and the annual repair and maintenance cost. Therefore, the unit cost of biomass pellet, UC_{bp}, can be estimated as

$$UC_{bp} = \frac{\{C_{bp}\,R(d,t_{bp})\}+\{\xi C_{bp}\}+\{8760CUF_{bp}(C_l N_l + P_{bp}r_{bf}C_{bf} + p_e \chi_e P_{bp})\}}{8760CUF_{bp}P_{bp}} \tag{4}$$

where C_{bp} represents the capital investment cost of the biomass pellet unit, ξ is the annual repair and maintenance cost as a fraction of the capital cost, C_l is the cost of the manpower required, N_l is the number of workers hired, C_{bf} is the cost of biomass feedstock, r_{bf} is the correction factor for estimating the requirement of biomass feedstock based on the production capacity of the pellet unit (to account for the moisture loss during the drying and pellet production processes), χ_e is the specific amount of electricity consumption in the biomass pellet unit, p_e is the unit cost of electricity, and R (d, t_{bp}) is the capacity recovery factor which can be estimated as

$$R(d,t_{bp}) = \frac{d(1+d)^{t_{bp}}}{\left((1+d)^{t_{bp}-1}\right)}R(d,t_{bp}) = \frac{d(1+d)^{t_{bp}}}{\left((1+d)^{t_{bp}-1}\right)} \tag{5}$$

where d is the discount rate and t_{bp} is the useful lifetime of the biomass pellet unit.

4.3 Economics of biomass pellet for electricity generation

The levelised cost of electricity is estimated as the ratio of the total annualised cost of the biomass power plant to the annual amount of electricity produced by a biomass power plant using biomass pellets as a feedstock. The annualised cost comprises the annualised capital cost, annual operation cost (including cost of fuel), and annual repair and maintenance cost.

The Net Present Value (NPV) of a BPBP project can be determined using the following expression:

$$NPV = \sum_i^T \frac{B_i - C_i}{1+d^i} - C_o NPV = \sum_i^T \frac{B_i - C_i}{1+d^i} - C_o \tag{6}$$

where T is the lifetime of the BPBP project. The salvage value of the BPPP project at the end of its useful life has been assumed to be negligibly small in writing the equation (6). The net annual monetary benefit accrued to the investor $(B_i – C_i)$ is assumed to be uniform over the useful life of the BPBP project.

5 Results

5.1 Biomass surplus for biomass pellets in India

5.1.1 Biomass surplus from agricultural residues

Of India's total geographic area of 328 million hectares (Mha), the net cropped area accounts for approximately 43%, and it appears that the net cropped area has stabilised at approximately 140 Mha since 1970 [34–35]. In contrast, the gross cropped area, accounting for the cultivation of multiple crops per year, increased from 132 Mha in 1950–51 to approximately 195 Mha in 2008–09. There are two main cropping seasons in India, viz. kharif (based on the southwest monsoon) and rabi (based on the north-east monsoon). The gross cropped area includes land areas subjected to multiple cropping (normally double cropping), mainly in irrigated land. The net irrigated area increased substantially from 21 Mha in 1950–51 to approximately 64 Mha in 2013–14 [36]. Rice and wheat are the dominant crops, together accounting for 41% of the total cropped area, while pulses, oilseeds, and other commercial crops account for 13.8%, 15.9%, and 10.2% respectively. Cereals dominate the agricultural crops and account for 60% of the total cropped area, followed by pulses, cotton, and sugarcane. Table 2 presents the area under cultivation and the production of different crops [37]. For 2020–21 and 2030–31, the area and productivity were projected based on the data from 1950–51 to 2011–12 [15].

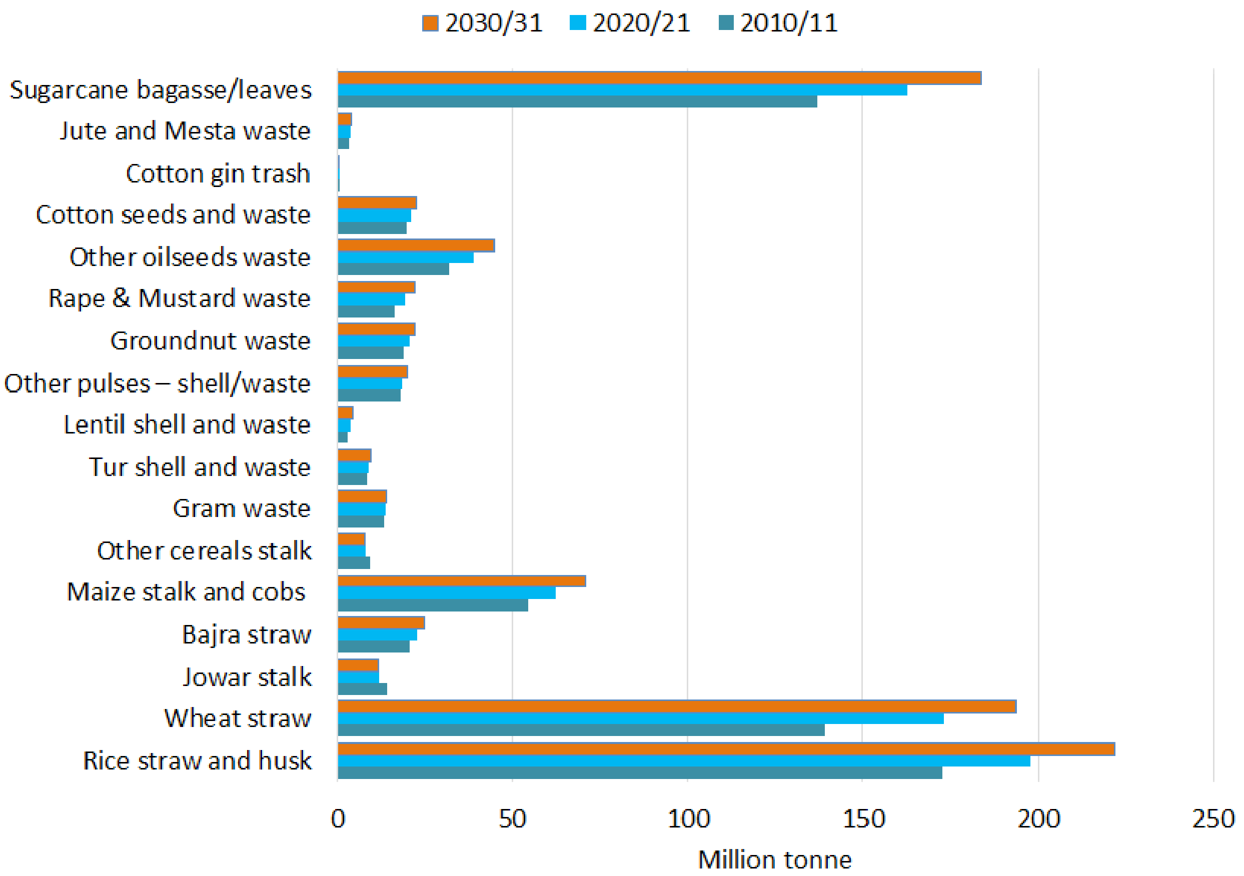
Table 2. Area under different crops and their production

