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PROMOTING LOW CARBON TRANSPORT IN INDIA

Second-Generation Biofuel Potential in India:
Sustainability and Cost Considerations

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Second-Generation Biofuel Potential in India: Sustainability and Cost Considerations

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Abbreviations

AEZ	Agro-ecological zone
BCR	Benefit Cost Ratio
BDBP	Biodiesel Blending Programme
BL	Billion Litres
BTL	Biomass-to-liquid
CCEA	Cabinet Committee on Economic Affairs
EBPP	Ethanol Blended Petrol Programme
ESCOs	Energy Service Companies
FDI	Foreign Direct Investment
GAEZ	Global Agro-ecological Zones
GoI	Government of India
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISSASS	International Society for Southeast Asian Agricultural Sciences
LC	Lignocellulosic
Mha	Million hectares
MNRE	Ministry of New and Renewable Energy
MoPNG	Ministry of Petroleum and Natural Gas
MPP	Minimum Purchase Price
MSP	Minimum Support Price

Mt	Million tons
NBF	National Biofuel Fund
NBM	National Biofuel Mission
NCAP	National Centre for Agricultural Economics and Policy Research
NGO	Non-Governmental Organisation
NOVOD	National Oilseeds and Vegetable Oils Development Board
NPV	Net Present Value
NRSC	National Remote Sensing Centre
PPAC	Petroleum Planning & Analysis Cell
OMC	Oil Marketing Company
R&D	Research and Development
SAUs	State Agricultural Universities
SHG	Self-Help Group
SI	Suitability Index
TBOs	Tree-borne Oilseeds

Photo of the field of oil seed rape. Photo courtesy of Matt Preston, 2012. Info on the rights reserved: http://creativecommons.org/licenses/by-sa/4.0/

1. Introduction

1.1 Context

This study is part of a larger research project on "Promoting Low-Carbon Transport in India", a major initiative of the United Nations Environment Programme (UNEP), hereafter referred to as the Low Carbon Transport (LCT) project in this document. The overall context in which the LCT project has been undertaken is the critical role of the transport sector in reducing greenhouse gas (GHG) emissions. India is currently the fourth largest GHG emitter in the world, although its per capita emissions are less than half the world's average. Furthermore, India's transport sector accounts for 13 percent of the country's energy related CO_2 emissions (MoEF, 2010). It is evident that opportunities exist to make India's transport growth more sustainable by aligning development and climate change agendas (Shukla and Dhar, 2011).

At present, India is pursuing a comprehensive set of policies to move the country to a low-carbon growth path (GoI, 2011). In 2009, India announced that it would reduce the emissions intensity of its gross domestic product (GDP) by 20 percent to 25 percent over the 2005 levels by the year 2020 (IEA, 2012). Specific measures to attain these goals are also being developed through the national missions identified in the National Action Plan on Climate Change (NAPCC) of 2008. The NAPCC recognises that GHG emissions from transport can be reduced by adopting a sustainability approach through a combination of measures such as increased use of public transport, higher penetration of bio-fuels, and enhanced energy efficiency of transport vehicles (GoI, 2008).

1.2 Biofuel in India

The Indian economy has been growing at a rate of approximately 7 percent since 2000 (EIA, 2013). The demand for energy is also growing at rapid rates to drive this high economic growth. The recent World Energy Outlook (WEO) report of the International Energy Agency (IEA) projects that India's primary energy demand will increase from 750 Mtoe to 1258-1647 Mtoe (the range is defined by WEO 450 Scenario and Current Policies Scenarios) between 2011 and 2035 (IEA, 2013), i.e., it will most likely more than double over these 25 years. The oil demand in India will reach more than 8 million barrels per day in 2035 (IEA, 2013), whereas the current domestic production of crude oil has been more or less stagnant over the years, meeting only 18 percent of the national requirement (MoPNG, 2012). The balance is met through imports of nearly 172 million tons of crude petroleum products that cost the country close to US$140 billion in 2011-12 (MoPNG, 2012). Volatile oil prices and the uncertainty about sustained oil supplies have led India to search for alternatives, particularly for substituting petroleum products, to promote energy security.

Biofuels are considered among the most promising alternative options, as they can be produced locally and can be substituted for diesel and petrol to meet the transportation sector's requirements. India, like many other countries, is setting targets for the substitution of petroleum products by biofuels (GoI, 2003; MNRE, 2009). Globally, countries have been setting varying targets, ranging from 5 percent to 20 percent for the transport of fuel products to be provided from renewable sources, to be met at various times within the period 2010–2030 (Koonin, 2006; Wiesenthal et al., 2009; Eisentraut, 2010). The interest in biofuels in the industrialised countries, apart from promoting energy security, is also aimed at supporting agriculture and rural development and mitigating the threat of climate change by replacing petroleum fuels with renewable sources (Lapola et al., 2010). According to IPCC (2007), biofuels have a large potential to reduce GHG emissions in the transportation sector. On the other hand, developing countries such as India have multiple constraints in promoting biofuels, such as promoting energy security, rural development, and the reclamation of degraded lands as well as coping with the challenges of land and water scarcity and improving food security.

1.3 Scope of the report

Energy derived from plant based biofuels has been the major thrust across countries in developing alternative energy sources. Bio-ethanol and biodiesel are the two most common biofuels that are commercially exploited. Palm oil, edible oil from various oilseed crops, and *Jatropha* oil are some of the feedstocks that are used for the production of biodiesel, while sugarcane, maize, sugar beet, and cassava are common commercially exploited feedstocks for bio-ethanol (Fischer et al., 2009). The increasing criticism of the sustainability of many first-generation biofuels, often called the “food vs. fuel debate”, has focused attention on the potential of so-called second-generation biofuels. Depending on the feedstock choice and the cultivation technique, second-generation biofuel production has the potential to provide benefits such as higher net GHG reduction and reducing competition with food consumption by consuming waste residues and making use of abandoned land (Eisentraut, 2010). In this way, the new fuels could offer considerable potential to promote rural development and improve economic conditions in emerging and developing regions. In India, molasses, a by-product of sugar production, is commonly used for alcohol and ethanol production. However, current estimates indicate that ethanol from sugarcane alone will not be sufficient to meet India’s mandated requirement of blending (Shinoj et al., 2011). At the same time, more than half of India’s land is used for agriculture, with massive production of crop residues and crop wastes. The aim of this study is, therefore, to assess biomass resource availability in India from sustainably derived agricultural residues that can potentially be used for biofuel production.

The remainder of this report is organised as follows. Chapter 2 briefly highlights the salient features of the national biofuel policy in India. Chapter 3 presents the current status of biofuel production and its utilisation. Chapter 4 estimates the potential of second-generation biofuels from sustainably derived agricultural residues, whereas Chapter 5 presents the economic feasibility of biofuels and the cost of agricultural residues. A logistical assessment of second-generation biofuels and sustainability aspects is discussed in Chapters 6 and 7, respectively. Chapter 8 discusses the policy implications of our main findings and offers concluding remarks.

Photo of biomass boiler using grass and wood chips. Photo courtesy of Kyle Spradley, Curators of the University of Missouri, 2014. Info on the rights reserved: http://creativecommons.org/licenses/by-nc/4.0/

2. The National Biofuel Policy in India

The Indian government has undertaken several policy measures to augment the production and use of biofuels during the past decade (GoI, 2003; MNRE, 2009). The National Biofuel Mission (NBM), launched in 2003 under the aegis of the Planning Commission, Government of India, is the frontrunner of such efforts in the country. The NBM laid special focus on the phased expansion of area under biofuel feedstock crops such as *Jatropha* and *Pongamia*. It has included several micro missions covering the promotion of the large-scale plantation of feedstock crops in forests and wastelands, the procurement of seeds, oil extraction, transesterification, blending, trade, and R&D. The government initially intended to plant *Jatropha* on 11.2 million hectares of wasteland by 2012 and achieve a 10 percent blending target (GoI, 2003). However, biodiesel production costs surpassed the purchase price (which is predetermined by national regulators on a six month basis), thus effectively hindering the ambitious targets proposed by the government (Singh, 2009). The ethanol blended petrol programme (EBPP) and biodiesel blending programme (BDBP) are integral parts of the NBM and are aimed to initiate the blending of biofuels with transport fuels such as petrol and high speed diesel on a commercial scale.

To make biofuel blending a binding obligation on the states, in 2003 the Indian Ministry of Petroleum and Natural Gas (MoPNG) made 5 percent ethanol blending in petrol mandatory in 9 states and across 5 union territories. It was implemented only partially because of the unavailability of ethanol due to low sugarcane production in 2003-04 and 2004-05. The blending mandate was further extended to cover 20 states and 8 union territories in 2006. This directive could also only be partially implemented due to the inability of Oil Marketing Companies (OMCs)[1] to procure sufficient ethanol at the prevailing support price. In September 2007, the Cabinet Committee on Economic Affairs (CCEA) implemented 5 percent ethanol blending across the country[2] and recommended 10 percent ethanol blending where feasible, effective October 2007 (CCEA, 2007). Subsequently, the "National Biofuel Policy" formulated by the Ministry of New and Renewable Energy (MNRE) was approved in September 2008 and finally released in December 2009. This policy foresees biofuels as a potential means to stimulate rural development and generate employment opportunities and aspires to reap environmental and economic benefits arising out of their large-scale use. It outlines research and development, capacity building, purchase policy, and registration for enabling biofuel use, including second-generation[3] biofuels. The policy is not feedstock-specific but maintains the government position that energy crops should not have any adverse impact on the food sector.

The policy envisages the utilisation of a wide range of crops, such as sugarcane, sweet sorghum, cassava, maize, and tree-borne oilseeds such as *Jatropha* and *Pongamia* for the production of biofuels. It also envisages the establishment of a National Biofuels Development Board (NBDB) to develop a roadmap for the use of biofuels in petrol and diesel engines in a timely manner, in addition to taking appropriate policy measures. The national indicative target of 5 percent blending by 2012, 10 percent by 2017, and 20 percent after 2017 has been recommended in the policy. Biodiesel plantations of nonedible oilseeds on community/government/waste/degraded/marginal lands would be encouraged, while the plantation

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[1] Presently, the state owned public sector OMCs, such as the Indian Oil Corporation (IOC), Hindustan Petroleum (HP) and Bharat Petroleum (BP), are involved in procuring biofuels.

[2] The policy excludes the areas of, among others, the Northeastern States and the Island Territories.

[3] Second-generation biofuels are produced from cellulosic materials such as bagasse, wood waste, agricultural and forestry residues, algae, etc.

in fertile irrigated lands would not be supported. A Minimum Support Price (MSP) with the provision of periodic revision for biodiesel oilseeds would be announced to provide a fair price to the growers. The details of the minimum support mechanism will be worked out subsequently and considered by the steering committee. The Minimum Purchase Price (MPP) for the purchase of bioethanol by the OMCs would be based on the actual cost of production and import price of bioethanol. In the case of biodiesel, the MPP should be linked to the prevailing retail diesel price. It is also stated in the Policy that no taxes and duties should be levied on biodiesel.

Moreover, the government is considering the creation of a National Biofuel Fund (NBF) for providing financial incentives such as subsidies and grants for new and second-generation biomass feedstocks, advanced technologies and conversion processes, and production units based on new and second-generation feedstocks. Moreover, the biofuel technologies and projects would be allowed 100 percent foreign equity through automatic approval routes to attract Foreign Direct Investment (FDI), provided such biofuels produced are put only to domestic use.

Courtesy of FAO Aquaculture Photo Library.

3. Current Status of Biofuel Production and Utilisation

As outlined in the previous section, the biofuel policy of India has an indicative target of 20 percent blending of bioethanol by 2017 (MNRE, 2009). India's biofuel production currently accounts for only 1 percent of global production (Shinoj et al., 2012). India has 330 distilleries, which can produce more than 4 billion litres of rectified spirit (alcohol) per year in addition to 1.5 billion litres of fuel ethanol. Of this total, approximately 140 distilleries have the capacity to distil approximately 2 billion litres of conventional ethanol per year and could meet the demand for 5 percent blending with gasoline. In 2012, the country produced nearly 2.17 billion litres of ethanol, of which an estimated 0.4 billion litres were blended with petrol (Aradhey, 2012). Because ethanol has many alternative uses, such as potable liquor and in the chemical and pharmaceutical industries, its availability for blending with petrol is highly dependent on the prevailing market prices, which determine its viability for the OMCs for its use as a fuel. Currently, the entire bio-ethanol requirement has to come from molasses, a by-product of sugarcane. The availability of molasses to meet the blending mandates depends on cane and sugar production. Due to the cyclical nature of sugarcane production and consequent shortfalls in molasses availability, the government has so far been unable to meet its mandated blending target of 5 percent. In April 2010, the government decided to raise the MPP of ethanol to $0.5 per litre[4] from the previous level of $0.4 per litre to increase its availability for blending and to meet the blending targets for 2011-12[5]. However, the ethanol supply for the ethanol blending program during 2011-12 is anticipated to only be sufficient to meet a 2 percent blending level (Aradhey, 2012).

Large-scale blending of biodiesel with conventional diesel has not yet begun in India (Shinoj et al., 2011). Approximately, 20 biodiesel plants annually produce 140-300 million litres of biodiesel, which is mostly utilised by the informal sector locally for irrigation and electricity generation and by the automobile and transportation companies to run their experimental projects (USDA, 2010). The NBM primarily focused on the expansion of *Jatropha* area in two phases. The first phase, which was the demonstration phase, was taken up during 2003-2007 and included several micro-missions on *Jatropha*, including the promotion of its large-scale plantations in forests and wastelands, the procurement of seed and oil extraction, transesterification, blending, and trade and technological research and development (GoI, 2003). The second phase of the expansion targets aims to make the program self-sustainable by producing enough biodiesel to meet the 20 percent blending target (NCAER, 2007). To ensure a fair price to *Jatropha* farmers, various state governments have offered an MPP for *Jatropha* seeds. The MPP is announced for biodiesel also, the present rate being $0.49 per litre for biodiesel. Some subsidy programs and tax concessions/exemptions are also part of the government's efforts to boost the production of feedstocks for biofuels (Raju et al., 2009). Several public institutions, such as National Oilseeds and Vegetable Oils Development Board (NOVOD), under the Ministry of Agriculture (MoA), State Biofuel Boards, State Agricultural Universities, and non-state actors, such as Non-Governmental Organisations (NGOs), self-help groups (SHGs), and co-operative societies, are also actively supporting the biofuel program in various capacities.

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[4] 1 USD = 54.1 Indian Rupees as of 7th May 2013.

[5] Recently, the cost of ethanol production has surged to $0.68/litre (Jog, 2012), and the Ethanol Manufacturers Association of India demands that OMCs pay $0.74 a litre.

The major challenges facing the biofuel industry are discussed separately for bioethanol and biodiesel in the following sub-sections.

3.1 Bioethanol

India is globally the second largest producer of sugarcane and a large producer of ethanol made from sugarcane molasses. Table 1 presents the area, production, and yield of sugarcane during 2010-11 in respect to major sugarcane producing states. The area under sugarcane production increased approximately 2.9 times (MOA, 2003), whereas sugarcane production since 1950–51 to 2010-11 has increased by approximately six times. Figure 1 presents the intensity and spatial distribution of sugarcane production in India for the base year 2010-11. The all-India area and production of sugarcane is shown in Figure 2 (MOA, 2013). It can be noted that from 1950–1951 to 2010-11, the yield of sugarcane production increased from 33.4 to 70.1 t/ha (Table 1). The percentage of sugarcane area under irrigation increased from 67.3 percent in 1950–1951 to 93.5 percent in the year 2010-11 (MOA, 2013).