Economic produce/Crop	Type of residue	Area (Mha)			Crop production (Mt)		
		2010/11	2020/21	2030/31	2010/11	2020/21	2030/31
Foodgrains							
Rice	Straw + husk	42.9	48.1	50.3	96.0	109.9	123.2
Wheat	Straw	29.1	33.7	36.6	87.0	108.2	121.1
Jowar	Stalk	7.4	5.2	3.4	7.0	6.0	5.7
Bajra	Straw	9.6	9.3	8.8	10.4	11.4	12.3
Maize	Stalk + cobs	8.6	8.4	9.0	21.7	24.8	28.3
Other cereals	Stalk	2.9	2.1	1.5	4.6	3.9	3.8
Gram	Waste	9.2	8.9	8.7	8.2	8.4	8.6
Tur (arhar)	Shell + waste	4.4	4.4	4.7	2.9	3.1	3.3
Lentil (masur)	Shell + waste	1.6	1.7	1.9	0.9	1.2	1.4
Other pulses	Shell + waste	11.2	12.8	13.2	6.2	6.3	6.8
Oilseeds							
Groundnut	Waste	5.9	6.0	6.1	8.3	8.9	9.6
Rapeseed and Mustard	Waste	6.9	7.2	7.9	8.2	9.6	11.0
Other oilseeds	Waste	14.5	16.7	18.6	16.0	19.3	22.4
Fibre							
Cotton	Seeds + waste	11.2	11.9	12.6	5.6	6.1	6.4
Jute and Mesta	Waste	0.9	1.0	1.0	1.9	2.3	2.5
Sugar							
Sugarcane	Bagasse + leaves	4.9	5.1	5.6	342.4	406.4	459.3
Total		171.0	182.4	190.1	627.3	735.9	825.8

Source: [36–37]

Figure 4 presents the total residue production in India based on the production of different foodgrains, oilseeds, fibres, and sugarcane. The specific ratios of residue to grain production of different crops are taken from [38–41]. For 2010–11, the area under cultivation and total crop production were 171 Mha and 627 Mt respectively. The gross residue availability is estimated at 680 Mt for 2010–11. Hiloidhari et al. [42] reported a gross crop residue production of 686 Mt during 2010–11 by considering 39 residues from 26 crops as compared to the 16 principal crops examined in this study. Singh and Gu [43] reported a gross potential of 1,055 Mt/year, including residues from spices (ginger, cardamom, coriander, garlic, cumin, and dry chilli) and plantation crops (such as rubber and coffee), while the present study and Hiloidhari et al. [42] did not include these residues. The highest average densities of agricultural residues of more than 500 tonne/km^2 were observed for Punjab and Haryana, where intensive wheat–rice systems are practised on mostly irrigated land [15].

Figure 4. Gross residue availability from crop production in India[1]



Source: Own estimates

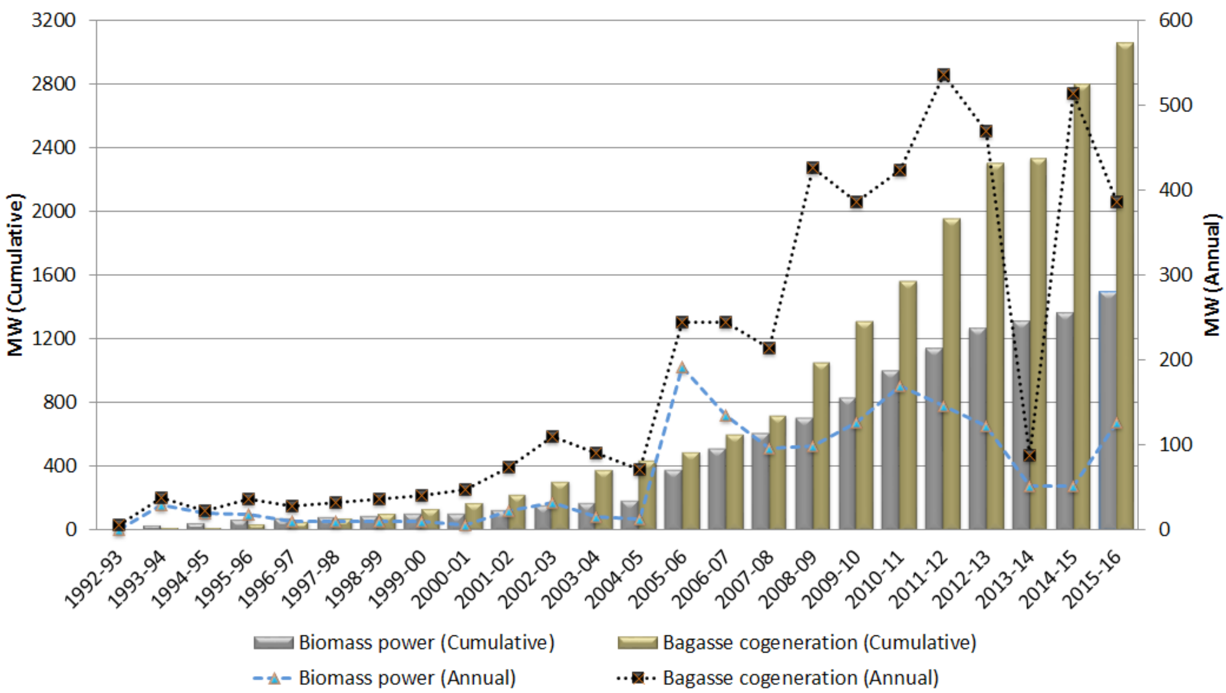
The use of crop residues varies from region to region, and depends on the calorific values of individual crops, their lignin content, density, palatability by livestock, and nutritive value. The residues of most cereals and pulses have fodder value. However, the woody nature of the residues of some crops restricts their utilisation to fuel use only. The dominant end uses of crop residues in India are as fodder for cattle, fuel for cooking, and thatch material for housing [17]. India has a large cattle population of 294 million [34]. Although India has over 10 Mha of grazing land, grass productivity is low due to climatic conditions and land degradation, leading to near-total dependence of cattle on the crop residues of cereals and pulses. The estimated total amount of residues utilised as fodder was 301 Mt in 1996–97 [35] and is estimated

1 Moisture content (air day): 30% for bagasse and 10% for all other agricultural residues

at over 363 Mt for 2010–11, accounting for approximately 53% of total residue generation, as shown in Table 3. Where cereals are concerned, the use of crop residues as fodder is the top priority in rural areas. Only some rice straw and maize stalks/cobs as well as ligneous residues are likely to be available for use as an energy source.

Another major alternative application of non-fodder and non-fertiliser agricultural residues is biomass power and bagasse cogeneration. India's Ministry of New and Renewable Energy (MNRE) implemented the Biomass Power and Cogeneration programme with the main objective of promoting technologies for the optimum use of the country's biomass resources for grid power generation. The promotion of biomass power/cogeneration in the country is encouraged through a conducive policy at the state and central levels. As of December 2015, 4,551 MW of biomass power (biomass gasification and bagasse cogeneration) (grid interactive) had been installed (Figure 5), and an additional 602 MW of biomass (non-bagasse) cogeneration and 179 MW of biomass gasification off-grid projects have also been installed in India [44]. *Therefore, the use of a significant proportion of* agricultural residues *for power generation has to be accounted for when estimating the net biomass pellet potential from agricultural residues in India.*

Figure 5. Installed capacity of biomass power/cogeneration projects in India



Source: MNRE annual reports.

For the base year 2010–11, the installed capacity of grid-connected bagasse cogeneration projects was 1,562 MW [45]. Using a specific bagasse consumption level of 1.6 kg/kWh [38] and a capacity factor of 53% [46], the amount of bagasse used in the cogeneration projects is estimated at 11.6 Mt, which is 20% of the bagasse availability for energy applications [15]. Similarly, the cumulative installed capacity of grid and off-grid biomass power/cogeneration projects was 1,400 MW (998 MW grid-connected biomass power, 274 MW off-grid biomass cogeneration [non-bagasse], and 128 MW biomass gasification projects) in 2010/11 [45]. Using the specific biomass consumption level of 1.21 kg/kWh [33] and the capacity factor of 80% [46], the biomass used in the power/cogeneration projects is estimated at 11.8 Mt, which is approximately 10% of (non-bagasse) agricultural residues available for energy applications. This share of residues used for power/cogeneration is kept constant in the estimation of the net biomass pellet production from agricultural residues in the near future. For 2010–11, agricultural residue availability for energy applications is estimated at approximately 150 Mt with a collection efficiency of 80%.[2] In the base year, the agricultural residue availability from select crops for biomass pellets is estimated at 123 Mt after adjusting moisture content for bagasse and residue used for power generation (Table 3). The net residue availability for biomass pellets in 2020/21 and 2030/31 is estimated at 141 Mt and 157 Mt respectively. In our estimation, this potential biomass pellet production represents approximately 20% of the theoretical maximum obtainable if all crop residues (e.g., straw, husks, stalks, cobs, shells, bagasse, etc.) were to be converted into biomass pellets (Table 3).

Table 3. Agricultural residues surplus for biomass pellets in India

Crop residue	Total residue production (air dry*) – Mt			% of agricultural residue used for			Net agricultural residue availability for biomass pellets[3]		
	2010/11	2020/21	2030/31	Fodder	Fuel	Other	2010/11	2020/21	2030/31
Rice straw and husk	172.8	197.9	221.8	80.8	11.1	8.0	13.8	15.8	17.8
Wheat straw	139.2	173.1	193.7	86.4	0.0	13.6	0.0	0.0	0.0
Jowar stalk	14.1	12.1	11.5	100.0	0.0	0.0	0.0	0.0	0.0
Bajra straw	20.7	22.8	24.7	89.8	0.0	10.2	0.0	0.0	0.0
Maize stalk and cobs	54.3	62.1	70.6	81.0	19.0	0.0	7.4	8.5	9.7
Other cereals stalk	9.1	7.8	7.6	100.0	0.0	0.0	0.0	0.0	0.0
Gram waste	13.2	13.5	13.8	0.0	100.0	0.0	9.5	9.7	10.0
Tur shell and waste	8.3	8.9	9.6	3.5	48.5	48.0	2.9	3.1	3.3
Lentil shell and waste	2.7	3.6	4.1	3.5	48.5	48.0	1.0	1.3	1.4
Other pulses shell/waste	18.0	18.4	19.8	3.5	48.5	48.0	6.3	6.4	6.9
Groundnut waste	19.0	20.6	22.0	0.0	13.2	86.8	1.8	1.9	2.1
Rape and Mustard waste	16.4	19.3	22.1	0.0	100.0	0.0	11.8	13.9	15.9
Other oilseeds waste	32.1	38.6	44.7	0.0	100.0	0.0	23.1	27.8	32.2
Cotton seeds and waste	19.6	21.2	22.5	0.0	100.0	0.0	14.1	15.3	16.2
Cotton gin trash	0.4	0.5	0.5	0.0	100.0	0.0	0.3	0.3	0.4
Jute and Mesta waste	3.1	3.6	3.9	0.0	100.0	0.0	2.2	2.6	2.8
Sugarcane bagasse/ leaves	137.0	162.6	183.7	11.8	41.0	47.2	28.7	34.1	38.6
Total	679.9	786.3	876.6				123.0	140.8	157.2

5.1.3 Biomass surplus from forestry/wasteland

India witnessed a 24% rise in forest cover between 1950 and 2010, increasing from around 40.48 Mha to 68 Mha during this period [47–48]. The 2013 Forest Survey of India states that the forest cover increased to 69.8 Mha by 2012, as per satellite measurements; this represents an increase of 5,871 sq km of forest cover in two years [49]. For 2002–04, the total surplus biomass from forest and wastelands is estimated at 104 Mt as per the Biomass Atlas of India (Table 4). The total surplus biomass from forest and wastelands will increase in the near future due to the increase in forest cover. However, a significant amount of forest residues is consumed by the population residing in or near the forest, and the plantation products are used by the timber, paper, and pulp industries [1]. Therefore, we have kept the biomass surplus from forest and wastelands as constant at the 2004 level.

2 It is assumed that 20% of agricultural residue is lost in collection, transportation, storage, etc.

3 Apart from fodder and other applications, the net agricultural residue availability for biomass pellets also takes into account the residue used for biomass power/cogeneration projects.

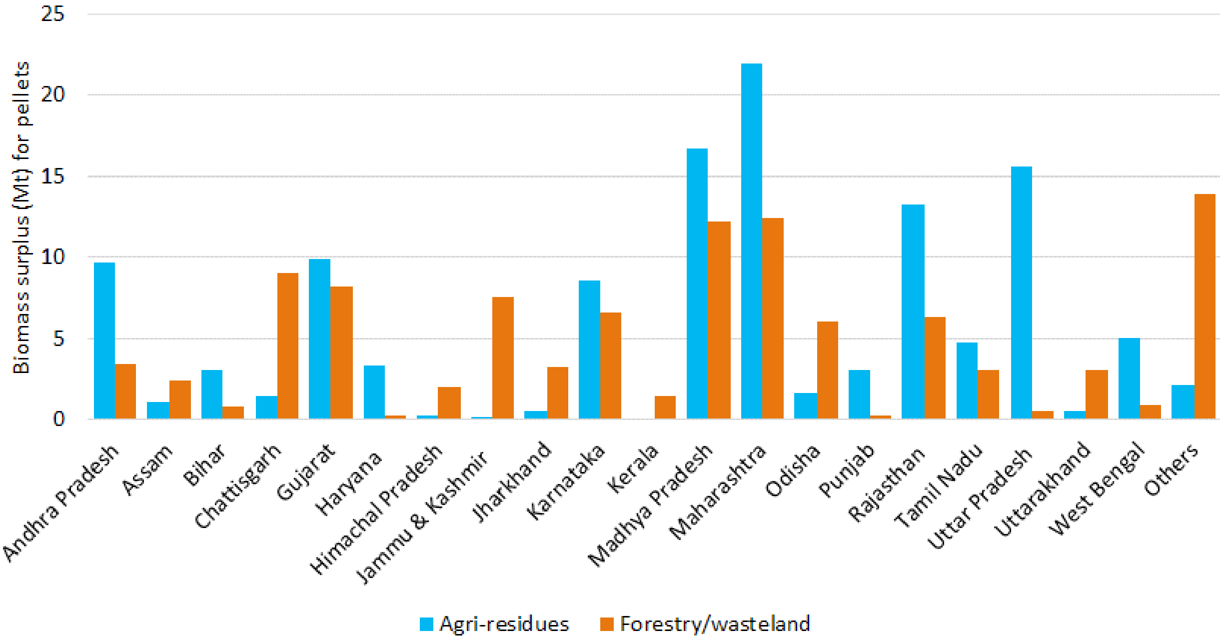
Table 4. State-wise biomass surplus through forestry and wasteland