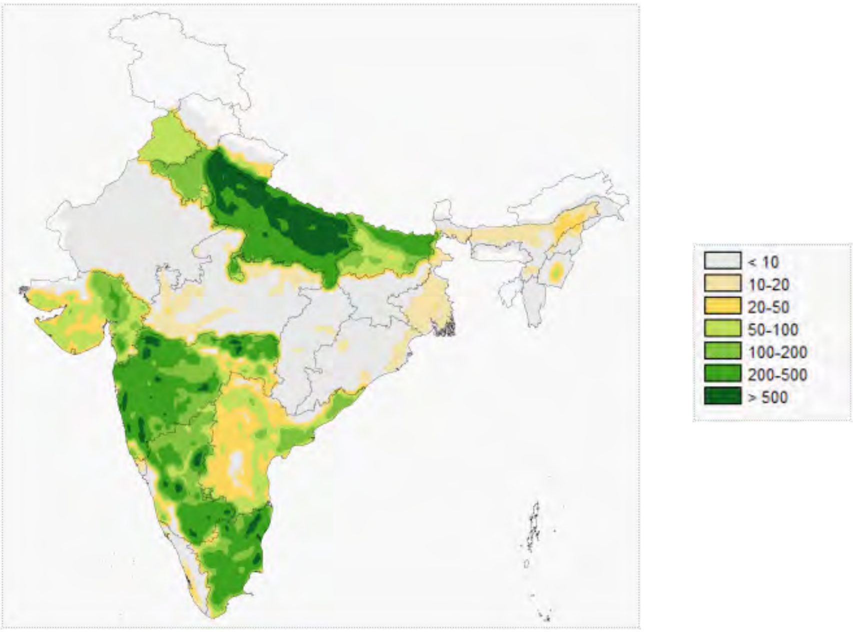
Table 1. Area, production, and yield of sugarcane in major sugarcane producing states

State	Area (Mha)	% of All India	Production (Mt)	% of All India	Yield (kg/ha)
Andhra Pradesh	0.19	3.89	14.96	4.37	78.7
Assam	0.03	0.61	1.08	0.32	36.0
Bihar	0.25	5.12	12.76	3.73	51.0
Gujarat	0.19	3.89	13.76	4.02	72.4
Haryana	0.09	1.84	6.04	1.76	67.1
Karnataka	0.42	8.61	39.66	11.58	94.4
Madhya Pradesh	0.07	1.43	2.67	0.78	38.1
Maharashtra	0.97	19.88	81.9	23.92	84.4
Odisha	0.01	0.20	0.9	0.26	90.0
Punjab	0.07	1.43	4.17	1.22	59.6
Tamil Nadu	0.32	6.56	34.25	10.00	107.0
Uttar Pradesh	2.13	43.65	120.55	35.21	56.6
Uttarakhand	0.11	2.25	6.5	1.90	59.1
West Bengal	0.02	0.41	1.13	0.33	56.5
Others	0.01	0.20	2.05	0.60	*
All India	4.88	100.00	342.38	100.00	70.1

*Because area/production is low in these states, a yield rate was not calculated

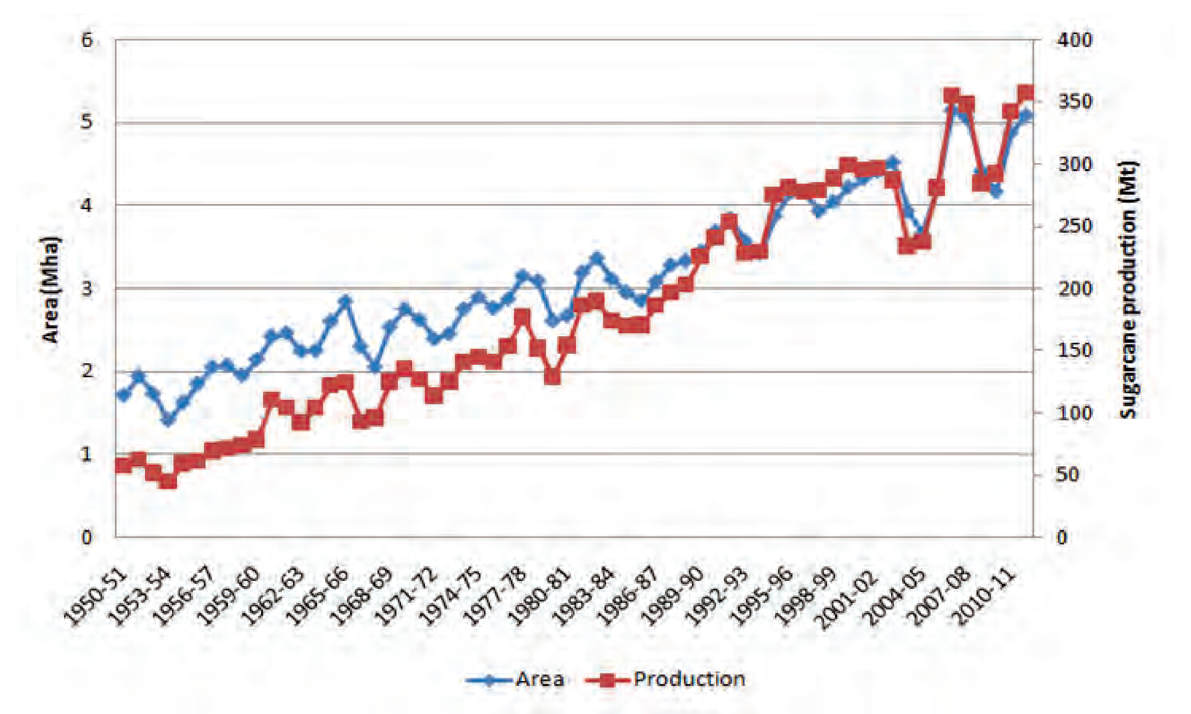
Source: MoA (2013)

Figure 1: Intensity and spatial distribution of sugarcane production in 2010-11 (tons/km^2)



As shown in Table 1 and Figure 1, sugarcane is cultivated in many of India's 28 states and seven union territories. However, production is centred in ten states: Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Gujarat, Bihar, Uttarakhand, Haryana, and Punjab (MOA, 2013). Table 1 indicates that more than 75 percent of the land under sugarcane cultivation in India is concentrated in only four states: Uttar Pradesh, Maharashtra, Karnataka, and Tamil Nadu (MOA, 2013). More than 40 percent of the sugarcane area and approximately 35 percent of India's sugarcane production in 2010-11 was located in Uttar Pradesh (see the spatial distribution of sugarcane production shown in Figure 1), followed in importance by Maharashtra (24 percent of production), Karnataka (12 percent of production) and Tamil Nadu (10 percent of production). Together, these four states contribute more than 80 percent of the total sugarcane production. Across India, the amount of land (and water) used to cultivate sugarcane has been increasing steadily from approximately 60 Mt in the 1950s to nearly 350 Mt in recent years (Figure 2).

Figure 2: Area and production of sugarcane in India



Source: MoA (2013)

Ethanol is primarily produced by the fermentation of molasses, and it is estimated that 85-100 kg of sugar (8.5–10 percent) and 35-45 kg (3.5-4.5 percent) of molasses can be obtained from 1 ton of sugarcane (Ghosh and Ghosh, 2003; Bhattacharya et al., 2010). The recovery of ethanol from molasses is 22-25 percent, as per Indian standards (Ravindranath et al., 2005). Using the data presented in Table 1, the theoretical molasses production is estimated at 15.41 Mt for 2010-11 if the entire sugarcane crop is used for sugar production. The associated ethanol yield is estimated at 3.62 billion litres. In reality, only approximately 70-80 percent of sugarcane produced in the country is utilised for the production of sugar, and the remaining 20-30 percent is used for alternative sweeteners (jiggery and khandsari) and seeds (Raju et al., 2009, Solomon, 2011). Thus, only molasses produced during sugar production is available for ethanol production. Therefore, in this study it is assumed that 75 percent of sugarcane production is used for sugar production.

Due to the cyclical nature of sugarcane and, thus, sugar production in India, sugarcane farmers and the processing industry experience periodic market gluts/deficits of sugarcane, sugar, and molasses, impacting their prices and farm incomes. The alcohol produced in the country is used for various purposes. Approximately one-fourth of the alcohol is being used for industrial purposes, while 30-35 percent is being used for beverages and the remaining 3-4 percent for other uses (Yadav and Solomon, 2006, Shinoj et al., 2011, Singh, 2011). The shares of molasses being used for potable, industry, and other applications are 32.5 percent, 25 percent, and 3.5 percent, respectively. The surplus available alcohol is being diverted for blending with transportation fuel. Table 2 presents the net availability of sugarcane ethanol for blending with transportation fuel across the major sugarcane producing states for the year 2010-11.

Table 2. State-wise availability of sugarcane ethanol for blending in the year 2010-11

State	Net molasses availability* (Mt)	Net ethanol yield (BL)	Ethanol utilisation (BL)			Available for blending** (BL)
			Potable	Industry	Other	
Andhra Pradesh	0.50	0.12	0.04	0.03	0.00	0.05
Assam	0.04	0.01	0.00	0.00	0.00	0.00
Bihar	0.43	0.10	0.03	0.03	0.00	0.04
Gujarat	0.46	0.11	0.04	0.03	0.00	0.04
Haryana	0.20	0.05	0.02	0.01	0.00	0.02
Karnataka	1.34	0.31	0.10	0.08	0.01	0.12
Madhya Pradesh	0.09	0.02	0.01	0.01	0.00	0.01
Maharashtra	2.76	0.65	0.21	0.16	0.02	0.25
Odisha	0.03	0.01	0.00	0.00	0.00	0.00
Punjab	0.14	0.03	0.01	0.01	0.00	0.01
Tamil Nadu	1.16	0.27	0.09	0.07	0.01	0.11
Uttar Pradesh	4.07	0.96	0.31	0.24	0.03	0.37
Uttarakhand	0.22	0.05	0.02	0.01	0.00	0.02
West Bengal	0.04	0.01	0.00	0.00	0.00	0.00
Others	0.07	0.02	0.01	0.00	0.00	0.01
All India	11.56	2.72	0.88	0.68	0.10	1.06

*Net molasses availability accounts for sugarcane used for alternative sweeteners (e.g., jiggery, khandsari) and seeds

**Ethanol used for potable, industry, and other applications is also taken into account

With the rising per capita income, urbanisation, infrastructural development, and the resultant increase in vehicle density, the demand for petrol in India is rapidly increasing. The growth rate in demand was 10.1 percent for petrol in the XIth 5-year-plan period (2007-2012), as per PPAC[6] estimates (PPAC, 2013). Similarly, the rate of growth in demand for ethanol increased by 3 percent for industrial and other uses and 3.3 percent for potable use (Shinoj et al., 2011). These growth rates are expected to continue over the next several years. With the government planning to bring into effect 20 percent blending of petrol with bioethanol by 2017, it is important to anticipate the demand it will incur for ethanol, so that necessary measures can be undertaken to achieve the targets. Keeping this in view, the demand for ethanol as fuel and for other alternative uses is projected until 2030-31 (Annexure I). Table 3 presents the ethanol demand for meeting the blending targets across the states in India. Gasoline demand was highest for major sugarcane producing states such as Maharashtra, followed by Gujarat, Tamil Nadu, Uttar Pradesh, and Andhra Pradesh.

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[6] Petroleum Planning & Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas (MoPNG), Government of India, New Delhi.

Table 3. Ethanol demand for meeting the blending targets across the Indian states

State	Petrol demand (Mt)	Ethanol demand (Mt)		
		For 5% blending	For 10% blending	For 20% blending
Andhra Pradesh	0.98	0.05	0.10	0.20
Assam	0.17	0.01	0.02	0.03
Bihar	0.36	0.02	0.04	0.07
Gujarat	1.62	0.08	0.16	0.32
Haryana	0.85	0.04	0.09	0.17
Karnataka	0.78	0.04	0.08	0.16
Madhya Pradesh	0.51	0.03	0.05	0.10
Maharashtra	1.65	0.08	0.17	0.33
Odisha	0.33	0.02	0.03	0.07
Punjab	0.56	0.03	0.06	0.11
Tamil Nadu	1.20	0.06	0.12	0.24
Uttar Pradesh	1.17	0.06	0.12	0.23
Uttarakhand	0.12	0.01	0.01	0.02
West Bengal	0.60	0.03	0.06	0.12
Others	2.62	0.13	0.26	0.52
Total	13.53	0.68	1.35	2.71

Table 4 presents the petrol demand along with the ethanol demand for various uses in the near future. Accordingly, it is estimated that the consumption of petrol will increase from 14.2 Mt in 2010-11 to 31.1 Mt in 2020-21 and 68.5 Mt in 2030-31. It is observed that the fuel ethanol demand during 2010-11 for 5 percent blending would be 0.7 Mt (0.9 billion litres), as shown in Table 4. The corresponding total ethanol demand after accounting for potable, industrial, and other uses would be 2.1 Mt, 2.8 Mt, and 4.2 Mt, respectively. In the year 2016-17, when blending at 20 percent is to be commenced, the total ethanol requirement would be 6.16 Mt, which is equivalent to 7.8 billion litres[7].

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[7] 1 metric ton of ethanol is equivalent to 1267 litres (density of ethanol is 0.789 g/ml)

Table 4. Projected ethanol demand for various uses in India

Year	Petrol demand (Mt)	Fuel ethanol demand (Mt)			Potable ethanol demand (Mt)	Ethanol demand for industrial and other uses (Mt)	Total ethanol demand (Mt)		
		5%*	10%	20%			5%	10%	20%
2010-11	14.2	0.7	1.4	2.8	0.7	0.7	2.1	2.8	4.2
2015-16	20.8	1.0	2.1	4.2	0.8	0.8	2.6	3.7	5.7
2020-21	31.1	1.6	3.1	6.2	1.0	0.9	3.4	5.0	8.1
2025-26	46.2	2.3	4.6	9.2	1.2	1.0	4.5	6.8	11.4
2030-31	68.5	3.4	6.9	13.7	1.4	1.2	6.0	9.4	16.2

*5%, 10% and 20% blending targets

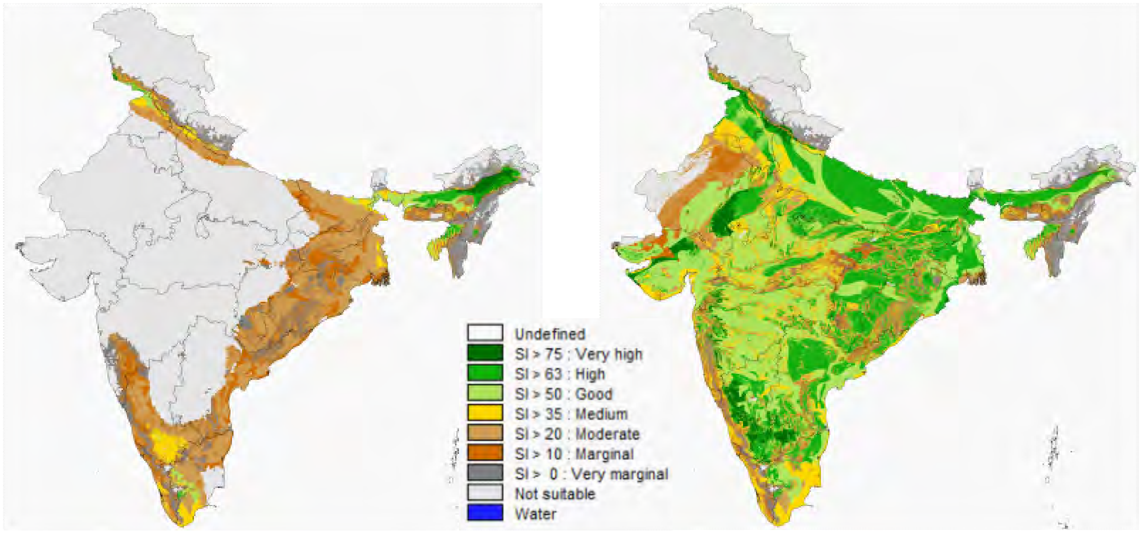
Source: Own estimates

In terms of water use, it makes a difference where and which biofuel crops are grown in India. For example, a litre of ethanol made from irrigated sugarcane in India needs more than 25 times as much irrigation water as a litre of ethanol made from mostly rain-fed sugarcane in Brazil (de Fraiture et al., 2008). From a resource use point of view, policymakers need to encourage farmers to grow biofuel crops under rain-fed rather than irrigated conditions. Not only could such a policy boost agricultural returns in rain-fed areas, but, provided competition with food crops can be avoided, the risk of inducing food insecurity would also be minimal.

Figure 3: Agro-ecological suitability of sugarcane under rain-fed and irrigated conditions

a) rain-fed

b) irrigated

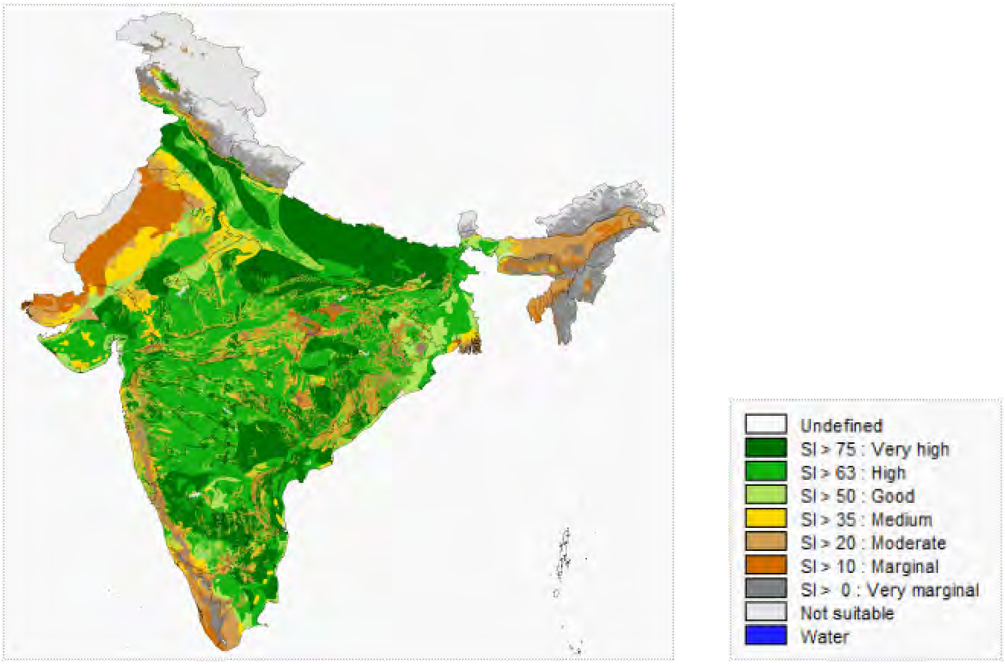


Source: IIASA/FAO (2012)

However, as model simulations can show, rain-fed sugarcane production is not a significant option in India. FAO, in collaboration with IIASA, has developed an Agro-ecological Zones (AEZ) methodology that enables rational land-use planning based on an inventory of land resources and the evaluation of biophysical limitations and production potentials (Fischer et al., 2009; see Annexure IV). Figure 3 presents crop suitability for rain-fed (left) and irrigated sugarcane production in India (for details of the agro-ecological assessment, see Annexure IV). The figure clearly shows that due to India's climate characteristics, with a rain-fed length of growing period (LGP) of less than 210 days in a large part of the country, there is little available area with good to very high suitability for rain-fed sugarcane production. This area is mainly located in the wet far eastern part of India. These soil moisture limitations are also reflected by the fact that approximately 93 percent of the current sugarcane area in India is irrigated. These resource constraints may render sugarcane production in India an option with only limited potential for large-scale biofuel production.