State	Area (Mha)	Gross availability of biomass from forestry/wasteland (Mt)	Net availability of biomass from forestry/wasteland (Mt)
Andhra Pradesh	3.6	5.2	3.5
Arunachal Pradesh	5.5	8.3	6.0
Assam	2.7	3.7	2.4
Bihar	0.9	1.2	0.8
Chhattisgarh	8.8	13.6	9.1
Goa	0.2	0.2	0.1
Gujarat	9.0	12.2	8.3
Haryana	0.3	0.4	0.3
Himachal Pradesh	2.3	3.1	2.0
Jammu & Kashmir	9.8	11.5	7.6
Jharkhand	3.5	4.9	3.2
Karnataka	7.0	10.0	6.6
Kerala	1.2	2.1	1.4
Madhya Pradesh	12.8	18.4	12.3
Maharashtra	13.2	18.4	12.4
Manipur	1.3	1.3	0.8
Meghalaya	1.5	1.7	1.1
Mizoram	1.6	1.6	1.1
Nagaland	0.8	0.8	0.6
Orissa	6.3	9.4	6.1
Punjab	0.2	0.4	0.3
Rajasthan	14.1	9.5	6.3
Sikkim	0.4	0.5	0.4
Tamil Nadu	3.2	4.7	3.1
Tripura	0.8	1.0	0.7
Uttar Pradesh	3.9	5.5	3.7
Uttaranchal	2.9	4.6	3.1
West Bengal	1.1	1.4	0.9
All India	118.8	155.5	104.0

Source: [50]

Figure 6 presents the biomass surplus available from agriculture and forestry/wasteland for the production of biomass pellets in India. The northern states such as Punjab, Haryana, and Uttar Pradesh have large amounts of agricultural residues available for biomass pellets as compared to the biomass surplus from forestry/wasteland. It may be noted that the hilly states in the north (J&K, Himachal Pradesh, and Uttarakhand) and the north-east have a large amount of surplus biomass from forestry/wasteland as compared to the agricultural sector.

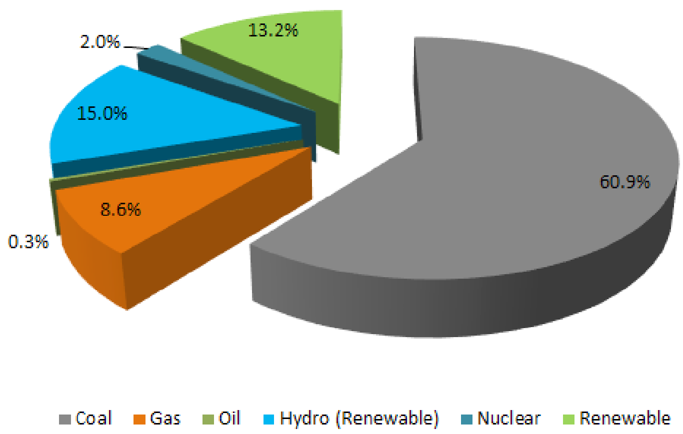
Figure 6. State-wise biomass surplus for biomass pellets in India



5.2 India's electricity generation and potential of biomass pellets

The utility electricity sector in India had an installed capacity of 288 GW as of 31 January 2016 [51]. The share of renewable (including large hydro) power plants constituted 28.2% of the total installed capacity, and non-renewable power plants constituted the remaining 71.8% (Figure 7). As coal is the mainstay of India's electricity production, and is expected to continue to remain so in the near future as well, it is important to understand the role of coal in India's power generation. The installed capacity of coal thermal power plants was 175.8 GW in February 2016, that is, around 61% of the total installed capacity in the country [51]. Sub-critical pulverised coal (PC) technology is currently used in most of the coal-based thermal power plants in the country. All newly constructed coal power plants in India are expected to be based on super-critical technology. Coal is required in large quantities for power generation, and India has abundant reserves of this fossil fuel. Coal consumption for power generation increased from 278 Mt in 2004–05 to 455 Mt in 2012–13, and is expected to increase to over 1,000 Mt in 2030–31 [52], using World Energy Outlook (WEO) current policy scenario trends provided by the International Energy Agency (IEA). India's proven non-coking coal resources, used primarily for power generation, are about 100 billion tonnes [53]. However, indigenous coal production has not been able to meet domestic demand, and hence a significant proportion of coal is imported. Currently, about 25% of India's coal supplies are imported [54]. Whether this number will change in the future depends on the rate at which domestic production grows, as well as the movement of coal prices in the international market. Domestic coal production is increasing thanks to domestic reforms in the coal sector, and international coal prices have also increased significantly in the last two years. Based on these two factors, it appears that Indian coal imports in the future will not increase in terms of share of total coal consumption. In the long run, if the cost of biomass pellet-based electricity generation becomes competitive with the cost of coal production, a proportion of the coal imports could be replaced by biomass imports as well. As shown in section 3, the biomass pellet trade is increasing. Stringent climate-policy requirements could further compel India to start seriously thinking about biomass pellet imports.

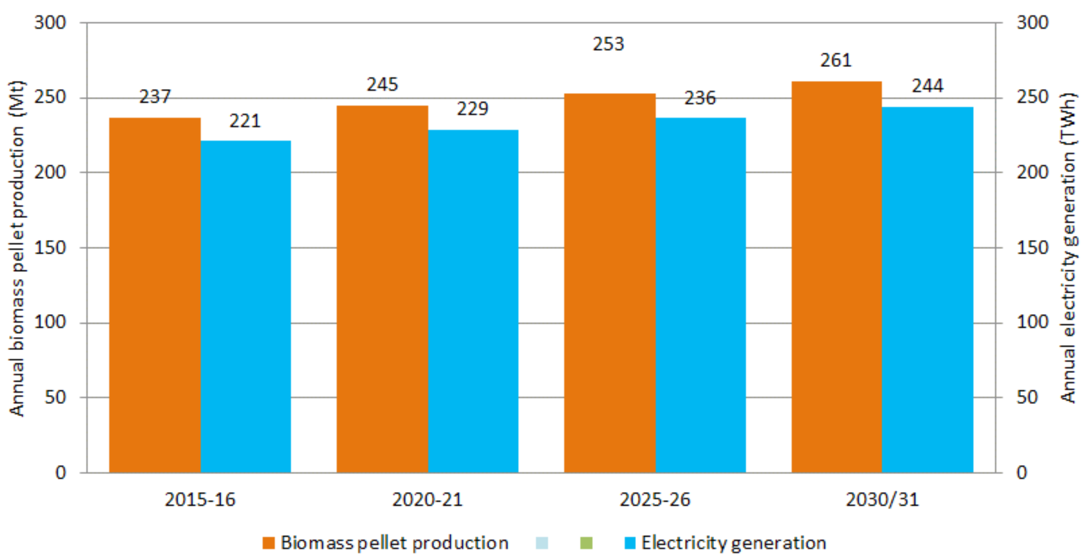
Figure 7. Installed capacity of power plants in India until February 2016



Source: [51]

The annual gross and net availability of agricultural and forestry/wasteland residues and/or waste has been estimated in the previous section. The net biomass surplus availability from agricultural residues and forestry/wasteland for biomass pellet production is estimated at 227 Mt for 2010–11; it is expected to increase to 245 Mt in 2020–21 and to 261 Mt in 2030–31. The surplus[4] biomass availability from the agricultural sector (133 Mt in 2015–16) alone is sufficient to substitute approximately 25% of the current coal consumption of 531 Mt [55] in the power sector (through the co-firing of coal with biomass pellets). Figure 8 presents the annual biomass pellet production based on surplus biomass available from agricultural residues and forestry/wasteland. The associated electricity generation potential of BPBP projects is estimated at 229 TWh for 2020–21 and is predicted to increase to 244 TWh in 2030–31. The associated CO_2 mitigation potential available through the substitution of coal is estimated at 192 and 205 Mt CO_2eq in 2020–21 and 2030–31 respectively using the baseline of 0.82 kg CO_2e/kWh [56] if the entire biomass surplus available from the agriculture and forestry/wasteland sectors were diverted for power generation.

Figure 8. Annual biomass pellet production through biomass surplus and associated electricity generation



4 Here surplus implies residue available after allocating for livestock, soil, and other competing applications.

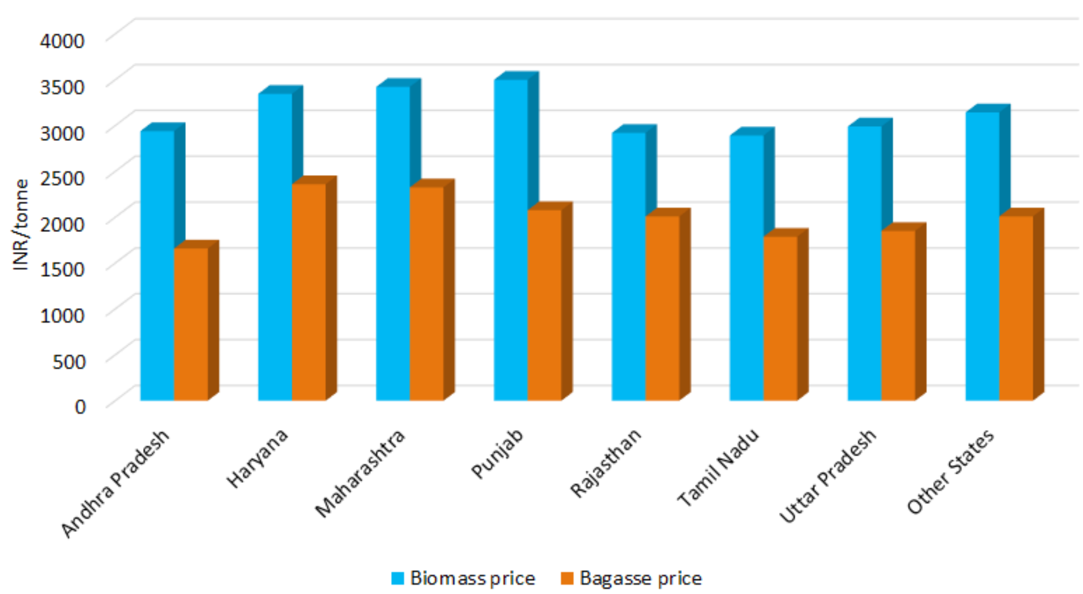
5.3 Techno-economic evaluation of electricity generation through pellets

The current market price of biomass pellets in India is INR 10 to 15/kg [57]. These pellets are mainly used for cooking application in the commercial sector. To ensure the success of a BPBP project, the biomass pellet unit should be installed near the project. The following sections discuss the cost of biomass pellets, the levelised cost of electricity generation through biomass pellets, the indicators of economic performance, and the impact of the internalisation of secondary benefits such as the beneficial effects of CO_2 emission mitigation on the financial/economic feasibility of a BPBP plant.

5.3.1 Cost of biomass pellets

The Central Electricity Regulatory Commission (CERC) of India, in terms of Regulation 44 of the Renewable Energy Tariff Regulations, had specified the biomass fuel price applicable during 2012–13 [58] and had also specified the fuel price indexation mechanism, in case the developer wished to opt for it, for the remaining years of the control period. Figure 9 presents the biomass and bagasse price applicable for FY 2015–16 by the states. The cost of biomass pellet units and other technical details (Table 5) have been obtained from Nishant Bioenergy Ltd., Mohali, Punjab. The unit cost of biomass (non-bagasse) is taken to be INR 3,500/tonne for Punjab. The total electricity consumption for biomass pellet production essentially depends on the type of biomass feedstock (fine or coarse granular/stalky) being used and the moisture content of the biomass feedstock. Drying consumes energy in the form of heat, while size reduction, densification, and cooling operations require electric power input. Mani et al. [28] observed that the drying process consumes more than 80% of energy, which results in the high energy cost of the pelleting operation. Energy demand for wood pelleting (including all stages, from reception of raw material to packing) is generally in the range of 80 to 150 kWh/tonne for electricity and around 950 kWh of heat/tonne of water to be vaporised [59]. In this study, we have considered specific electricity consumption of 100 kWh/tonne assuming that the biomass feedstock is air dried (moisture content 10%).

Figure 9. Biomass and bagasse price (INR/tonne) by state in India



Source: [58]

Table 5 presents the techno-economics parameters used in the estimation of the cost of biomass pellet production. The biomass pellet unit works 20 hours/day and 300 days in a year as per Nishant Bioenergy Ltd of Mohali, Punjab. Using Eq (3) to Eq. (5), and based on the key assumptions and input parameters given in Table 5, the unit cost of pellet production is estimated at INR 4,473/tonne for a 1,500 kg/hour biomass pellet unit (Figure 10). For a small unit with a rated capacity of 250 kg/hour, the unit cost of pellet production is estimated at a higher figure, INR 4,689/tonne, due to economies of scale. An average agricultural residue transportation cost of INR 175/tonne for a distance of 50 km is also incorporated in the unit cost of biomass pellet using the methodology developed by Tripathi et al. [39] and updated by Purohit and Fischer [15].

Table 5. Techno-economics parameters used in the unit cost of biomass pellets

Parameter	Symbol	Unit	Value
Capacity of biomass pellet unit	P_{bp}	kg/hour	1500
Capital cost of biomass pellet unit	C_{bp}	Million INR	2
Discount rate	d	%	10
Useful lifetime of biomass pellet unit	t_{bp}	Years	10
Repair and maintenance cost of biomass pellet unit as a fraction of capital cost	ξ	%	10
Capacity factor of biomass pellet unit	CUF_{bp}	%	68
Cost of manpower	C_l	INR/man-hour	40
Number of manpower	N_l	Number	5
Cost of biomass feedstock	C_{bf}	INR/kg	3.5
Specific electricity consumption in biomass pellet unit	χ_e	kWh/kg	0.1
Unit cost of electricity	p_e	INR/kWh	6.04

Source: As per telephonic interview with a representative of Nishant Bioenergy Ltd., Mohali, Punjab (http://www.nishantbioenergy.com/)

Figure 10 shows how the unit cost of biomass pellets can increase depending on the transportation distance. An increase in the transportation distance from 50 km to 100 km leads to a 4% increase in the unit cost of pellets. The unit cost will further increase with the high moisture content of the biomass feedstock, the type of biomass feedstock used (cutting of stalky materials), and the long transportation distance from the farm gate to the biomass pellet unit, as shown in Figure 10.