Efforts to further increase sugarcane area and production would undoubtedly intensify the severe competition for land and scarce water resources. An alternative option, technologically similar and proven for the production of bio-ethanol, yet agro-ecologically much better suited in the Indian context, is ethanol production using the stalks of sweet sorghum as feedstock. Demonstration plants and agronomic research indicate that the sweet sorghum route could provide an agronomically successful and economically viable pathway that could produce simultaneously fair quantities of food grain and substantial amounts of biofuel feedstocks (ISSASS, 2007). Unlike sugarcane, sorghum can be grown with good success under rain-fed conditions in nearly all of India (Figure 4). Sorghum is drought tolerant and is also much less demanding of soils than sugarcane.

Figure 4: Agro-ecological suitability of sorghum under rain-fed conditions



Source: IIASA/FAO (2012)

Nevertheless, using the sugarcane production data from 1950-51 to 2011-12, we have projected the area and production of sugarcane in India until 2030-31 (see Figure AII.5) and estimated the net ethanol availability as shown in Table 5. It is quite clear from Table 5 that to achieve a 20 percent blending target without compromising industrial, potable, and other requirements, India has to either increase its ethanol production by nearly 3 times the present levels or must opt for massive imports of ethanol. There are several constraints for increasing ethanol production to such levels, given that the sugarcane yield in the country has been stagnating at approximately 65-70 tons per hectare for the past several years (MoA, 2013). It also does not appear feasible to increase the area under sugarcane, as this will come at the cost of diverting land from other staple food crops. Because sugarcane consumes approximately 20,000-30,000 cubic meters of water per hectare per crop, the overexploitation of groundwater for energy production would not be a sustainable option. While only molasses is used in India to produce ethanol, its direct production from sugarcane juice, a more efficient method practiced in Brazil and elsewhere, would compete with sugar production for the food market.

Table 5: Availability and utilisation of ethanol in India

Year	Sugarcane production (Mt)	Net ethanol availability (BL)	Total ethanol demand (BL)			Deficit/Surplus (BL)		
			5%*	10%	20%	5%	10%	20%
2010-11	342.4	2.72	2.6	3.5	5.3	0.1	-0.8	-2.6
2015-16	346.9	2.75	3.3	4.6	7.3	-0.6	-1.9	-4.5
2020-21	370.9	2.94	4.3	6.3	10.2	-1.4	-3.3	-7.3
2025-26	394.8	3.13	5.7	8.6	14.4	-2.5	-5.4	-11.3
2030-31	418.8	3.32	7.5	11.9	20.5	-4.2	-8.5	-17.2

*5%, 10% and 20% blending targets

Moreover, even an occasional shortage of molasses bids up the cost of ethanol production, making its blending with petrol an uneconomical proposition. The import of ethanol for fuel use is currently restricted through policy, and even if made free, it would cost the exchequer dearly, as the international markets for ethanol are already very tight due to demand from other biofuel-consuming countries. Therefore, to meet expected future demand, ethanol production needs to be augmented with alternative feedstocks.

3.2 Biodiesel

Biodiesel is considered an important bioenergy option for India (GoI, 2006). There is a potential to increase biodiesel production by tapping into the existing resources of Tree-borne Oilseeds (TBOs) in the country as well as by establishing new plantations. The efforts towards biodiesel production are focused on using non-edible oils obtained from *Jatropha, Pongamia,* and other TBOs (Kalbande et al., 2008). The emphasis has been on encouraging the use of wastelands and other unproductive lands for the cultivation of these relatively hardy 'new' biofuel crops. The Indian government does not want biofuel feedstock crop cultivation to compete with food crops for scarce agricultural land and water (MNRE, 2009). Government policy is also driven by the vast rural population in India, considering their needs for food security, energy access, and gainful employment. There is some concern about the definition of 'wastelands' in land use statistics, as informal uses, such as some grazing or less intensive dry land farming, may be taking place on these lands. The availability of land for biodiesel as per GoI estimate is discussed in detail in Annexure-II, and statistics of culturable wasteland are presented in Annexure V. Nevertheless, commercial-scale biodiesel production from non-edible oil crops is still at the research and development stage in India.

The NBM has identified *Jatropha* as the most suitable treeborne oil crop for biodiesel production in India (GoI, 2003). Although various other oil crops also qualify as feedstocks for biodiesel production, *Jatropha* has been specifically chosen because it is a short gestation, non-edible oil crop that, when grown on marginal land, does not impinge on the food security of the nation, even if promoted commercially. *Jatropha* is a drought-tolerant and hardy crop that can be grown in relatively less fertile and marginal lands with low inputs and minimal management (except labour for harvesting and farm inputs for crop establishment). Figure 5 presents the agro-ecological suitability of rain-fed *Jatropha*. Several other TBOs, such as *Pongamia, Simaruba, Neem, and Mahua,* have also been found suitable and are being promoted but are less favoured than *Jatropha* due mainly to their long gestation periods (Altenburg et al., 2008). Several studies (Fargione et al., 2008; Tilman et al., 2009; Yang et al., 2012) at the global level have also favoured *Jatropha* over other crops for cultivation in marginal or less-productive lands for biodiesel production. On a global level, considerable investments have been made in *Jatropha*-based biodiesel development projects (Fairless, 2007). A survey conducted by the Global Exchange for Social Investment (GEXSI, 2008) has identified 242 *Jatropha* projects in different parts of the world, the majority of which are located in Asia. India is currently the leading cultivator of *Jatropha*, with nearly 0.5 million hectares (Mha) of area under this crop.

The diesel demand in India has been increasing at a rate of 7.5 percent per annum since 2004-05. Demand projections suggest that nearly 3.0 million tons (Mt) of biodiesel would be required for 5 percent blending by the year 2011-12 (Tables 6-7). To bring this into effect, and assuming that *Jatropha* would be the major feedstock for biodiesel (i.e., 80 percent of the requirement would be met from *Jatropha*) with an average seed yield[8] of 2.5 t/ha and a 30 percent biodiesel recovery rate, the area required under this crop has been estimated as 3.2 Mha.

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[8] The NCAP survey conducted in Rajasthan, Chhattisgarh and Uttarakhand suggests that the average yield of *Jatropha* under normal management practices in farmers' fields ranges between 2.0 and 2.9 ton/ha.

Table 6. Biodiesel demand and corresponding *Jatropha* area required for meeting the blending targets across the states in India

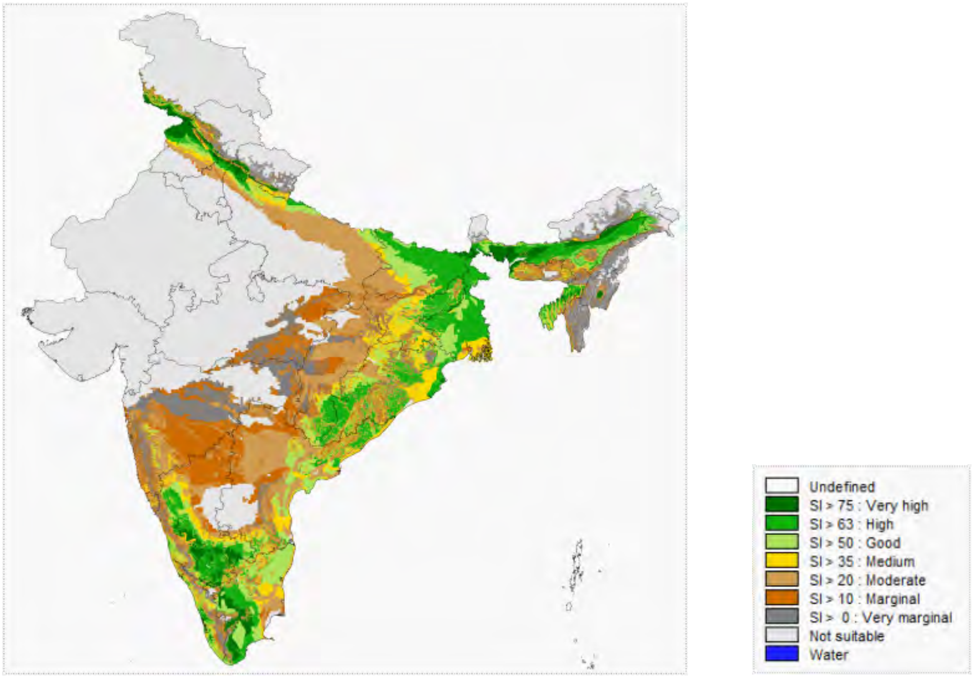
State	Diesel demand (Mt)	For 5% blending		For 10% blending		For 20% blending	
		Biodiesel demand (Mt)	Jatropha area (Mha)	Biodiesel demand (Mt)	Jatropha area (Mha)	Biodiesel demand (Mt)	Jatropha area (Mha)
Andhra Pradesh	4.37	0.22	0.23	0.44	0.47	0.87	0.93
Assam	0.77	0.04	0.04	0.08	0.08	0.15	0.16
Bihar	1.60	0.08	0.09	0.16	0.17	0.32	0.34
Gujarat	7.18	0.36	0.38	0.72	0.77	1.44	1.53
Haryana	3.79	0.19	0.20	0.38	0.40	0.76	0.81
Karnataka	3.46	0.17	0.18	0.35	0.37	0.69	0.74
Madhya Pradesh	2.25	0.11	0.12	0.23	0.24	0.45	0.48
Maharashtra	7.33	0.37	0.39	0.73	0.78	1.47	1.56
Odisha	1.47	0.07	0.08	0.15	0.16	0.29	0.31
Punjab	2.49	0.12	0.13	0.25	0.27	0.50	0.53
Tamil Nadu	5.33	0.27	0.28	0.53	0.57	1.07	1.14
Uttar Pradesh	5.19	0.26	0.28	0.52	0.55	1.04	1.11
Uttarakhand	0.55	0.03	0.03	0.05	0.06	0.11	0.12
West Bengal	2.67	0.13	0.14	0.27	0.28	0.53	0.57
Others	11.64	0.58	0.62	1.16	1.24	2.33	2.48
Total	60.07	3.00	3.20	6.01	6.41	12.01	12.82

Table 6 presents the biodiesel demand and corresponding *Jatropha* area required for meeting the blending targets across the states in India. An estimated area of 23.6 Mha and 44 Mha would be required under *Jatropha* to meet a 20 percent blending target by the year 2020-21 and 2030-31, respectively, as shown in Table 7, when assuming the yield and oil content of *Jatropha* would remain at the assumed level and that no new superior feedstocks would be introduced.

Table 7. Projections of biodiesel demand and corresponding *Jatropha* area required for meeting the blending targets in India

Year	Diesel demand (Mt)	For 5% blending		For 10% blending		For 20% blending	
		Biodiesel demand (Mt)	Jatropha area (Mha)	Biodiesel demand (Mt)	Jatropha area (Mha)	Biodiesel demand (Mt)	Jatropha area (Mha)
2010-11	60.1	3.0	3.2	6.0	6.4	12.0	12.8
2015-16	81.6	4.1	4.3	8.2	8.7	16.3	17.4
2020-21	110.8	5.5	5.9	11.1	11.8	22.2	23.6
2025-26	151.2	7.6	8.1	15.1	16.1	30.2	32.2
2030-31	206.4	10.3	11.0	20.6	22.0	41.3	44.0

Figure 5: Agro-ecological suitability of rain-fed *Jatropha*



Source: IIASA/FAO (2012)

This FAO/IIASA global agro-ecological zone modelling framework (GAEZ v3.0) has been used to assess the spatial availability and suitability of culturable wastelands for *Jatropha* production in India. Table 8 presents estimates of wasteland by different suitability classes (very suitable, suitable, and moderately suitable), its potential production, and the average attainable oil yields. The total extent of culturable wasteland (excluding protected areas) taken from district level land utilisation statistics of 2006-07, amounts to some 12.9 Mha.

Table 8. Suitability of rain-fed *Jatropha* in land classified as culturable wasteland (2006-07)

	Culturable Wasteland	Suitable Area (1000 ha)		Potential Production (1000 tons)		Potential Yield (tons oil/ha)	
	(1000 ha)	VS+S	MS	VS+S	MS	VS+S	MS
State							
Andhra Pradesh	695	29.4	186.9	34	165	1.2	0.9
Arunachal Pradesh	37	15.0	2.4	19	2	1.3	1.0
Assam	77	76.1	0.5	94	1	1.2	1.0
Bihar	40	19.7	14.6	23	13	1.2	0.9
Chhattisgarh	350	83.0	88.9	99	75	1.2	0.8
Goa	0	0.0	0.0	0	0	0.0	0.0
Gujarat	1904	0.0	0.0	0	0	0.0	0.0
Haryana	57	2.5	0.2	3	0	1.3	0.9
Himachal Pradesh	134	25.0	7.5	35	7	1.4	0.9
Jharkhand	334	112.6	94.3	127	83	1.1	0.9
Karnataka	416	245.6	60.6	325	49	1.3	0.8
Kerala	90	39.1	47.8	51	43	1.3	0.9
Madhya Pradesh	1177	0.0	0.0	0	0	0.0	0.0
Maharashtra	914	0.0	22.8	0	19	0.0	0.8
Manipur	0	0.0	0.0	0	0	0.0	0.0
Meghalaya	450	40.1	74.0	48	62	1.2	0.8
Mizoram	0	0.0	0.0	0	0	0.0	0.0
Nagaland	64	0.0	0.2	0	0	0.0	0.9
Orissa	375	231.1	107.8	272	91	1.2	0.8
Punjab	4	2.3	0.0	3	0	1.4	0.0
Rajasthan	4611	0.0	0.0	0	0	0.0	0.0
Sikkim	0	0.0	0.0	0	0	0.0	0.0
Tamil Nadu	353	234.1	78.9	295	65	1.3	0.8
Tripura	0	0.0	0.0	0	0	0.0	0.0
Uttar Pradesh	440	9.6	12.1	12	10	1.2	0.8
Uttarakhand	367	35.3	1.6	50	1	1.4	0.9
West Bengal	33	31.7	0.3	37	0	1.2	0.8
Union Territory							
A. & N. Islands	0	0.0	0.0	0	0	0.0	0.0
Chandigarh	0	0.0	0.0	0	0	0.0	0.0
D. & N. Haveli	0	0.0	0.0	0	0	0.0	0.0
Daman & Diu	0	0.0	0.0	0	0	0.0	0.0
Delhi	10	0.0	0.0	0	0	0.0	0.0
Lakshadweep	0	0.0	0.0	0	0	0.0	0.0
Puducherry	4	0.0	0.0	0	0	0.0	0.9
Total	12937	1232.3	801.6	1527	687	1.2	0.9

Source: Calculation by authors based on AEZ suitability assessment and land utilisation statistics of 2006-07.

Table 8 presents, in the first numerical column, the extents of land classified as culturable wasteland, aggregated from district level data. The remaining columns show suitable extents, potential production, and average attainable yields of land classified as culturable wasteland for land assessed as very suitable or suitable and land assessed as moderately suitable. According to the AEZ definitions, very suitable land (VS) can produce 80-100 percent of maximum attainable yields, suitable land (S) 60-80 percent of maximum attainable yields, and moderately suitable land (MS) 40-60 percent of maximum attainable yields. Land assessed as marginally suitable or unsuitable is regarded as economically unviable and was excluded from the calculation of potential production.

According to the AEZ suitability results summarised in Table 8, there is approximately 2 Mha of culturable wasteland out of a total of 12.9 Mha that is assessed as very suitable, suitable, or moderately suitable, with average attainable oil yields estimated at 0.8-1.4 tons per hectare. When all this land is brought under *Jatropha* cultivation, the potential production is estimated at 2.2 Mt of oil.

Table 9. Suitability of rain-fed *Jatropha* in non-food and non-forest land (2006-07)

	Total Non-food Land	Suitable Area (1000 ha)		Potential Production (1000 tons)		Potential Yield (tons oil/ha)	
	(1000 ha)	VS+S	MS	VS+S	MS	VS+S	MS
State							
Andhra Pradesh	11687	59.0	613.2	68	547	1.2	0.9
Arunachal Pradesh	171	17.5	10.5	22	10	1.3	1.0
Assam	2789	416.9	983.4	512	921	1.2	0.9
Bihar	1355	111.2	635.4	132	592	1.2	0.9
Chhattisgarh	5476	125.9	182.1	150	149	1.2	0.8
Goa	0	0.0	0.0	0	0	0.0	0.0
Gujarat	3580	0.0	0.0	0	0	0.0	0.0
Haryana	669	4.9	44.9	6	40	1.3	0.9
Himachal Pradesh	2605	64.9	26.8	89	23	1.4	0.9
Jharkhand	2369	185.1	178.6	209	157	1.1	0.9
Karnataka	10880	864.2	1715.4	1145	1357	1.3	0.8
Kerala	2148	39.2	381.7	51	333	1.3	0.9
Madhya Pradesh	8443	0.0	0.0	0	0	0.0	0.0
Maharashtra	18172	0.0	65.5	0	56	0.0	0.9
Manipur	0	0.0	0.0	0	0	0.0	0.0
Meghalaya	800	40.1	74.0	48	62	1.2	0.8
Mizoram	0	0.0	0.0	0	0	0.0	0.0
Nagaland	284	0.0	0.2	0	0	0.0	0.9
Orissa	6195	554.8	1245.6	650	1071	1.2	0.9

Punjab	1335	3.6	156.3	5	133	1.4	0.8
Rajasthan	8477	0.0	0.0	0	0	0.0	0.0
Sikkim	0	0.0	0.0	0	0	0.0	0.0
Tamil Nadu	5367	303.4	1020.4	379	882	1.2	0.9
Tripura	0	0.0	0.0	0	0	0.0	0.0
Uttar Pradesh	6404	11.0	485.3	13	406	1.2	0.8
Uttarakhand	1389	35.5	2.7	51	2	1.4	0.9
West Bengal	1653	36.0	370.7	42	328	1.2	0.9
Union Territory							
A. & N. Islands	0	0.0	0.0	0	0	0.0	0.0
Chandigarh	0	0.0	0.0	0	0	0.0	0.0
D. & N. Haveli	1	0.0	0.0	0	0	0.0	0.0
Daman & Diu	0	0.0	0.0	0	0	0.0	0.0
Delhi	26	0.0	0.0	0	0	0.0	0.0
Lakshadweep	0	0.0	0.0	0	0	0.0	0.0
Puducherry	15	0.0	0.3	0	0	0.0	0.9
Total	102291	2873.1	8193.0	3573	7071	1.2	0.9

Source: Calculation by authors based on AEZ suitability assessment and land utilisation statistics of 2006-07.