Figure 10. Unit cost of biomass pellet at different biomass feedstock transportation distances

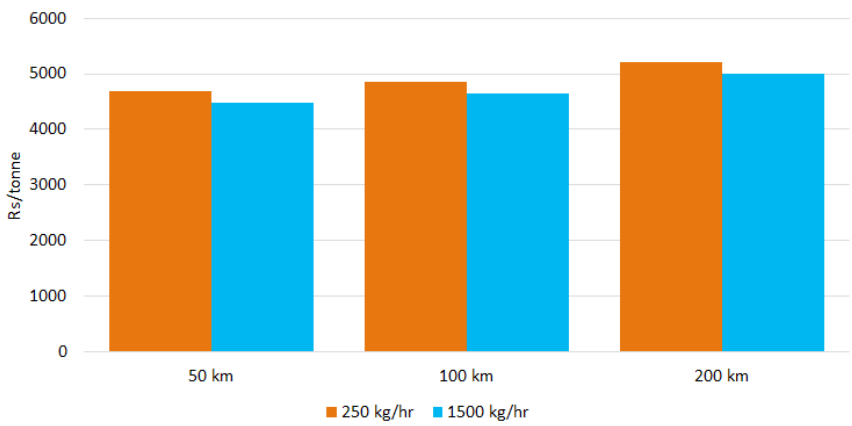
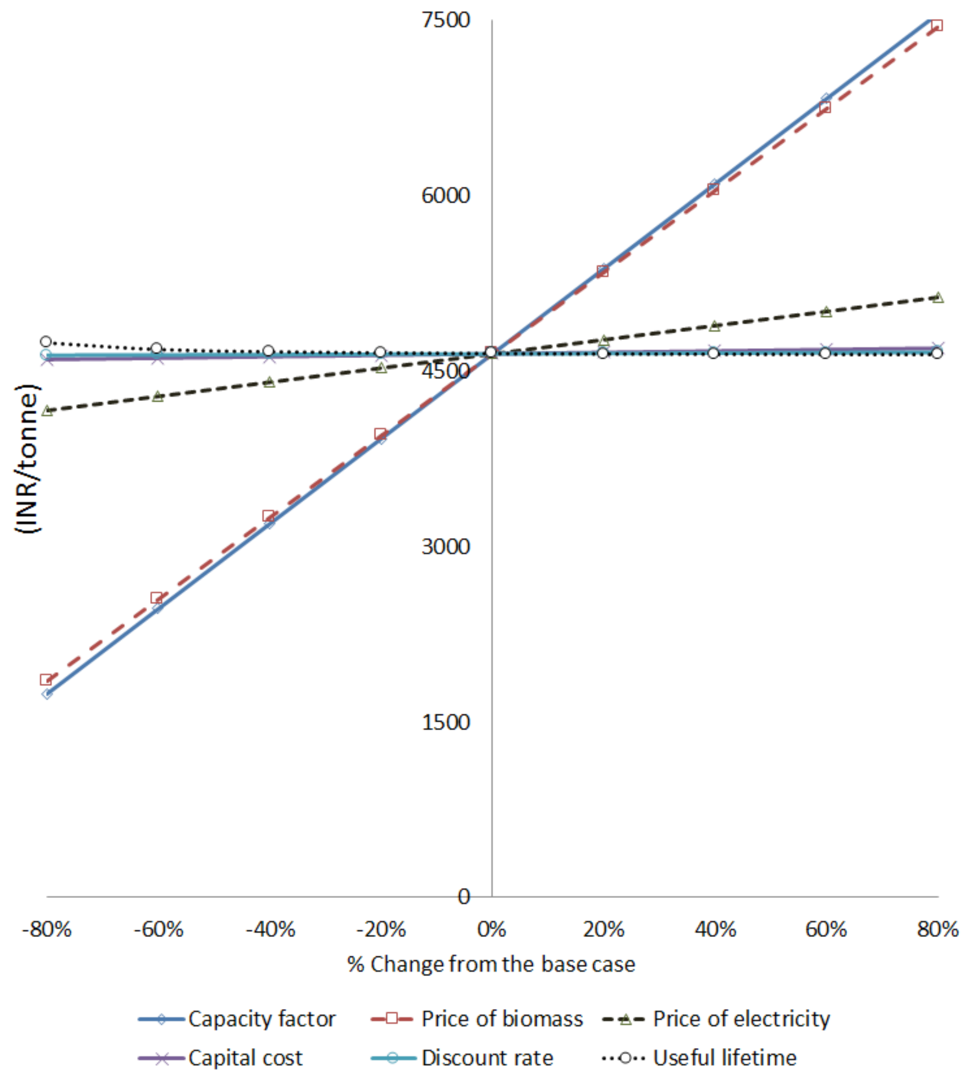


Figure 11 shows the results of a sensitivity analysis of the effect of uncertainties associated with some important input parameters used in the analysis of the unit cost of biomass pellets. The unit cost of biomass pellets is found to be quite sensitive to the price of biomass feedstock and the capacity utilisation factor of the biomass pellet unit, followed by the price of electricity. It is observed that the capital cost, the discount rate, and the useful lifetime of the biomass pellet unit have a rather moderate effect on the unit cost of pellet production.

Figure 11. Sensitivity analysis for unit cost of biomass pellet with respect to capital cost, capacity utilisation factor, biomass feedstock cost, price of electricity, discount rate, useful lifetime of the biomass pellet unit



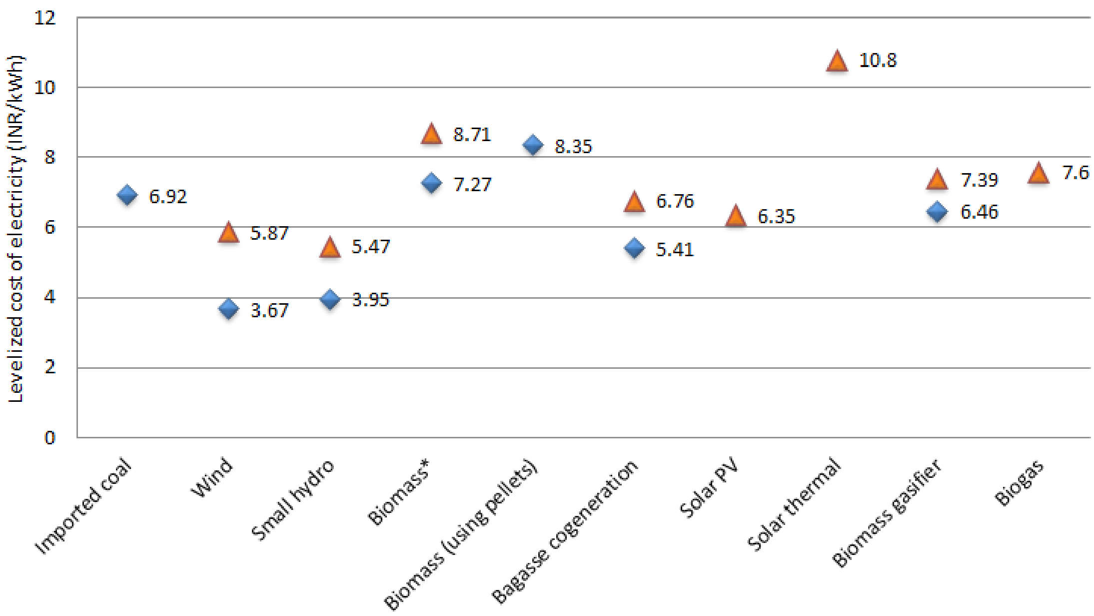
5.3.2 Levelised cost of electricity generation through biomass pellets

The levelised cost of electricity produced through biomass pellets can be obtained as the ratio of the total annualised cost of the biomass power plant to the annualised cost of electricity generation. CERC considered the capital expenditure (capex) for independent biomass projects as INR 61 million/ MW and the operation and maintenance (O&M) cost for a 10 MW biomass power as ~ INR 6.5 million/MW [58]. Biomass-fired boilers fueled mainly on paddy straw/Juliflora require a lot of mechanisation for collection and pre-processing, for which the developer has to make additional investment to procure equipment like tractors, trolleys, rippers, dozers, and balers. Use of biomass pellets essentially reduces the cost of the fuel supply chain mechanism due to the uniform size of pellets. The cost of biomass pellets is estimated at INR

4,473/tonne as per the estimates presented in the previous section. Transportation of biomass pellets from the biomass pelletisation unit to the BPBP project tacks on additional transportation cost. In this study, the biomass pellet units are assumed to be located within a radius of 50 km of the plant. Therefore, the cost of biomass pellets at the BPBP project will be INR 4,648/tonne after including the transportation cost. The useful lifetime of the 100% BPBP plant is taken to be 20 years, and an auxiliary consumption of 10% is considered to assess the levelised cost of electricity [58]. The levelised cost of BPBP projects is estimated at INR 8.35/kWh, which is higher than the levelised cost of imported coal-based power production at INR 6.92/kWh [60].