A similar estimation was performed to assess the suitability of rain-fed *Jatropha* across all non-food/non-forest land. For this estimation, we excluded all current agricultural land (net sown areas, fallow land, land under misc. tree crops and groves (i.e., areas corresponding to columns 6, 9, and 10 in Table A.V.1), areas classified as forested land (i.e., land with tree cover in each grid cell of the GIS layer), and land classified as being put under non-agricultural uses (such as housing, roads, and airports). We excluded all land with legal protection status (according to the Global Database of Protected Areas 2009), and we included in the calculation unprotected (i.e., without legal protection status) pastures and other grazing land (10 Mha), culturable wasteland (12.9 Mha), and various other unprotected land, including barren and unculturable land (79.4 Mha). Using district-level statistical data of 2006-07, this non-food/non-forest land amounts to 102 Mha (see Table 9). Of this land, approximately 11.1 Mha was assessed as very suitable and suitable (1.9 Mha) or as moderately suitable (8.2 Mha), with an estimated production potential of 10.6 Mt *Jatropha* oil.

So far, only approximately 0.5 million hectares of land has been put under *Jatropha* cultivation, and the government has not initiated the purchase of biodiesel through the designated purchase centres, even though an MPP of $0.49 per litre was announced a few years ago. There are several reasons behind the slow progress of India's national biofuels program towards its stated goals. The *Jatropha* production program was started rather in haste without any planned varietal improvement program preceding it. In almost every state where it was implemented, conventional low-yielding cultivars were used for new feedstock plantings. For this reason, the producers are ill suited to the crop yields, especially under low management conditions[9], as indicated by the field studies. Moreover, the longer gestation period (3-4 years) of *Jatropha* also discourages farmers in places where state support is not readily available.

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[9] The yield can be as low as 500 kg/ha if no initial irrigation and fertilizer applications are provided.

However, a financial assessment based on discounted measures[10] on long-term investment in *Jatropha* cultivation has suggested promising prospects (Shinoj et al., 2011). The estimates of the net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) for *Jatropha* investment (Table 10) were found to be encouraging and suggest that with some initial support, *Jatropha* cultivation could be made profitable in farmers' fields. The relatively higher estimates for the state of Chhattisgarh could be attributed to the lower cost of *Jatropha* production and its higher yields in the state.

Table 10. Financial measures for assessing the feasibility of investment in *Jatropha* cultivation in three states of India

State	NPV[11] ($)	BCR	IRR (%)
Rajasthan	874	1.5	25
Chhattisgarh	1853	10.2	85
Uttarakhand	901	1.8	45

Source: Adapted from (Shinoj et al., 2011).

The *Jatropha* seed distribution channels are currently underdeveloped, and there are an insufficient number of processing plants in operation. Although several private companies have ventured into *Jatropha* cultivation and biodiesel production, their involvement is still very low. There are no specific markets for *Jatropha* seed supply, and hence, the middlemen play a major role in taking the seeds to the processing centres, which inflates the marketing margin. The processing industry suffers from low backward integration with the seed market and forward integration with biodiesel distribution channels. The distribution channels are almost non-existent, as most of the biofuel produced is used either by the producing companies for self-use or by certain transport companies on a trial basis. Unless the large-scale use of biodiesel commences or a demand pull from the mandatory blending of biodiesel comes, these channels will remain under-developed. Furthermore, the cost of biodiesel depends substantially on the cost of seeds and the economy of scale at which the processing plant is operating.

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[10] Assuming that the parity between the seed prices and cost of inputs would remain the same as of today throughout the economic lifespan of *Jatropha*.

[11] The economic life-span of *Jatropha* was assumed to be 20 years; a 10 percent discount rate was used for the calculations.

Courtesy of FAO Aquaculture Photo Library.

4. Second-Generation Biofuel Production in India

Currently, the production of biofuels is limited to the so-called first generation biofuels, comprising biodiesel from vegetable oils and bioethanol from sugar or starch containing plants. The production of feedstocks and of first generation biofuels relies on well-known technologies, and the actual exploitation of the final products is well established (Cheng and Timilsina, 2011). However, these biofuels have significant costs and disadvantages mainly due to the limited feedstock species suitable for first-generation conversion technologies (Damartzis and Zabaniotou, 2011). Furthermore, there is great concern about feedstock competition between the biofuel and food industries, the risks for food security, and other potential – mainly economical – impacts that the use of food crops for fuel production would have on the food industry and society in general. The discussion triggered by the 2008 global food crisis highlighted that feedstocks for first-generation biofuels require large amounts of land, water, and chemical fertilisers, with substantial environmental and economic costs and with highly uncertain outcomes for GHG mitigation.

Second-generation biofuels derived from lignocellulosic feedstocks can overcome the problem of feedstock availability, enabling the use of a much broader variety of biomass sources (Zabaniotou et al., 2008). Second-generation biofuels originate from agricultural residues and by-products, organic wastes, and materials derived from purposely grown energy plantations (Sims et al., 2010), offering a more preferable variety of woody, grassy, and waste materials as a feedstock. Major national biofuel programs have been initiated to produce cost-efficient ethanol and other fuels from agricultural and forest lignocellulosic biomass in countries such as the USA and China (Ojeda et al., 2011). Although second-generation biofuels are still under technological investigation regarding conversion technologies and process operation, they are expected to meet the requirements for lower land use and much better CO_2 emission reduction potential after commercialisation (Suurs and Hekkert, 2009).

Second-generation biofuels are compatible with today's fuels, and the necessary infrastructure may come, to some extent, from the existing infrastructure of the petroleum and sugar industries. It is believed that the market transition from first to second-generation biofuels will be slow but steady based on this compatible infrastructure. Second-generation biofuels are expected to be slowly integrated in the first generation biofuels market and after commercialisation through strenuous technological investigation, finally becoming the predominant fuel products (Sims et al., 2010). Of course, the economic feasibility and success of these biofuels strongly depends on the legislation and taxation policies invoked upon their introduction in the energy market. Thus, favorable policies at the international and national levels are mandatory for the successful introduction and distribution of these second-generation biofuels into the market.

In India, the concerns regarding the feedstock availability, economic viability, and sustainability of molasses-based ethanol have necessitated the search for alternative feedstocks to produce ethanol (Findlater and Kandlikar, 2011; Sasmal et al., 2012). For example, sweet sorghum has been found to be one such potential source of raw material for commercial ethanol production due to various advantages (Basavaraj et al., 2013). The potential of second-generation biofuels from agricultural residues essentially depends upon the total amount of crop residues generated annually, their current usage levels, and the potential surplus availability for energy use. Hence, the focus of this section is to assess the energy potential of biomass resources in the form of residues and wastes, i.e., biomass from non-plantation sources in India, with the following specific objectives: (i) to estimate total crop residues, (ii) to estimate the fraction of crop residues available for energy purposes, and finally (iii) to assess the current and future biofuel potential from agricultural residues. The methodologies used to estimate the energy potential of the biomass sources are presented elsewhere (Kumar et al., 2002; Purohit et al. 2006; Purohit and Michaelowa, 2007; Purohit, 2009; Bhattacharya et al., 2010). To assess the potential availability of crop residues for energy purposes, it is imperative to understand the area under agricultural crops, the prevailing cropping patterns, and the utilisation of crop residues.

4.1 Market price of agricultural residues

A large variation is observed in the reported market price(s) of agricultural residues in India. In Chhattisgarh, at $74 per truck, it is practically possible to collect rice husks from a distance of up to 100 km (Pandey et al., 2012). In this case, rice mill owners will earn approximately $9 per ton from rice husks. In Uttar Pradesh, the price of rice husks is $37 to $46 per ton, while the price of coal is $83 to $92 per ton (Yadav et al., 2011). In Punjab, rice husks were being sold for $55 per ton in 2010 against $46 per ton in 2009. The price even touched $74 per ton (Sharma et al., 2010). Overall, the price of rice husks varied from $18 to $74 per ton in 2010, whereas the price of rice straw was $11 to $13 per ton (Sharma et al., 2010). The competing uses for straw are varied and intense. Food grain straw is primarily used for cattle feed in India. At the same time, food grain straw is being used as, e.g., construction material, straw board, paper and hardboard units, and packing materials for glass wares. As per CSE (2010) estimates, $92 to $111 per ton is the standard rate for wheat or bajra straw anywhere in Rajasthan at the time of harvest. In Gujarat, it varies from $74 to $92 per ton, while in Maharashtra it varies from $83 to $102 per ton. In urban areas, particularly around Hyderabad and Bangalore, dairy animal owners have purchased chaffed sorghum stalks at prices as high as $102 to $120 per ton (Hegde, 2010). Even wheat straw has been sold in the range of $37 to $55 per ton, while paddy straw has been sold at $28 to $37 per ton.

In India, molasses is commonly used for alcohol and ethanol production. Molasses prices fluctuated substantially, ranging from $18 to $92 per ton, during the previous decade. The ex-factory prices of molasses generally remained at approximately $18 per ton during the period 1998-2003. Since the second half of 2003-04, molasses prices witnessed an upward movement, reaching $65 per ton in 2004-05 before correcting to the $37 to $46 range in 2005-06 and remaining in this range thereafter (ICRA, 2006). However, the drought during 2008-09 resulted in a substantial reduction in sugarcane production and a resultant dramatic increase of molasses prices to $92 per ton (Raju et al., 2012).

The large-scale utilisation of agricultural residues as energy sources depends upon a variety of factors, such as their availability, characteristics as fuel, and of course, their financial viability compared with other options. The financial viability of their use, in turn, critically depends upon the “price tag” attached to them and their opportunity cost to the user. Agricultural residues are produced as a by-product along with the main crops. Thus, they are normally assumed to be available at “no cost” to the user, which is not a valid assumption. As long as the agricultural residues are utilised by the producers themselves, their costs may not be explicitly determined. However, when critically analysing the various factors responsible for the overall cost of residues (from their production and handling on the farm and their transport to and handling at the point of their utilisation), it is found that the cost of agricultural residues may be substantial (see Section 5.3).

4.2. Potential of bio-ethanol production from agricultural residues

Of India's total geographic area of 328 million hectares (Mha), the net cropped area accounts for approximately 43 percent, and it appears that the net cropped area has stabilised at approximately 140 Mha since 1970 (Ravindranath et al., 2005). However, the gross cropped area, accounting for multiple crops grown per year, increased from 132 Mha in 1950-51 to approximately 195 Mha in 2008-09. A table reporting the land utilisation by state in India is presented in Annexure–V. Maps showing the intensity and spatial distribution of total cultivated land (net sown area and current fallow) and of irrigated cultivated land (net sown area), displayed as the percentage of total area on a spatial grid of 5 arc-minute resolution (ca 10 km by 10 km), are shown in Figures 6 and 7, respectively. Maps compiled from district-level data of land utilisation in 2006-07 are included in Annexure V.

Figure 6: Intensity and spatial distribution of cultivated land (percent of 5' grid cell)

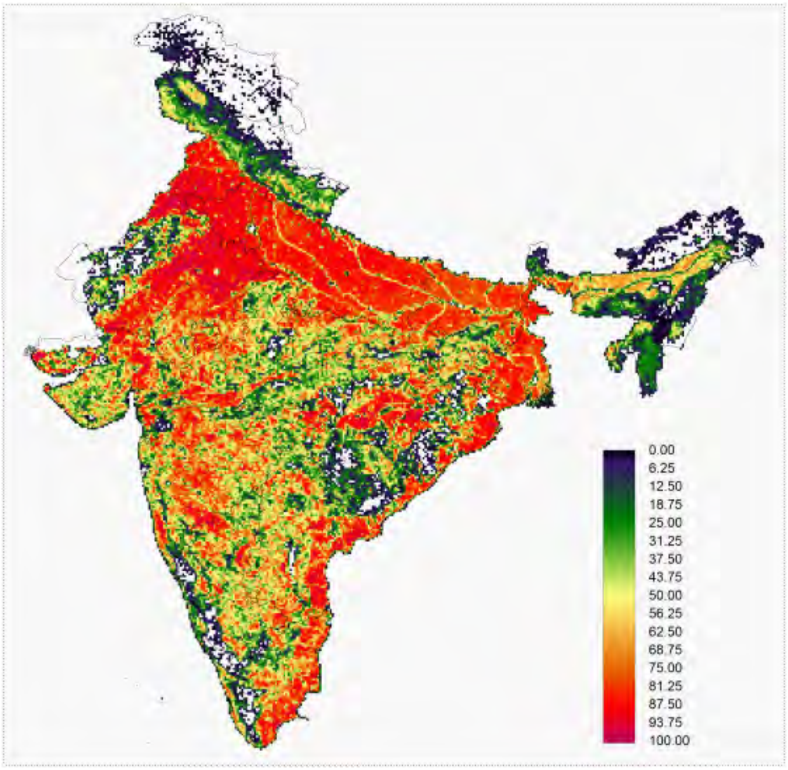


Figure 6 demonstrates that land in India is very intensively used in agriculture except for regions with severe biophysical limitations – concerning slopes and/or moisture availability – such as the mountainous regions in northwest and northeast India, the arid areas in western India, and some sloped land in southwest and central India.

Due to the monsoonal seasonal climate, irrigation is necessary for year-round exploitation of the thermal resources in India's sub-tropical and tropical conditions. Irrigation is intensively practiced in the Indo-Gangetic plain (Figure 7), particularly in Punjab, Haryana, and Uttar Pradesh, where irrigated areas dominate the net sown area (Figure 8).

Figure 7: Intensity and spatial distribution of irrigated cultivated land (percent of 5’ grid cell)

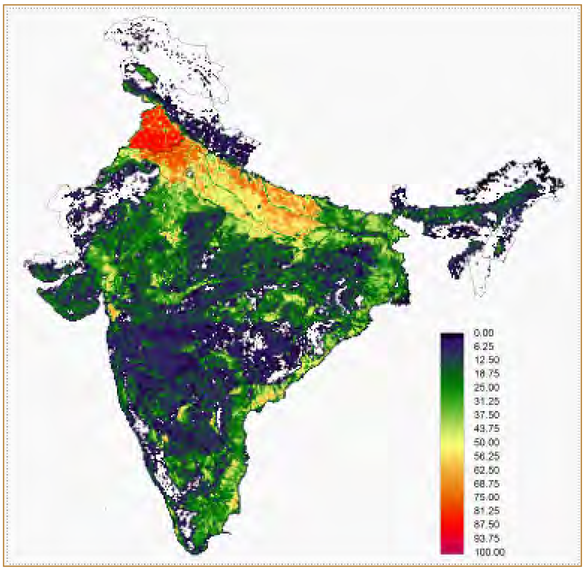


Figure 8: Share of irrigated in total cultivated land (percent of 5’ grid cell)

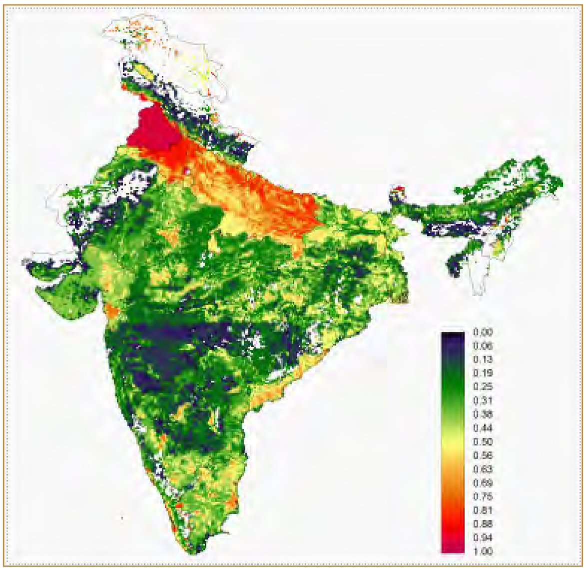
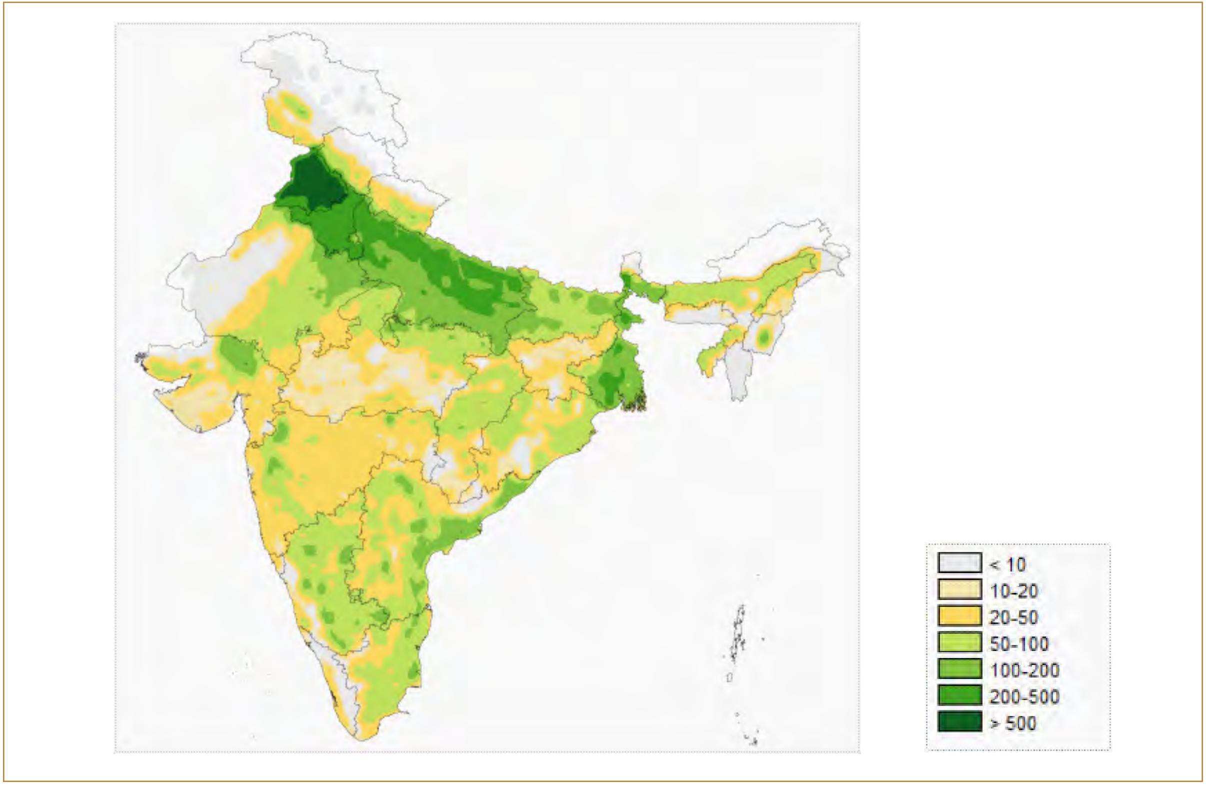


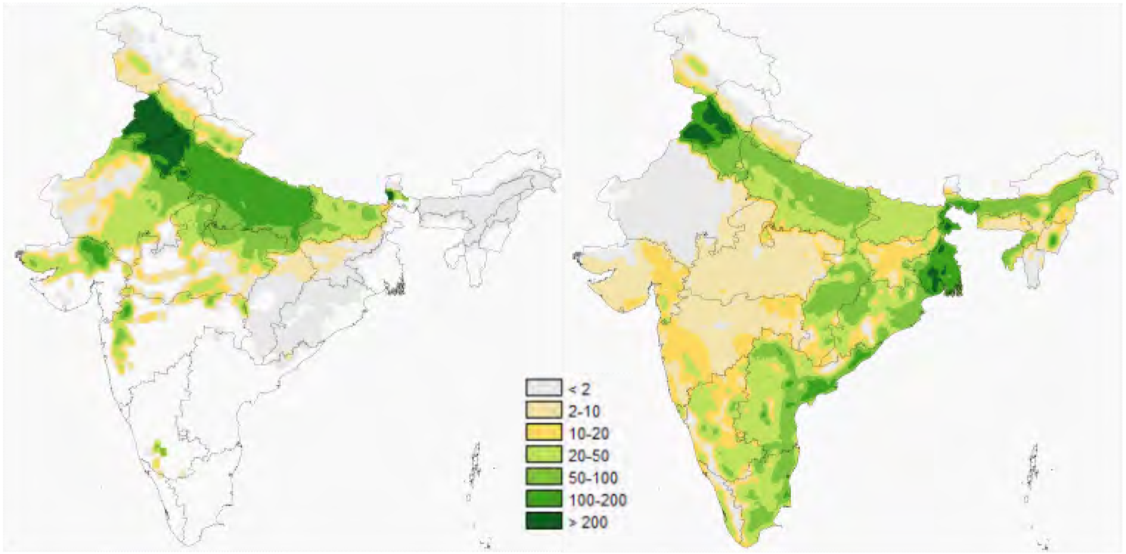
Figure 9: Intensity and spatial distribution of cereal production in 2010-11 (tons/km^2)



Combining the spatial distribution of net sown area and the intensity of use made possible through the application of irrigation explains the intensity and spatial spread of cereal production (Figure 9). Figure 9 was obtained by spatial downscaling the statistical cereal production of 2010-11. This spatial attribution (see Annexure IV) of cereal production used (i) state-wise data of sown area and production and crop-wise irrigated areas for wheat, rice, maize, jowar, bajra, and the remaining group of minor cereals; (ii) a spatial inventory of agricultural land use/cover at a resolution of 30" latitude/longitude; and (iii) agro-ecological suitability and attainable yields of cereal crops taken from an AEZ assessment for India.

There are two main cropping seasons in India, namely Kharif (based on the southwest monsoon) and Rabi (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 during 1950–51 to 63 Mha by 2008-09. Rice and wheat are the dominant crops, together accounting for 41 percent of the cropped area, while pulses, oil seeds, and other commercial crops account for 13.8 percent, 15.9 percent and 10.2 percent, respectively. Cereals dominate the agricultural crops and account for 60 percent of the cropped area, followed by pulses, cotton, and sugarcane. Examples of the spatial attribution of the statistical production of wheat and rice are shown in Figure 10.

Figure 10: Intensity of wheat (left) and rice (right) production in 2010-11 (tons/km^2)



a) Wheat

b) Rice

Table 11 presents the area and production of different crops (MoA, 2012) along with their respective residue production in India. The specific ratios of residue to crop production of different crops are taken from (Kumar et al., 2002; Purohit and Parikh, 2005. Ravindranath et al., 2005; Purohit et al., 2006, Purohit and Michaelowa, 2007; Purohit, 2009). For the year 2010-11, the area and total crop production were 171 Mha and 627 Mt, respectively. The gross residue availability is estimated at 708 Mt for 2010-11. For the years 2020-21 and 2030-31, the area and productivity were projected based on the data from 1950-51 to 2011-12 (See: Annexure-III).

Table 12-20 below presents the state-wise area and production of major crops and associated agricultural residue availability for 2010-11. The cost of crop residues as obtained by using a simple supply side approach is also presented in Tables 12-20 (See: Section 5.3 below and Annexure-VI).

Table 11. Area under different crops and their respective residue production in India

Crop	Economic produce	Type of residue	Residue to crop ratio	Area (Mha)			Total economic production (Mt)			Total residue production (air dry*) - Mt		
				2010/11	2020/21	2030/31	2010/11	2020/21	2030/31	2010/11	2020/21	2030/31
Rice	Foodgrains	Straw + husk	1.8	42.9	48.1	50.3	96.0	109.9	123.2	172.8	197.9	221.8
Wheat	Foodgrains	Straw	1.6	29.1	33.7	36.6	87.0	108.2	121.1	139.2	173.1	193.7
Jowar (Sweet sorghum)	Foodgrains	Stalk	2.0	7.4	5.2	3.4	7.0	6.0	5.7	14.1	12.1	11.5
Bajra	Foodgrains	Straw	2.0	9.6	9.3	8.8	10.4	11.4	12.3	20.7	22.8	24.7
Maize	Foodgrains	Stalk + cobs	2.5	8.6	8.4	9.0	21.7	24.8	28.3	54.3	62.1	70.6
Other cereals	Foodgrains	Stalk	2.0	2.9	2.1	1.5	4.6	3.9	3.8	9.1	7.8	7.6
Gram	Foodgrains	Waste	1.6	9.2	8.9	8.7	8.2	8.4	8.6	13.2	13.5	13.8
Tur (Arhar)	Foodgrains	Shell + waste	2.9	4.4	4.4	4.7	2.9	3.1	3.3	8.3	8.9	9.6
Lentil (Masur)	Foodgrains	Shell + waste	2.9	1.6	1.7	1.9	0.9	1.2	1.4	2.7	3.6	4.1
Other pulses	Foodgrains	Shell + waste	2.9	11.2	12.8	13.2	6.2	6.3	6.8	18.0	18.4	19.8
Groundnut	Oilseeds	Waste	2.3	5.9	6.0	6.1	8.3	8.9	9.6	19.0	20.6	22.0
Rapeseed & Mustard	Oilseeds	Waste	2.0	6.9	7.2	7.9	8.2	9.6	11.0	16.4	19.3	22.1
Other oilseeds	Oilseeds	Waste	2.0	14.5	16.7	18.6	16.0	19.3	22.4	32.1	38.6	44.7
Cotton	Fibre	Seeds + waste	3.5	11.2	11.9	12.6	5.6	6.1	6.4	19.6	21.2	22.5
		Cotton gin trash	0.1							0.4	0.5	0.5
Jute and Mesta	Fibre	Waste	1.6	0.9	1.0	1.0	1.9	2.3	2.5	3.1	3.6	3.9
Sugarcane	Sugar	Bagasse + leaves	0.4	4.9	5.1	5.6	342.4	406.4	459.3	137.0	162.6	183.7
Total				171.0	182.4	190.1	627.3	735.9	825.8	679.9	786.3	876.6

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

Source: Ravindranath et al. (2005); Purohit et al. (2006), MoA (2012)

Table 12. State-wise availability and cost of rice straw and husks, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km#	15 km	50 km	100 km	
Economic produce: Foodgrains; Crop: Rice; Type of residue: Straw and husk	Andhra Pradesh	4.8	14.4	26.0	2.6	10.2	15.2	20.4	37.0	The residue to crop ratio is taken to be 1.8; the share of residue used for fodder, fuel, and other applications is taken to be 80.8 percent, 11.1 percent and 8 percent, respectively. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Assam	2.6	4.7	8.5	0.8					
	Bihar	2.8	3.1	5.6	0.5					
	Chhattisgarh	3.7	6.2	11.1	1.1					
	Gujarat	0.8	1.5	2.7	0.3					
	Haryana	1.3	3.5	6.2	0.6					
	Jharkhand	0.7	1.1	2.0	0.2					
	Karnataka	1.5	4.2	7.5	0.7					
	Kerala	0.2	0.5	0.9	0.1					
	Madhya Pradesh	1.6	1.8	3.2	0.4					
	Maharashtra	1.5	2.7	4.9	0.5					
	Odisha	4.2	6.8	12.3	1.3					
	Punjab	2.8	10.8	19.5	2.0					
	Tamil Nadu	1.9	5.8	10.4	1.1					
	Uttar Pradesh	5.7	12.0	21.6	2.2					
	West Bengal	4.9	13.1	23.5	2.3					
	Others	1.8	3.8	6.8	0.7					
	All India	42.9	96.0	172.8	17.3					

*Moisture content (At harvest: 30%; at use: 10%)

**Net available for biofuel

#Cost of crop residues at farm gate

Table 13. State-wise availability and cost of wheat straw, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Economic produce: Foodgrains; Crop: Wheat; Type of residue: Straw	Assam	0.0	0.1	0.1	0.0	11.3	16.3	21.5	38.1	The residue to crop ratio is taken to be 1.6; the share of residue used for fodder and other applications is taken to be 86.4 percent and 13.6 percent, respectively. Application of wheat straw for fuel use is not reported. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Bihar	2.1	4.1	6.6	0.0					
	Gujarat	1.3	4.0	6.4	0.0					
	Haryana	2.5	11.6	18.6	0.0					
	Himachal Pradesh	0.4	0.6	0.9	0.0					
	Jammu & Kashmir	0.3	0.6	0.9	0.0					
	Jharkhand	0.1	0.2	0.3	0.0					
	Karnataka	0.3	0.3	0.4	0.0					
	Madhya Pradesh	4.3	7.6	12.2	0.0					
	Maharashtra	1.3	2.3	3.7	0.0					
	Punjab	3.5	16.5	26.4	0.0					
	Rajasthan	2.5	7.2	11.5	0.0					
	Uttar Pradesh	9.6	30.0	48.0	0.0					
	Uttarakhand	0.4	0.9	1.4	0.0					
	West Bengal	0.3	0.9	1.4	0.0					
	Others	0.2	0.3	0.4	0.0					
	All India	29.1	87.0	139.2	0.0					

*Moisture content (At harvest: 30%; at use: 10%);

**Net available for biofuel

Table 14. State-wise availability and cost of jowar (sweet sorghum) and bajra stalks, 2010/1

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Jowar (Sweet sorghum) stalk										
Economic produce: Foodgrains; Crop: Sweet sorghum (Jowar); Type of residue: Stalk	Andhra Pradesh	0.3	0.3	0.6	0.0	9.3	14.3	19.5	36.1	The residue to crop ratio is taken to be 2; 100 percent Jowar stalks are reportedly being used for animal fodder at present.
	Gujarat	0.1	0.1	0.3	0.0					
	Haryana	0.1	0.0	0.1	0.0					
	Karnataka	1.2	1.5	2.9	0.0					
	Madhya Pradesh	0.4	0.6	1.2	0.0					
	Maharashtra	4.1	3.5	6.9	0.0					
	Rajasthan	0.7	0.5	1.0	0.0					
	Tamil Nadu	0.2	0.3	0.5	0.0					
	Uttar Pradesh	0.2	0.2	0.4	0.0					
	All India	7.4	7.0	14.1	0.0					
Bajra stalk										
Economic produce: Foodgrains; Crop: Bajra; Type of residue: Straw	Andhra Pradesh	0.1	0.1	0.2	0.0	9.1	14.1	19.3	35.9	The residue to crop ratio is taken to be 2; the share of residue used for fodder and other applications is taken to be 89.8 percent and 10.2 percent, respectively. Application of bajra straw for fuel use is not reported.
	Gujarat	0.9	1.1	2.2	0.0					
	Haryana	0.7	1.2	2.4	0.0					
	Karnataka	0.3	0.3	0.7	0.0					
	Madhya Pradesh	0.2	0.3	0.6	0.0					
	Maharashtra	1.0	1.1	2.2	0.0					
	Rajasthan	5.5	4.6	9.1	0.0					
	Tamil Nadu	0.1	0.1	0.2	0.0					
	Uttar Pradesh	0.9	1.6	3.1	0.0					
	All India	9.6	10.4	20.7	0.0					

*Moisture content (At harvest: 30%; at use: 10%)

**Net available for biofuel

Table 15. State-wise availability and cost of maize stalks and cobs, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Economic produce: Foodgrains; Crop: Maize; Type of residue: Stalk + cobs	Andhra Pradesh	0.7	4.0	9.9	1.7	15.3	20.3	25.4	42.1	The residue to crop ratio is taken to be 2.5; the share of residue used for fodder and fuel use is taken to be 81 percent and 19 percent, respectively. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Bihar	0.7	1.4	3.6	0.6					
	Gujarat	0.5	0.8	2.1	0.4					
	Himachal Pradesh	0.3	0.7	1.7	0.3					
	Jammu & Kashmir	0.3	0.5	1.3	0.3					
	Jharkhand	0.2	0.3	0.7	0.1					
	Karnataka	1.3	4.4	11.1	1.9					
	Madhya Pradesh	0.8	1.1	2.6	0.5					
	Maharashtra	0.9	2.6	6.5	1.1					
	Punjab	0.1	0.5	1.2	0.2					
	Rajasthan	1.1	2.1	5.1	0.9					
	Tamil Nadu	0.2	1.0	2.6	0.5					
	Uttar Pradesh	0.8	1.1	2.8	0.5					
	West Bengal	0.1	0.4	0.9	0.2					
	Others	0.5	0.9	2.3	0.4					
	All India	8.6	21.7	54.3	9.3					

*Moisture content (At harvest: 30%; at use: 7%)

**Net available for biofuel

Table 16. State-wise availability and cost of the residue obtained from gram and tur, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Gram waste										
Economic produce: Foodgrains; Crop: Gram; Type of residue: Waste	Andhra Pradesh	0.6	0.7	1.2	1.1	20.4	25.4	30.6	47.2	The residue to crop ratio is taken to be 1.6; 100 percent residue obtained from gram waste is reportedly being used for other energy applications (not for biofuel). Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Bihar	0.1	0.1	0.1	0.1					
	Chhattisgarh	0.3	0.2	0.4	0.4					
	Gujarat	0.2	0.2	0.3	0.3					
	Haryana	0.1	0.1	0.2	0.2					
	Karnataka	1.0	0.6	1.0	0.9					
	Madhya Pradesh	3.1	2.7	4.3	3.9					
	Maharashtra	1.4	1.3	2.1	1.9					
	Rajasthan	1.8	1.6	2.6	2.3					
	Uttar Pradesh	0.6	0.5	0.8	0.7					
	Others	0.1	0.1	0.1	0.1					
	All India	9.2	8.2	13.2	11.9					
Tur waste										
Economic produce: Foodgrains; Crop: Tur (Arhar); Type of residue: Shell + waste	Andhra Pradesh	0.6	0.3	0.8	0.4	28.7	33.7	38.9	55.5	The residue to crop ratio is taken to be 2.9; the share of residues used for fodder, fuel and other applications is taken to be 3.5 percent, 48.5 percent, and 48 percent, respectively. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Bihar	0.0	0.0	0.1	0.1					
	Gujarat	0.3	0.3	0.8	0.4					
	Jharkhand	0.1	0.1	0.2	0.1					
	Karnataka	0.9	0.5	1.5	0.6					
	Madhya Pradesh	0.5	0.2	0.5	0.2					
	Maharashtra	1.3	1.0	2.8	1.3					
	Odisha	0.1	0.1	0.3	0.2					
	Tamil Nadu	0.0	0.0	0.1	0.0					
	Uttar Pradesh	0.3	0.3	0.9	0.4					
	Others	0.1	0.1	0.3	0.1					
	All India	4.4	2.9	8.3	3.6					