Figure 12 presents the levelised cost of electricity from biomass power plants using biomass pellets along with the net levelised tariff (after adjusting for accelerated depreciation benefit, if availed) for renewable energy technologies for FY 2015–16 [58]. The net levelised tariff for biomass power projects (other than rice straw- and Juliflora (plantation)-based projects) with air-cooled condenser and travelling grate boiler is higher than the levelised cost of BPBP projects in the major states of India.

Figure 12. Levelised cost of electricity for biomass power plant (using biomass pellets) along with generic tariff for renewable energy technologies for FY 2015–16[5]



*Biomass power projects (other than rice straw- and Juliflora (plantation)-based project)
Source: [58]

In India, the current electricity tariffs across states/provinces do not reflect the actual cost of supply to different consumer groups. Industrial and commercial consumers, particularly high-voltage consumers, are charged substantially more than the cost of supply, whereas the agricultural sector and, to a lesser extent, the residential sector, are heavily subsidised. The CERC tariff for biomass power projects varies across the states depending on the availability of biomass feedstock, the price of biomass feedstock, the technology used for the condenser (water cooled or air cooled) and boiler, etc. A lower tariff of INR 7.27/kWh for Tamil Nadu is provided for biomass power projects with water- cooled condenser and travelling grate boiler, whereas a higher tariff of INR 8.71/kWh for Punjab is provided for biomass power projects with air-cooled condenser and travelling grate boiler (Figure 12). It may be noted that the above-mentioned

5 Lower and upper values of the levelised cost of electricity through wind is for different wind zones (CUF = 20% for zone 1 and CUF = 32% for zone 5); lower and upper values for small hydro projects are different for Uttarakhand, Himachal Pradesh, the North-eastern states, and other states [45].

tariff rates are not applicable to rice straw- and Juliflora (plantation)-based projects. We have used the lower tariff of INR 7.27/kWh for biomass power projects provided by CERC [58] for FY 2015–16 for which the NPV of the BPBP project is negative. Internalisation of secondary benefits such as emissions trading improves the financial feasibility of BPBP projects for which the break-even price of carbon is estimated at 18 Euro/tonne CO_2 (assuming 1 Euro = INR 70).

6 Discussion

6.1 Creation of rural jobs

The large-scale use of biomass pellets for power generation could play an important role in stimulating the local economy and in hastening industrial development. Job opportunities in the biomass pellet development sector will mainly come from the collection, transportation, and processing of biomass feedstock (agricultural/forestry residues) and from the manufacturing of biomass pellets. As per our telephonic conversation with a representative of Nishant Bioenergy Ltd. of Mohali, Punjab five persons are employed full time for the biomass pellet unit with a capacity of 1,500 kg/hr (9,000 tonne/year). In addition, for the transportation of agricultural residues from the farm/industry site to the biomass pellet unit, it is assumed that a truck of 6 tonne carrying capacity is used three times a day to transport the raw material within a 50-km collection radius. To meet the biomass feedstock requirement on a daily basis, two trucks are needed, with a driver and a loader assigned to each truck. Our preliminary estimates indicate that the biomass pellet production process could generate 224,000 full-time employments in biomass pelletisation and in the transportation of agricultural and forestry residues if the entire biomass surplus were diverted to the biomass pellets route. Moreover, the collection and storage of biomass and the manufacturing of biomass pellets are estimated to also create indirect jobs. For 2030/31, it is expected that the biomass pellet industry will create over 260,000 full-time employments in rural areas.

Additional employment will be generated during the construction of biomass power plants. A 10 MW biomass power project can generate employment for approximately 100 workers during the 18-month construction phase, 25 full-time workers for the operation of the facility, and 35 workers for the collection, processing, and transportation of biomass material, as per MNRE estimates [61]. With a capacity factor of 80% and a specific biomass pellet consumption of 1.15 kg/kWh, the related potential of biomass power plants (using pellets) is estimated at 30 GW for 2010–11 and at approximately 35 GW for 2030–31. This translates to over 6.3 million man-months in the construction of 35 GW biomass power plants and 87,500 full-time employments in the operation of biomass power plants for 2030–31.

6.2 Climate policy and the international biomass pellet market

Trade in biomass pellets has already started, and has been driven to a large extent by climate-policy concerns. EU political and regulatory policy interventions have incentivised wood pellets as a vehicle to help de-carbonise the energy sector. More than 190 countries have submitted their INDCs to the UNFCCC, and these are reflected in the Paris Agreement at the 21st Conference of the Parties (COP-21). Preliminary analysis has shown that the INDCs are a step forward in the direction of global GHG mitigation, but the efforts are still far from what is required to align with a 2°C pathway.[6] The pathway chosen by the world till 2030 implies that emission mitigation will have to be even deeper post 2030. Negative-emission technologies like biomass with carbon capture and storage have been proposed as an important part of the technology suite under the 2°C pathway, although these technologies have yet to be commercialised. Nevertheless, this implies that biomass is being adopted on a large-scale in the shape of

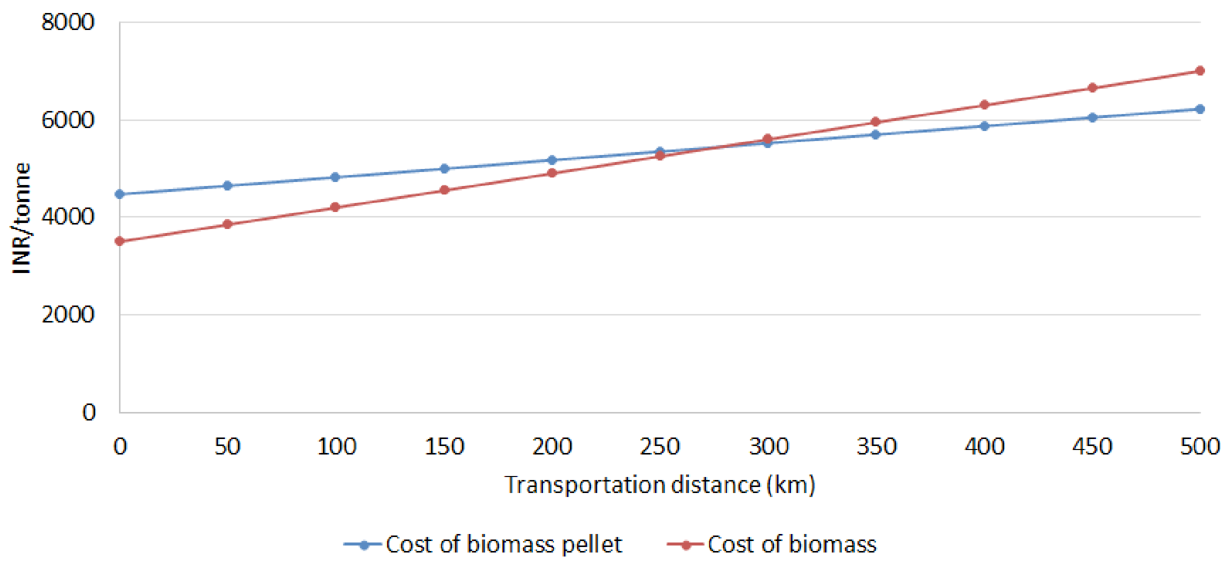
6 As per the recent Agreement at the 21st Conference of the Parties (COP-21) in Paris, world leaders have agreed to attempt limiting the temperature increase to 1.5°C.