*Moisture content (At harvest: 20%; at use: 10%)

**Net available for biofuel

Table 17. State-wise availability and cost of the residue obtained from lentil and other pulses, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks#
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Lentil waste										
Economic produce: Foodgrains; Crop: Lentil (Masur); Type of residue: Shell + waste	Bihar	0.2	0.2	0.6	0.3	21.8	26.8	31.9	48.6	The residue to crop ratio is taken to be 2.9; the share of residue used for fodder, fuel, and other applications is taken to be 3.5 percent, 48.5 percent, and 48 percent, respectively.
	Madhya Pradesh	0.6	0.2	0.5	0.3					
	Rajasthan	0.0	0.0	0.1	0.1					
	Uttar Pradesh	0.6	0.4	1.2	0.5					
	West Bengal	0.1	0.1	0.1	0.1					
	Others	0.1	0.0	0.1	0.1					
	All India	1.6	0.9	2.7	1.2					
Waste obtained from other pulses										
Economic produce: Foodgrains; Crop: Other pulses; Type of residue: Shell + waste	Andhra Pradesh	0.9	0.5	1.3	0.5	21.8	26.8	31.9	48.6	The residue to crop ratio is taken to be 2.9; the share of residue used for fodder, fuel, and other applications is taken to be 3.5 percent, 48.5 percent, and 48 percent, respectively.
	Bihar	0.3	0.2	0.7	0.3					
	Chhattisgarh	0.6	0.3	0.9	0.4					
	Gujarat	0.4	0.3	0.7	0.4					
	Haryana	0.1	0.1	0.1	0.1					
	Jharkhand	0.3	0.3	0.8	0.4					
	Karnataka	0.9	0.4	1.2	0.5					
	Madhya Pradesh	1.0	0.4	1.0	0.5					
	Maharashtra	1.3	0.8	2.4	1.1					
	Odisha	0.7	0.3	0.8	0.4					
	Rajasthan	2.9	1.6	4.7	2.1					
	Tamil Nadu	0.6	0.2	0.7	0.3					
	Uttar Pradesh	1.0	0.8	2.3	1.0					
	West Bengal	0.1	0.1	0.3	0.2					
	Others	0.1	0.1	0.2	0.1					
	All India	11.2	6.2	18.0	7.8					

*Moisture content (At harvest: 20%; at use: 10%)

#Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.

**Net available for biofuel

Table 18. State-wise availability and cost of groundnut shells and rapeseed & mustard stalk, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Groundnut shells										
Economic produce: Oilseeds; Crop: Groundnut; Type of residue: Waste	Andhra Pradesh	1.6	1.5	3.4	0.4	22.2	27.2	32.4	49.0	The residue to crop ratio is taken to be 2.3; the share of residue used for fuel and other applications is taken to be 13.2 percent and 86.8 percent, respectively. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Gujarat	1.8	3.4	7.8	0.9					
	Karnataka	0.9	0.7	1.7	0.2					
	Madhya Pradesh	0.2	0.3	0.7	0.1					
	Maharashtra	0.4	0.5	1.1	0.1					
	Odisha	0.1	0.1	0.2	0.0					
	Rajasthan	0.4	0.7	1.6	0.2					
	Tamil Nadu	0.4	0.9	2.1	0.3					
	Uttar Pradesh	0.1	0.1	0.2	0.0					
	Others	0.1	0.2	0.4	0.1					
	All India	5.9	8.3	19.0	2.3					
Rapeseed and mustard stalk										
Economic produce: Oilseeds; Crop: Rapeseed & Mustard; Type of residue: Waste	Assam	0.2	0.1	0.3	0.3	18.1	23.1	28.3	44.9	The residue to crop ratio is taken to be 2; 100 percent residue obtained from rapeseed and mustard waste is reportedly being used for other energy application (not for biofuel). Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Bihar	0.1	0.1	0.2	0.2					
	Gujarat	0.2	0.4	0.7	0.6					
	Haryana	0.5	0.9	1.9	1.7					
	Madhya Pradesh	0.8	0.9	1.7	1.5					
	Punjab	0.0	0.0	0.1	0.1					
	Rajasthan	3.7	4.4	8.7	7.8					
	Uttar Pradesh	0.6	0.7	1.4	1.3					
	West Bengal	0.4	0.4	0.8	0.7					
	Others	0.4	0.3	0.5	0.5					
	All India	6.9	8.2	16.4	14.7					

*Moisture content (At harvest: 20%; at use: 10%)

**Net available for biofuel

Table 19. State-wise availability and cost of cotton waste and jute & mesta sticks, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Cotton waste										
Economic produce: Fibre; Crop: Cotton; Type of residue: Seeds + waste	Andhra Pradesh	1.9	0.9	3.2	2.9	23.8	28.8	33.9	50.6	The residue to crop ratio is taken to be 3.5; 100 percent waste obtained from cotton is reportedly being used for energy application. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Gujarat	2.6	1.8	6.2	5.6					
	Haryana	0.5	0.3	1.0	0.9					
	Karnataka	0.6	0.2	0.7	0.6					
	Madhya Pradesh	0.7	0.3	1.2	1.1					
	Maharashtra	3.9	1.4	5.1	4.6					
	Punjab	0.5	0.4	1.2	1.1					
	Rajasthan	0.3	0.2	0.5	0.5					
	Tamil Nadu	0.1	0.1	0.3	0.3					
	Others	0.1	0.1	0.2	0.2					
	All India	11.2	5.6	19.6	17.6					
Jute and Mesta sticks										
Economic produce: Fibre; Crop: Jute & Mesta; Type of residue: Sticks/Waste	Andhra Pradesh	0.0	0.0	0.1	0.1	15.5	20.5	25.7	42.3	The residue to crop ratio is taken to be 1.6; 100 percent waste obtained from jute and mesta is reportedly being used for energy application. Values of agricultural residues shown as net available for biofuel production assume 10 percent used for power generation.
	Assam	0.1	0.1	0.2	0.2					
	Bihar	0.2	0.2	0.4	0.4					
	West Bengal	0.6	1.5	2.4	2.2					
	All India	0.9	1.9	3.1	2.8					

*Moisture content (Cotton waste: At harvest: 20% and at use: 10%; Jute and Mesta sticks: At harvest: 30% and at use: 10%)

**Net available for biofuel

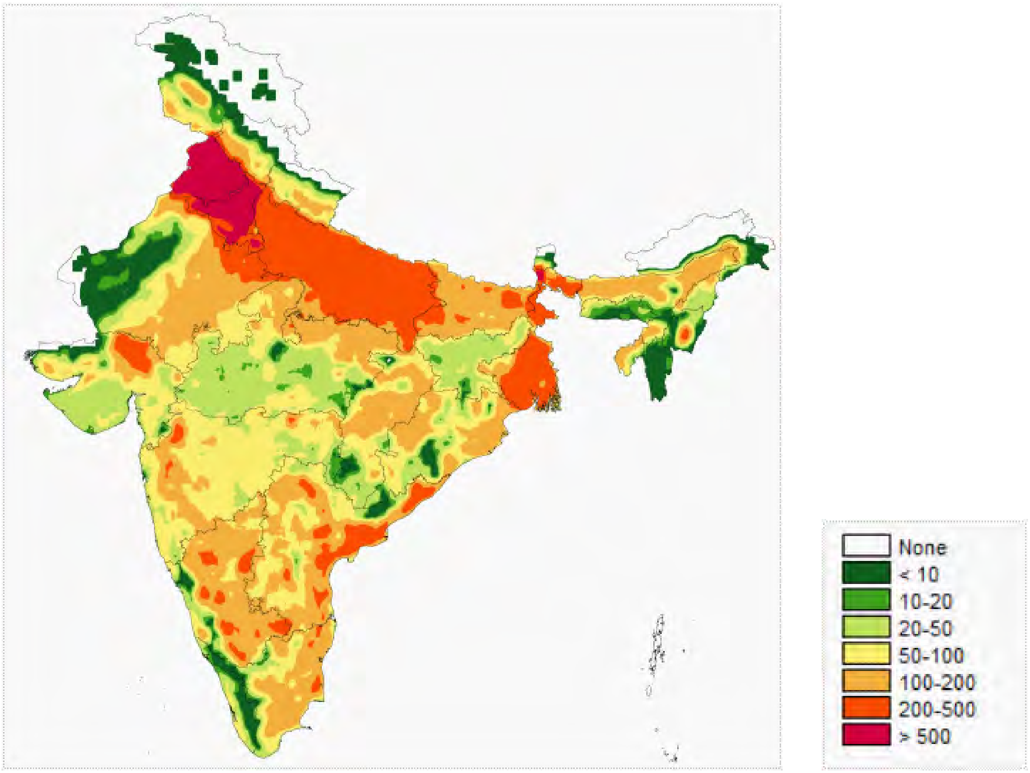
Table 20. State-wise availability and cost of sugarcane bagasse, 2010/11

Crop	State	Gross cropped area (Mha)	Total economic production (Mt)	Agricultural residue availability (air dry*)		Cost of crop residues ($/ton)				Remarks
				Gross (Mt)	Net** (Mt)	0 km	15 km	50 km	100 km	
Economic produce: Sugar; Crop: Sugarcane; Type of residue: Bagasse + leaves	Andhra Pradesh	0.2	15.0	6.0	2.0	13.8	18.8	24.0	40.6	The residue to crop ratio is taken to be 0.4; the share of residue used for fuel, fodder, and other applications is taken to be 41 percent, 11.8 percent, and 47.2 percent, respectively. Values shown as net available for biofuel production assume 20 percent used for power generation.
	Assam	0.0	1.1	0.4	0.2					
	Bihar	0.3	12.8	5.1	1.7					
	Gujarat	0.2	13.8	5.5	1.8					
	Haryana	0.1	6.0	2.4	0.8					
	Karnataka	0.4	39.7	15.9	5.2					
	Madhya Pradesh	0.1	2.7	1.1	0.3					
	Maharashtra	1.0	81.9	32.8	10.7					
	Odisha	0.0	0.9	0.4	0.1					
	Punjab	0.1	4.2	1.7	0.6					
	Tamil Nadu	0.3	34.3	13.7	4.5					
	Uttar Pradesh	2.1	120.6	48.2	15.8					
	Uttarakhand	0.1	6.5	2.6	0.9					
	West Bengal	0.0	1.1	0.5	0.2					
	Others	0.0	2.1	0.8	0.2					
	All India	4.9	342.4	137.0	44.9					

*Moisture content (At harvest: 30%; at use: 10%)

**Net available for biofuel

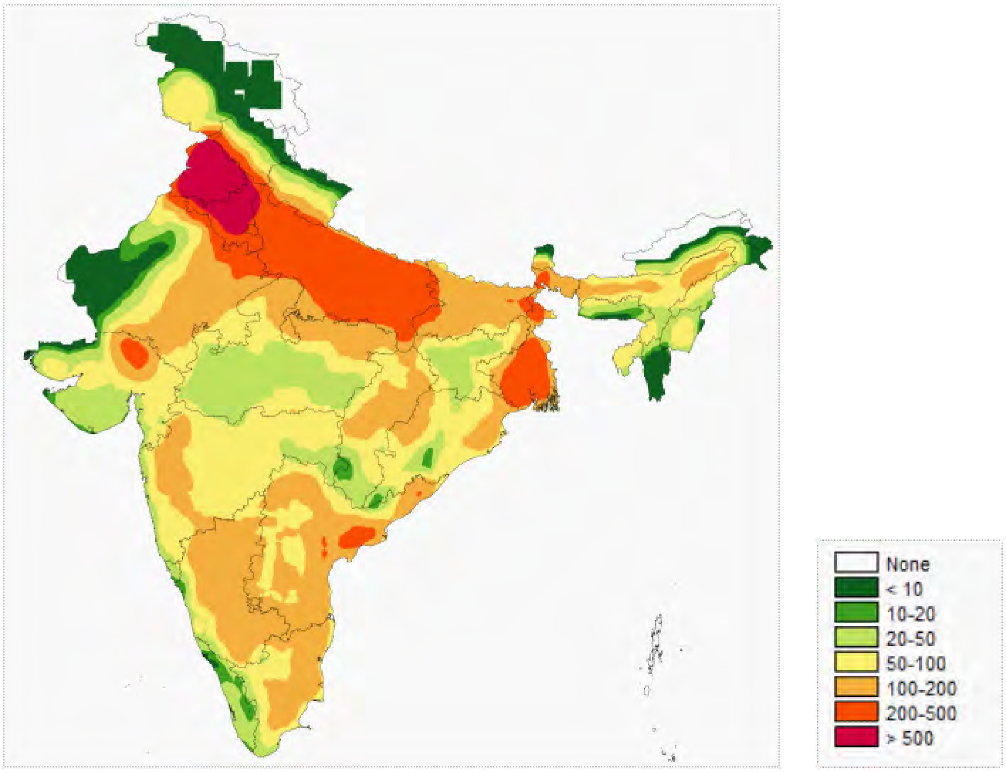
Figure 11: Density of annual cereal crop residue production in 2010-11 within a circle of 20 km around the shown location (tons/km^2)



The spatial distribution of cereal production, as discussed previously and shown in Figures 9 and 10, and the technical crop residue coefficients presented in Table 11 were used to estimate the spatial availability of cereal crop residues (Figure 11, Figure 12).

The pixel value for each location as shown in Figure 11 was calculated by adding up the estimated crop residue production for all pixels in a circle of 20 km around the location and dividing by the total surface area of the circle, i.e., calculating the average density of crop residue availability within this circle. The highest average densities of more than 500 tons per km^2 were calculated for Punjab and Haryana, where intensive wheat-rice systems are practiced on mostly irrigated land. Similar calculations were also performed for circles of 50 kilometres around each 30 arc-sec grid cell, as shown in Figure 12. The map shows a similar pattern but, as is to be expected, generalises the spatial features of the crop residue availability. The pixels shown in dark red, with an average density exceeding 500 tons per km^2, indicate that the estimated total crop residue production in a circle of 50 km around the location was more than 3.9 Mt in 2010-11. For pixels shown in this same colour in Figure 11, the estimated respective total crop residue production in a 20 km circle around the location exceeded 0.6 Mt.

Figure 12: Density of annual cereal crop residue production in 2010-11 within a circle of 50 km around the shown location (tons/km^2)



4.2.1 Alternative application of agricultural residues

The use of crop residues varies from region to region and depends on their calorific values, lignin content, density, palatability by livestock, and nutritive value. The residues of most of the cereals and pulses have fodder value. However, the woody nature of the residues of some crops restricts their utilisation to fuel uses only. The dominant end uses of crop residues in India are as fodder for cattle, fuel for cooking, and thatch material for housing (Purohit et al., 2006). Four studies (Ravindranatha et al., 2005; Purohit et al., 2006; Varshney et al., 2010; Sukumaran et al., 2010) have attempted to quantify the amount of residues that are already being used by competing applications, being mainly cattle feeding and traditional domestic energy uses, which consume the largest share of crop residues in India.

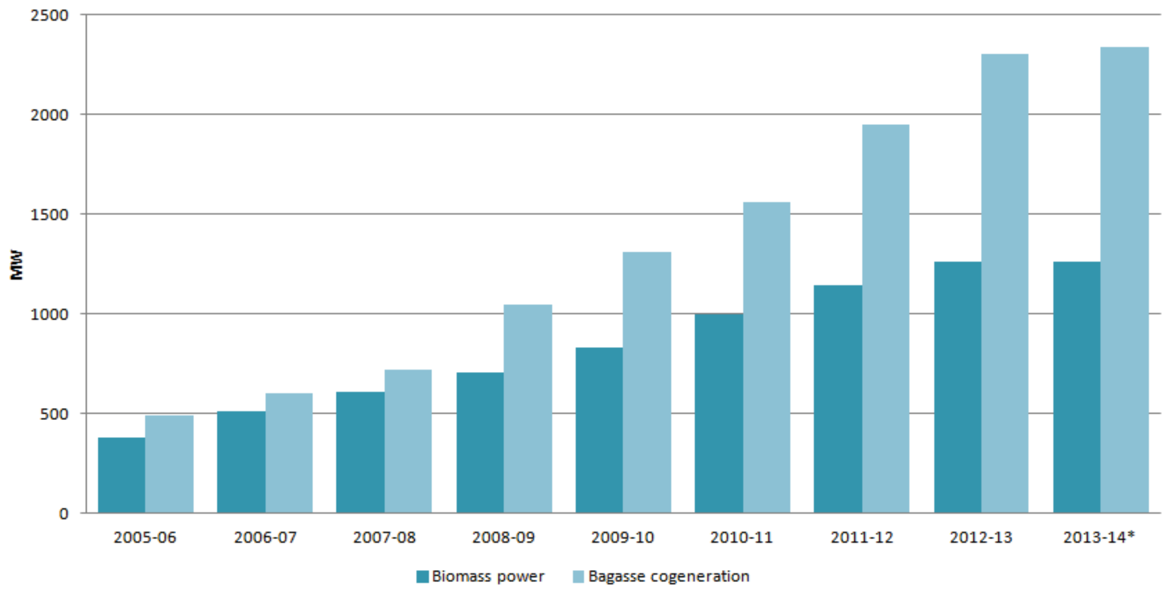
4.2.1.1 Cattle feed

India has a large cattle population of 294 million (Ravindranath et al., 2005). 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 (CMIE, 1997) and is estimated at over 360 Mt for 2010-11, accounting for approximately 53 percent of total residue generation, as shown in Table 21. For cereals, the use of crop residues as fodder is the 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. It is worth noting that the cereal crop residues allocated as fodder in 2010-11 could produce some 124 billion litres of bioethanol, 143 billion litres in 2020-21 and 160 billion litres in 2030-31.

4.2.1.2 Biomass feedstock for power generation

A major alternative application of non-fodder and non-fertiliser agricultural residues is biomass power and bagasse cogeneration. MNRE implemented the Biomass power/cogeneration (bagasse) programme with the main objective of promoting technologies for optimum use of the country's biomass resources for grid power generation. The promotion of biomass power/cogeneration in the country is encouraged through conducive policy at the State and Central levels. In India, 17 states have policies for the development of biomass power, while one state, Rajasthan, has an exclusive policy for the promotion of biomass power that was announced in 2010 and continues to date (GoR, 2010). A package of fiscal concessions, such as accelerated depreciation, concessional custom duty, excise duty exemption, income tax exemption on projects for power generation for 10 years, and electricity duty exemption, are available to biomass power/cogeneration projects. Thus far, 1265 MW of biomass power projects and 2337 MW of bagasse cogeneration projects have been installed (Figure 13) in the country (MNRE, 2013). The market for some agricultural residues such as rice husks has matured, and nearly the entire quantity is currently consumed in industry and power plants. On the other hand, technology for straw and stalks is at the initial stage of development.

Figure 13. Installed capacity of biomass power and bagasse cogeneration projects in India



*until August 2013

Source: MNRE Annual Reports

MNRE is also promoting power plants for electricity production based on multifaceted biomass gasifiers using locally available biomass resources in rural areas, including small wood chips, rice husks, arhar stalks, cotton stalks, and other agro-residues. A package of financial and fiscal concessions is also available to biomass power projects. The main components of the biomass gasifier programmes are: a) distributed/

off-grid power for rural areas, b) captive power generation applications in rice mills and other industries, and c) tail end grid connected power projects up to 2 MW capacities. These programmes are being implemented through State Nodal Agencies (SNAs) with the involvement of Energy Service Companies (ESCOs), Cooperatives, Panchayats, NGOs, manufacturers, and entrepreneurs, among others. A total of 160 MW biomass gasifier power capacity has been installed in India by July 2013 (MNRE, 2013). At the same time, 487 MW biomass (non-bagasse) cogeneration and 160 MW biomass gasification off-grid projects have also been installed in the country (MNRE, 2013). Therefore, a significant use of agricultural residues for power generation has to be accounted for when estimating the net biofuel potential from agricultural residues in India.

For the base year 2010-11, the installed capacity of grid-connected bagasse cogeneration projects was 1562 MW. Using a specific bagasse consumption of 1.6 kg/kWh and a capacity factor of 53 percent (MNRE, 2012), the bagasse used in the cogeneration projects is estimated at 11.6 Mt, which is 20 percent of the bagasse availability for energy applications. Similarly, the cumulative installed capacity of grid and off-grid biomass power/cogeneration projects was 1400 MW (998 MW grid-connected biomass power and 274 MW off-grid biomass cogeneration (non-bagasse), and 128 MW biomass gasification projects) during 2010/11 (MNRE, 2011). Using the specific biomass consumption of 1.21 kg/kWh and capacity factor of 80 percent (MNRE, 2012), the biomass used in the power/cogeneration projects is estimated at 11.8 Mt, which is approximately 10 percent 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 bioethanol production from agricultural residues in the near future.

For the year 2010-11, the agricultural residues available for energy applications is estimated at 187 Mt, of which 163 Mt agricultural residues can be used to produce 50 billion litres of ethanol annually, as shown in Table 21. The net residue availability in 2020/21 and 2030/31 for biofuel production is estimated at 187 Mt and 209 Mt, respectively. Assuming ethanol yields as listed in Table 21, the net obtainable ethanol production is estimated at 58 and 65 billion litres in 2020/21 and 2031/31, respectively, which would be sufficient to meet the 20 percent blending target by 2030/31. In our estimation, this potential biofuel production represents approximately one-fifth of the theoretical maximum obtainable if all crop residues (e.g., straw, husks, stalks, cobs, shells, bagasse, etc.) were to be converted into biofuels. Due to the predominant feed use, this potential production accounts for only 7.5 percent of the theoretical maximum from foodgrain straw, stalks and husks. The net ethanol production would increase by 26 percent (from 58 to 74 billion litres) in 2020/21 if an additional 10 percent of crop residues obtained from foodgrains (viz. paddy straw, wheat straw, jowar stalks, bajra straw) could be diverted to the biofuel production route.

Table 21. Ethanol production from net availability of agricultural residues

Crop	Economic produce	Type of residue	Total residue production (Mt)			Share of agricultural residues used as fodder, fuel, and for other purposes			Net residue availability for biofuels (Mt)			Ethanol yield (litre/t)	Net ethanol availability (billion litres)		
			2010/11	2020/21	2030/31	Fodder	Fuel	Others	2010/11	2020/21	2030/31		2010/11	2020/21	2030/31
Rice	Foodgrains	Straw + husk	172.8	197.9	221.8	0.8	0.1	0.1	17.3	19.8	22.2	416.0	7.2	8.2	9.2
Wheat	Foodgrains	Straw	139.2	173.1	193.7	0.9	0.0	0.1	0.0	0.0	0.0	290.0	0.0	0.0	0.0
Jowar	Foodgrains	Stalk	14.1	12.1	11.5	1.0	0.0	0.0	0.0	0.0	0.0	290.0	0.0	0.0	0.0
Bajra	Foodgrains	Straw	20.7	22.8	24.7	0.9	0.0	0.1	0.0	0.0	0.0	290.0	0.0	0.0	0.0
Maize	Foodgrains	Stalk + cobs	54.3	62.1	70.6	0.8	0.2	0.0	9.3	10.6	12.1	427.8	4.0	4.5	5.2
Other cereals	Foodgrains	Stalk	9.1	7.8	7.6	1.0	0.0	0.0	0.0	0.0	0.0	290.0	0.0	0.0	0.0
Gram	Foodgrains	Waste	13.2	13.5	13.8	0.0	1.0	0.0	11.8	12.2	12.4	214.0	2.5	2.6	2.7
Tur (Arhar)	Foodgrains	Shell + waste	8.3	8.9	9.6	0.0	0.5	0.5	3.6	3.9	4.2	214.0	0.8	0.8	0.9
Lentil (Masur)	Foodgrains	Shell + waste	2.7	3.6	4.1	0.0	0.5	0.5	1.2	1.6	1.8	214.0	0.3	0.3	0.4
Other pulses	Foodgrains	Shell + waste	18.0	18.4	19.8	0.0	0.5	0.5	7.9	8.0	8.7	214.0	1.7	1.7	1.9
Groundnut	Oilseeds	Waste	19.0	20.6	22.0	0.0	0.1	0.9	2.3	2.4	2.6	214.0	0.5	0.5	0.6
Rape & Mustard	Oilseeds	Waste	16.4	19.3	22.1	0.0	1.0	0.0	14.7	17.3	19.9	214.0	3.2	3.7	4.3
Other oilseeds	Oilseeds	Waste	32.1	38.6	44.7	0.0	1.0	0.0	28.9	34.8	40.3	214.0	6.2	7.4	8.6
Cotton	Fibre	Seeds + waste	19.6	21.2	22.5	0.0	1.0	0.0	17.7	19.1	20.2	214.0	3.8	4.1	4.3
		Cotton gin trash	0.4	0.5	0.5	0.0	1.0	0.0	0.4	0.4	0.5	215.0	0.1	0.1	0.1
Jute and Mesta	Fibre	Waste	3.1	3.6	3.9	0.0	1.0	0.0	2.8	3.3	3.5	214.0	0.6	0.7	0.8
Sugarcane	Sugar	Bagasse + leaves	137.0	162.6	183.7	0.1	0.4	0.5	44.9	53.3	60.3	439.9	19.8	23.5	26.5
Total			679.9	786.3	876.6				162.7	186.7	208.6		50.4	58.3	65.3

Source: Ravindranath et al. (2011) and own estimates

Courtesy of FAO Aquaculture Photo Library.

5. Costs of Biofuel Production

The economic viability and sustainable development of biofuel technologies is greatly dependent on the various costs associated with feedstock provision, capital investments, and the operating and maintenance costs of conversion plants. It is estimated that feedstock costs typically account for 40–80 percent of the total production cost of biofuels (Demirbas, 2009a; Carriquiry et al., 2011). This Chapter assesses the economic feasibility of bio-ethanol and bio-diesel along with the cost of agricultural residues.

5.1 Economic feasibility of bio-ethanol

India's bio-ethanol programme depends to a large extent on the economic viability of molasses-ethanol conversion. The supply of molasses in turn depends on the sugarcane production in the country. Shortage spells in sugarcane production lead to reduced availability of molasses, accompanied by a steep rise in the price of molasses. The shortage of molasses availability also forces distilleries to utilise less than their actual plant capacity. During the previous decade, the prices of molasses fluctuated substantially, ranging from $18 to $37 per ton (Raju et al. 2012). This had a serious impact on the viability of molasses-based ethanol production. The cost of production of ethanol as per the report of the Planning Commission (GoI 2003) was $0.18 per litre, assuming a molasses price of $18 per ton. Based on this price, the government fixed the minimum purchase price of $0.4 per litre for ethanol in 2006 (MNRE, 2009), the price at which the sugar industry also then agreed to offer oil market companies (OMCs). However, the cost of production exceeded the minimum purchase price when the molasses price shot up to $92 per ton and even higher during 2008-09.

In 2010, the National Centre for Agricultural Economics and Policy Research (NCAP) conducted a survey at three distilleries in Uttar Pradesh. As per the NCAP survey, the average cost of production of ethanol ranged from $0.45 to $0.57 per litre in the case of stand-alone distilleries and $0.36 to $0.48 per litre in case of distilleries integrated with sugar production. The costs were estimated under two scenarios of molasses prices, viz. $65 to $92 per ton, as shown in Table 22. It is observed that the share of feedstock costs (i.e., molasses) ranges within 63-83 percent of the total cost of ethanol production (Shinoj et al. 2011).

Table 22. Cost of ethanol production from molasses in Uttar Pradesh, India

Inputs	Stand alone distillery ($/litre)	Distillery integrated with sugar production ($/litre)
Cost of steam	0.006	0.000
Cost of power	0.024	0.000
Cost of chemicals	0.004	0.004
Cost of labour	0.002	0.001
Cost of repair and maintenance	0.003	0.003

Total variable cost excluding molasses	0.039	0.008
Interest on fixed capital	0.040	0.040
Depreciation of machinery and fixed assets	0.034	0.034
Total fixed cost	0.074	0.074
Cost of molasses (@ $65/ton)	0.281	0.281
Cost of molasses (@ $92/ton)	0.402	0.402
Transportation cost	0.052	0.000
Total cost of ethanol production	0.45-0.57	0.36-0.48

Note: Recovery of ethanol was assumed to be 230 litres/ton of molasses

Source: NCAP Field Survey (2010)

Fluctuations of molasses production (and price) are also expected to occur in the future, and therefore, high levels of instability in prices of both ethanol and petrol are deterring the OMCs from strike long-term contracts with the distilleries. In contrast, the ethanol distillers enjoy a better price and are ensured demand from the beverage and pharmaceutical industries. This has prompted them to show more affinity with these industries than with OMCs. This experience indicates that OMCs, thus far, have been unable to procure sufficient ethanol at the prevailing market rates to effect a mandatory blending of 5 percent. Although the government revised the purchase price to $0.5/litre in April 2010, ethanol blending still remains far below the targeted levels. In 2012, ethanol manufacturers demanded a payment of $0.74/litre considering the current rate of alcohol of $0.68/litre and $102 to $111 per ton of molasses (Jog, 2012). Moreover, ethanol manufacturers want consistency in procurement from the OMCs. The Ethanol Manufacturers Association of India has conveyed to OMCs that they would be able to supply 1.02 billion litres by the end of October 2013.

5.2 Economic viability of bio-diesel

The cost of *Jatropha* plantation varies depending upon its geographical location, agro-climatic conditions, input-use, and other operational practices. Goswami et al. (2011) assessed the profitability of *Jatropha* plantations in four states of North-East India, viz. Arunachal Pradesh, Assam, Nagaland, and Tripura, through cost-benefit analysis. Their study showed positive returns from investment in *Jatropha* plantation, making it an economically viable venture for the growers of the region. Raju et al. (2012) observed that the economics of *Jatropha* cultivation vary considerably depending upon the cultivation model and location, as is evident from the cost of cultivation for the three selected states in India presented in Table 23. While farmers in Rajasthan incurred a cost of approximately $578/ha during the first year, the estimates for Chhattisgarh and Uttarakhand states were $158/ha and $223/ha, respectively (Raju et al., 2012). This can be attributed to the inter-state variations in subsidies on seedlings and other inputs, variations in labour charges, and differential usage of inputs, among others.

Table 23. Economic analysis of *Jatropha* cultivation in selected states of India ($/ha)

Particulars	Rajasthan			Chhattisgarh			Uttarakhand		
	1st yr.	2nd yr.	3rd yr. onwards	1st yr.	2nd yr.	3rd yr. onwards	1st yr.	2nd yr.	3rd yr. onwards
Land reparation	20.8	0.0	0.0	6.9	0.0	0.0	16.6	0.0	0.0
Digging pits	104.0	0.0	0.0	39.3	0.0	0.0	88.7	0.0	0.0
Sapling cost	207.9	27.7	0.0	19.7	4.2	0.0	0.0	0.0	0.0
Planting	55.5	6.9	0.0	20.8	6.9	0.0	44.4	0.0	0.0
Manuring	57.8	0.0	0.0	43.9	0.0	0.0	44.4	0.0	0.0
Fertiliser	61.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigation	18.5	18.5	18.5	9.2	0.0	0.0	9.2	0.0	0.0
Harvesting	0.0	0.0	124.8	0.0	0.0	46.2	0.0	0.0	99.8
Sub-total	525.9	53.1	143.3	139.8	11.1	46.2	203.3	0.0	99.8
Incidentals (10%)	52.6	5.3	14.3	14.0	1.1	4.6	19.4	0.0	10.0
Total cost	578.5	58.5	157.6	153.8	12.2	50.8	222.7	0.0	109.8
Returns	0.0	0.0	329.2	0.0	0.0	330.4	0.0	0.0	249.5
Net profit	-578.5	-58.5	171.7	-153.8	-12.2	279.6	-222.7	0.0	139.7

Source: Adapted from Raju et al. (2012)

The physical and monetary details regarding input requirements per day and the corresponding production of biodiesel and other by-products at two manufacturing plants, viz. the Rajasthan State Mines and Minerals Ltd. (RSMML) biodiesel plant in Udaipur and the Chhattisgarh Biodiesel Development Authority (CBDA) processing plant at Raipur are presented separately in Table 24. It is observed that the RSMML plant crushed 1 ton of *Jatropha* seeds, while the CBDA plant processed 10 tons of seeds with respective biodiesel yields of 250 kg and 2730 kg. The cost of biodiesel production at the RSMML facility was approximately $0.74/kg, whereas in the CBDA unit it was nearly $0.35/kg, the difference being significant. However, there were multiple reasons behind the cost difference (Shinoj et al., 2010). In Rajasthan, the cost of seeds at the factory gate was approximately $0.22/kg for the reasons stated above. In contrast, the CBDA unit was able to procure seeds at $0.12/kg directly from the farmers and incurred nominal costs for handling and transportation, as sufficient seeds were available in the nearby location. In addition, the economy of scale favoured the CBDA processing plant in bringing down the cost in comparison with the RSMML plant. The RSMML plant also faced a shortage of seeds, despite that sufficient seeds are produced in Rajasthan, due to the diversion of seeds for nurseries under government support. Due to all these constraints, the RSMML plant is on the verge of closure and currently uses the produced biodiesel in the company's own fleet of trucks.