dedicated commercial plantations across the world. Not all countries, however, will be biomass suppliers. Land-use modelling within integrated assessment models shows that countries in Latin America will be net exporters of biomass, while many other regions across the world will be producers of bioenergy [12]. A stringent climate-control policy will fundamentally change the architecture of the international energy trade. India is not expected to be a significant producer of dedicated bioenergy in the future, not just because of land constraints, but also because of water stress. Thus, if Indian energy systems also need to shift towards bioenergy in a big way, the country will have to become an importer of bioenergy. India has significant other resources like solar energy, but these will not lead to negative emissions, which will be required if the INDC emission pathway till 2030 has to shift towards 2^{0}C as a long-term goal. Hence, it is important to invest in developing domestic bioenergy resources as much as possible to minimise potential imports, as well as move India towards a low-carbon economy.

6.3 Pelletised versus Non-Pelletised Biomass

Our cost analysis shows that the cost of biomass pellet-based electricity production is well within the range of tariff provided by CERC. However, there is one critical variable that could completely change the economics of biomass-based electricity—the transportation cost of biomass. Figure 13 presents the price of biomass pellets and unprocessed biomass feedstock at different transportation distances. It may be noted that at a critical distance of approximately 275 km, the cost of biomass pellets will be similar to the cost of unprocessed biomass feedstock, whereas at distances of more than 275 km, the cost of biomass pellets will be lower than the cost of unprocessed biomass feedstock.

Figure 13. Price of biomass pellet and unprocessed biomass feedstock at different transportation distance



The market price of biomass feedstock is taken to be INR 3,500/tonne (Table 5) and the cost of biomass pellets is estimated at INR 4,473/tonne. The carrying capacity of the truck is assumed to be 6 tonne of biomass pellets and 3 tonne of unprocessed biomass. The pelletisation process can increase the bulk density of biomass from an initial bulk density of 40–200 kg/m^3 to a final compact density of 600–1,200 kg/m^3 [62–66] and significantly reduce the transportation cost. For this reason, it is, generally, only economically feasible to transport unprocessed biomass for short distances. However, if there is a geographical region that has limited biomass residue and has to still increase the penetration of biomass-based electricity, it makes economic sense to invest only in BPBPs.

The pelletisation process resolves some typical problems of biomass fuels: transport and storage costs are minimised, handling is improved, and the volumetric calorific value is increased. Pelletisation may not increase the energy density on a mass basis, but it can increase the energy content of the fuel on a volume basis. Hence, for long-distance transport, it makes sense to transport pellets rather than biomass feedstock only. Our analysis also shows that the potential of the different states varies in terms of agriculture and forestry residues. For example, Tamil Nadu has limited potential for producing forest and agriculture residue. The adjoining states of Karnataka and Andhra Pradesh, in contrast, have significant potential. Tamil Nadu's population exceeds Karnataka's population by 20% and Andhra Pradesh's population by 40%. For increasing domestic electricity generation capacity based on biomass, it makes sense for Tamil Nadu to import biomass pellets, as compared to biomass feedstock, from either Andhra Pradesh or Karnataka. This will significantly reduce the cost of feedstock. The same is true for Kerala as well. The states thus have to decide whether to invest in the production of biomass pellets based on their own potential for residue generation, or the biomass-based electricity generation target they want to achieve, or the excess residue potential in the adjoining states.

Based on the financial analysis undertaken by us, we conclude that the cost of electricity production based on the import of biomass pellets from other states will be higher. This scenario will only be possible if there is a high carbon price or if there are stringent targets for biomass-based electricity generation for states that do not have enough domestic residue potential.

7 Conclusions and policy implications

Bioenergy is being recognised as an increasingly important low-carbon resource by policy makers around the world to meet climate-policy targets. In India also, there is a clear recognition of the significant role of bioenergy in electricity generation as well as in other applications. Bioenergy for power generation can be used in two different forms—pelletised and non-pelletised. The non-pelletised form has been used for a long time for co-firing in coal-based power plants or biomass power plants. Biomass pellets are now being used extensively and international trade is increasing year on year, largely driven by climate-policy targets adopted by developed countries. We focus on this form of energy and estimate the potential for the use of biomass pellet production in India, and the potential for electricity generation from it. We then estimate the cost of 100% biomass pellet-based electricity production and assess its financial viability.

After allocating biomass feedstock for key existing uses of agriculture and forest residues, including for fodder and other competing uses, we estimate that the net residue availability for biomass pellet production will increase from 227 Mt in 2010/11 to 261 Mt in 2030/31. The surplus biomass availability from the agricultural sector (123 Mt in 2010–11) alone was sufficient to substitute 25% of current coal consumption in the power sector (through the co-firing of coal with biomass pellets). The annual electricity generation potential from biomass pellets is estimated to be 244 TWh in 2030/31 out of a total 4,000 TWh of electricity production in India in 2030/31. Thus, pelletised biomass can potentially produce 6% of India's total electricity in 2030/31, in addition to direct biomass co-firing for electricity production.

The cost of biomass pellet-based electricity generation will ultimately determine whether its technical potential will be utilised or not. Based on detailed assumptions concerning input cost and technical factors, we estimate that the cost of a biomass pellet would be INR 4,473/tonne. The levelised cost of electricity will be INR 8.35/KWh, which is even higher than the cost of imported coal-based electricity. However, this is within the range of the non-pelletised biomass-based generic levelised tariff as determined by CERC.

We find that, generally speaking, the financial viability of biomass pellet-based electricity generation depends on the surplus availability of biomass feedstock, the price of biomass, the transportation distance from the farm to the BPBP project, and the cooling technology, which together determine the tariff provided by CERC. A carbon price can play an important role in increasing the penetration of biomass pellets in India's electricity generation if the tariff is at the lower end of the range as determined by CERC. For states with lower tariff for biomass power, the break-even price of carbon for BPBP projects is estimated at 18 Euros/tCO_2.

India's status as a primarily agrarian economy makes it the perfect candidate for a bioenergy-led model of energy generation and sustainable development, utilising the country's large volumes of leftover agricultural and forestry residues as well as civic waste, and generating income and employment opportunities, especially at the grass-roots, rural-community level. Our preliminary estimates indicate that the biomass pellet sector currently generates over 5 million person-months in the construction of BPBP plants and over 200,000 full-time employments in the operation of biomass power plants and in the production of biomass pellets. Agricultural and forestry residues have very important long-term potential in India. Biomass pellets are important for socio-economic development. Hence, central and provincial governments and institutions should start working on specific strategies and policies to support the exploitation of agricultural and forestry residues for energy purposes.

Ultimately, transportation distance is a decisive factor in the economics of BPBP plants. States should assess their respective potential for the production of agricultural and forestry residues, determine their targets and ambitions for biomass-based electricity generation, and then devise strategies for the use of pelletised versus non-pelletised biomass in electricity generation plants.

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