Table 24. Cost of production of biodiesel in Rajasthan and Chhattisgarh — A comparative study

Inputs	RSMML plant		CBDA plant	
	Quantity	Value ($)	Quantity	Value ($)
Jatropha seeds	1 ton/day	221.8	10 tons/day	1201.5
Unskilled labour	2 man days	5.5	6 man days	13.3
Managerial labour	1 man day	8.3	1 man day	11.1
Administrative labour	1 man day	4.6	4 man days	29.6
Chemicals				
Methanol	60 litres	11.6	600 litres	122.0
Sodium hydroxide	2 kg	0.9	21 kg	10.0
Electricity	25 units	4.6	250 units	46.2
Interest on fixed capital	@10%	12.0	@ 10%	125.7
Depreciation on machinery	@10%	5.0	@10%	31.4
Depreciation on other assets	@4%	8.1	@4%	50.6
Freight and other incidentals		6.5		120.1
a. Total cost		289.1		1761.6
Revenue from by-products				
Glycerol	46 kg	25.5	467 kg	189.9
Oil cake	700 kg	77.6	6750 kg	623.8
b. Total revenue		103.1		813.8
Net cost incurred (a-b)		186.0		947.8
Recovery of biodiesel per ton of Jatropha seeds	250 kg	0.0	273 kg	0.0
Net cost/kg of biodiesel		0.7		0.3

Source: Adapted from Raju et al. (2012)

5.3 Cost of agricultural residues in India

The large-scale utilisation of non-fodder and non-fertiliser agricultural residues as energy sources depends upon a variety of factors, such as their availability, characteristics as fuel, and, of course, their financial viability compared with other options. The financial viability of their use, in turn, critically depends upon the "price tag" attached to them and their opportunity cost to the user. While some of the agricultural residues that are replacing commercial fuels or are already being used in industries have some sort of price tag associated with them, for others, it may be necessary to estimate their cost to the users. It is observed that assessments of the cost of an agricultural residue to the user are somewhat involved (Kumar et al., 2002; Purohit et al., 2006). However, as a first approximation, we can assume that the costs of crop production, harvesting, collection, transportation, and storage of the residues would be the primary contributors towards the cost of residues. We applied a simple and robust approach to estimating the cost of agricultural residues, taking into account the above factors. The methodology used to estimate the costs of agricultural residues was presented in Tripathi et al. (1998), where the total cost of agricultural residues, TC_{ar}, can be approximated by five cost components:

$$TC_{ar} = PC_{ar} + HC_{ar} + CC_{ar} + TC_{ar} + SC_{ar} \tag{1}$$

where PC_{ar} represents the production cost of agricultural residues, HC_{ar} the harvesting cost of agricultural residues, CC_{ar} the collection cost of agricultural residues, TC_{ar} the transportation cost of agricultural residues, and SC_{ar} the storage cost of agricultural residues. A detailed methodology for estimating the cost of agricultural residues and other input parameters is presented in Annexure–VI.

The total estimated cost of the agricultural residues at the farm gate and at distances of 15 km, 50 km, 100 km, and 200 km from agricultural farms is presented in Table 25. It is observed that the costs of residues are quite substantial. The estimated cost of agricultural residues varies from a minimum of $14/ton for bajra straw to a maximum of $34/ton for arhar stalks at the farm gate. Transportation costs contribute significantly to the total estimated cost of the residues. At a transportation distance of 100 km, the cost of agricultural residues varied from a minimum of $36/ton for bajra straw to a maximum of $55/ton for arhar stalks. With reference to UNFCC (2011), a recent IRENA (2012) report gives feedstock costs for agricultural residues in India, indicating the price of bagasse to be approximately US$12-14 and the price of rice husks at approximately US$22-30.

Table 25. Cost of agricultural residues

Economic produce	Crop	Type of residue	Procurement price[12] ($/ton)	Cost of agricultural residues ($/ton)			
				0-15 km	50 km	100 km	200 km
Foodgrains	Rice	Straw + husk	184.8	15.2	20.4	37.0	61.1
	Wheat	Straw	207.0	16.3	21.5	38.1	62.2
	Jowar	Stalk	166.4	14.3	19.5	36.1	60.1
	Bajra	Straw	162.7	14.1	19.3	35.9	60.0
	Maize	Stalk + cobs	162.7	20.3	25.4	42.1	66.1
	Other cereals	Stalk	162.7	14.1	19.3	35.9	60.0
	Gram	Waste	388.2	25.4	30.6	47.2	71.2
	Tur (Arhar)	Shell + waste	554.5	33.7	38.9	55.5	79.5
	Lentil (Masur)	Shell + waste	415.9	26.8	31.9	48.6	72.6
	Other pulses	Shell + waste	415.9	26.8	31.9	48.6	72.6
Oilseeds	Groundnut	Waste	425.1	27.2	32.4	49.0	73.1
	Rapeseed & Mustard	Waste	342.0	23.1	28.3	44.9	68.9
	Other oilseeds	Waste	342.0	23.1	28.3	44.9	68.9
Fibre	Cotton	Seeds + waste	554.5	28.8	33.9	50.6	74.6
	Cotton	Cotton gin trash	554.5	28.8	33.9	50.6	74.6
	Jute and Mesta	Waste	291.1	20.5	25.7	42.3	66.4
Sugar	Sugarcane	Bagasse + leaves	25.7	18.8	24.0	40.6	64.7

Source: MoA (2011) and own estimates

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[12] The procurement price of a commodity refers to the price at which the Government procures the commodity from producers/manufactures for maintaining the buffer stock or the public distribution system. These prices are announced by the Government of India on the recommendations of the Commission for Agricultural Costs and Prices before the harvest season of the crop. At these announced prices, the Government procures the food grains (wheat, paddy and coarse grains) in the needed quantity either for maintaining the buffer stock or for distribution through fair price shops. Procurement prices are generally fixed at a level that is somewhat higher than the level of minimum support prices but lower than the prevailing market prices. The procurement prices are lower in relation to the actual market prices, and as such, farmers and traders are unwilling to sell their stocks voluntarily to the Government. In such circumstances, the Government procures food grains at the announced procurement prices either by imposing a levy on the farmers or traders or through other methods.

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6. Logistical Assessment of Second-Generation Biofuel Options

The general framework for the biofuel supply chain is as follows. Biomass feedstocks are first collected and processed into bale (e.g., maize stover) or pellets (woody biomass) for easier storage and transportation. For example, maize stover bales typically have a moisture mass fraction of 30 percent (Zhang and Hu, 2013). The bales are stored on the farm before being transported to preprocessing facilities. In the preprocessing facility, maize stover is chopped into small pieces of 2.5–5.0 cm and then further dried to a moisture content of approximately 7 percent and crushed to 1–2 mm (Ileleji et al., 2010). Preprocessed biomass is then sent to bio-refinery facilities to be converted into drop-in[13] biofuels (Ravula et al. 2008; Demirbas, 2009b; Wang, 2009). The drop-in biofuels can be transported to the end use locations for blending. Supply chain design and operational planning is among the greatest challenges in the cellulosic biofuel industry (Tsiakis and Papageorgiou, 2008; Bai et al., 2011; Dal-Mas et al., 2011). Feedstock production and logistics constitute 35 percent or more of the total production costs of advanced biofuel (Aden et al., 2002; Phillips et al. 2007), and logistics costs can make up 50–75 percent of the feedstock costs (Hess et al., 2006). To facilitate the commercialisation of biofuel production, it is important to investigate the optimal number and locations for biorefinery facilities and to find the optimal allocation of feedstock and biofuel. There has been an emerging literature on biofuel supply chain design (Eksioglu et al. 2010; Wright, 2010; Bowling et al. 2011).

The potential biofuel production and associated number of production plants in a region can be defined based on the current and projected availability of agricultural residues. It may be noted that the calculations are based on actual material flows and represent only a theoretical estimation. Not all types of residues are currently considered suitable for the available second-generation biofuel options. However, because using a wide range of feedstocks is the aim of further R&D, all residue types were assumed to be usable for biofuel production in the future. The amount of second-generation biofuels indicated in this study could theoretically easily meet the current 20 percent blending target across the country if all unused (i.e., after subtracting feed and other uses) residues were converted into cellulosic-ethanol. The results show that sustainable second-generation biofuel production from agricultural residues, even when effectively used, can only provide a limited share of total transport fuels. This share might increase in the long term through technology improvements and higher conversion efficiencies. Nonetheless, second-generation biofuels represent only one technology to help reduce global transport emissions; increased efficiency of vehicles and transport systems will still be the most important way to reduce overall GHG emissions in this sector (IEA, 2009).

States with the highest production levels of agricultural residues (Tables 12-20) can be potential hot spots for setting up second-generation biofuel plants. As discussed in Chapter 4 of the report, residues of the main crops – rice, wheat, and sugar cane – are mainly found in West Bengal, Andhra Pradesh, Uttar Pradesh, Punjab, Orissa, Tamil Nadu, Madhya Pradesh, Rajasthan, Maharashtra, and Karnataka (Tables 12, 13 and 20). There are also other potential feedstock sources, such as corn stover and sorghum stover, which could add other states as hot spots for production. The states with the greatest production of maize stover are Andhra Pradesh, Karnataka, Bihar, Rajasthan, Maharashtra, and Madhya Pradesh

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[13] "Drop-in" fuels are renewable fuels that can be blended with petroleum products and used in the current infrastructure.

(Table 15), while those states with high yields of sorghum are Maharashtra, Karnataka, Madhya Pradesh, and Andhra Pradesh (Table 14). Due to geographical peculiarities, soil types, and irrigation, many regions can provide more than one type of feedstock. In such cases, biofuel plants that run on mixed feedstock may be envisaged.

6.1 Capital investment and biomass feedstock supply costs

Currently, second-generation biofuel plants are much more capital intensive than first-generation biofuel refineries. Investment costs for a commercial scale second-generation biofuel plant with a capacity of approximately 50–150 Ml/yr are estimated to be $125–250 million (IEA, 2008), up to ten times more than those for a first-generation biodiesel plant of the same capacity. The financial risks should not pose insurmountable difficulties for India, as large bioenergy projects with investments exceeding $200 million have already been successfully realised (Eisentraut, 2010). Specific total capital investment typically decreases with increasing plant capacity due to economy of scale, but sudden price increases cannot be predicted.

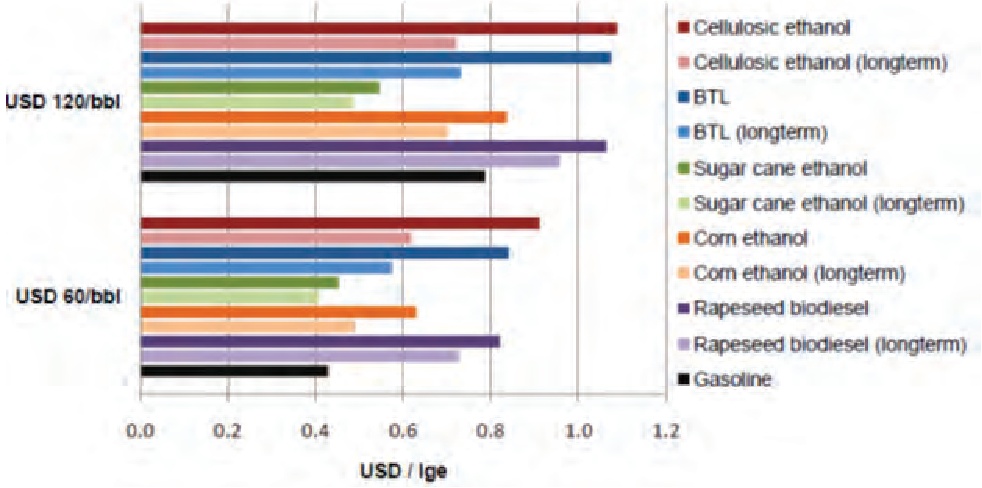
The costs of biomass feedstock supply at biofuel production facilities strongly depend on regionally specific conditions, such as biomass potentials and density of feedstock availability related to the total area of the region, infrastructure with regard to the transport network and its utilisation, and the availability of multimodal plant sites that have access to roads, rail, and/or harbours. Because there are no established markets for most of the primary agricultural residues, there are no reliable data for costs. As mentioned in the previous Chapter, the prices of agricultural residues vary from a minimum of $14/ton for bajra straw to a maximum of $34/ton for arhar stalks at the farm gate (See: Annexure VI). Typically, the complexity of logistics and transport requirements of biomass supply increase when scaling up biofuel plant sizes, e.g., with an annual biomass demand of approximately 600,000 ton/yr for a large commercial BTL plant, due to increased transport distances, and it often involves more handling and higher storage demand.

According to our estimation method (Annexure VI), storage and transportation will further add $40 to $45 per ton for biomass when collected from distant locations (up to 200 km, Table 25). For favorable plant sites, biomass provision costs are approximately 10-25 percent of total biomass costs (including production and provision costs), but provision costs can be more than 65 percent (thus exceeding production costs) under unfavourable conditions. Infrastructure and road maintenance in rural areas are sometimes precarious and will make biomass and biofuel provision costs potentially higher. Moreover, a complex land property structure and the predominance of small land holdings may increase the complexity of feedstock logistics.

6.2 Biofuel production costs

Cost estimates for second-generation biofuels show significant differences depending on plant complexity and biomass conversion efficiency (Cherubini, 2010; Sims et al. 2010; Shie et al. 2011). Important factors include annual full-load hours of plant operation, feedstock costs and capital requirements. Accordingly, biofuel plants with a higher biomass-to-biofuel production ratio are typically able to accept higher biomass supply costs compared with less efficient plants (de Wit et al. 2010; Eisentraut, 2010). Figure 14 shows IEA projections for short- and long-term production costs of different biofuels under two oil price scenarios. With oil at $60/bbl, the production costs for both BTL-diesel and lignocellulosic ethanol are currently in the range of $0.84–0.91/lge and, thus, are not competitive with fossil fuels and most first generation biofuels. In the long term, however, with increasing plant capacities and improved conversion efficiencies, both BTL-diesel and lignocellulosic ethanol could be produced at significantly reduced costs. In this case, production costs are projected to be approximately $0.62/lge for lignocellulosic ethanol and $0.58/lge for BTL-diesel (IEA, 2009). The estimated production prices are less than those for rapeseed biodiesel but still more expensive than gasoline and other first-generation biofuels. With oil at $120/bbl, production costs rise to $1.07/lge for BTL-diesel and $1.09/lge for lignocellulosic ethanol. In the long term, prices are projected to fall to $0.73/lge for BTL-diesel and $0.72/lge for lignocellulosic ethanol (Figure 14). Therefore, with reduced overall costs and oil prices at $120/bbl, second-generation biofuels could be produced at lower costs than gasoline and rapeseed biodiesel and close to the costs of corn ethanol (IEA, 2009).

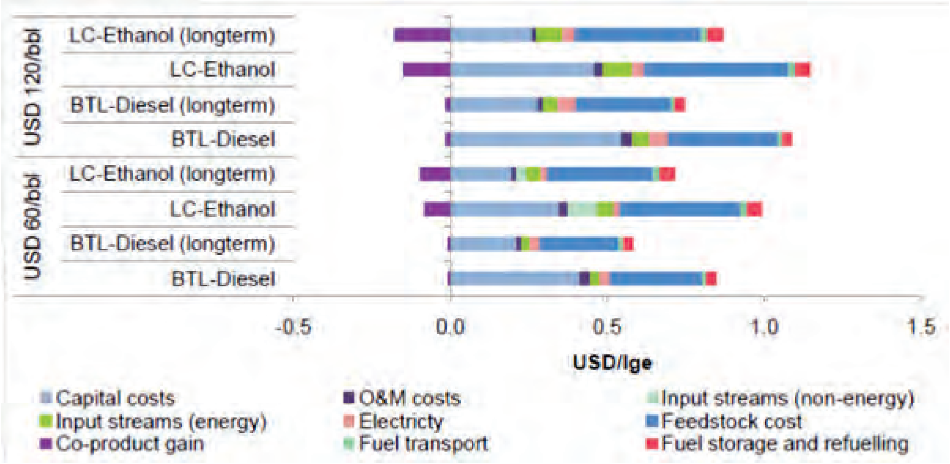
Figure 14: Comparison of biofuel cost estimates in the short and long term



Source: IEA (2009)

Currently, the largest cost factor for BTL-diesel production is the capital costs, which account for 49 percent of total production costs with oil at $60/bbl and 51 percent of costs with oil at $120/bbl. Feedstock costs account for 35 percent and 33 percent in the two scenarios, whereas all other cost factors, such as O&M costs, energy demand, and others, have a share between 1-4 percent. For lignocellulosic ethanol, feedstock costs are currently the largest cost factor, accounting for 42 percent of total production costs in both oil price scenarios. Capital costs are approximately 38 percent with oil at $60/bbl and approximately 42 percent with oil at $120/bbl (IEA, 2009). The share of all other cost factors ranges between 2 and 6 percent of total production costs (Figure 15).

Figure 15: Composition of second-generation biofuel costs



Source: IEA (2009)

In the long term, feedstock costs are expected to account for the major share (44 percent) of total BTL production costs at $60/bbl price levels, whereas capital costs are expected to be reduced by 49 percent of the present level, accounting for 37 percent of overall production costs for BTL-diesel. With oil price levels at $120/bbl, feedstock costs are the main cost factor (44 percent of total), followed by capital costs (38 percent) and others with shares between 2-8 percent. For lignocellulosic ethanol, feedstock costs are expected to remain the largest cost factor in the long term, accounting for 55 percent of total production costs at an oil price of $60/bbl and 56 percent with oil at $120/bbl. Due to expected cost reductions of 44 percent, capital costs account for approximately 31 percent of total production costs with the oil price at $60/bbl and for 37 percent in the long term with oil at $120/bbl, making it significant for overall production costs. The cost reduction from co-production gains currently lies in the range of 9-14 percent and is estimated to reach between 15 and 25 percent of total production costs in the long term (Figure 15).

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7. Sustainability

7.1 Economic impacts and viability

All the fuel ethanol currently used in India for gasoline blending comes from molasses, which is a by-product of the sugar industry. Although the availability of subsidised molasses can help keep the prices of molasses ethanol lower, such a system is unsustainable in the long run. As observed in Chapter 3, the projected increasing demand for bioethanol cannot be met solely by molasses, and alternative feedstocks will need to be used. A competitive second-generation bioethanol production scheme using lignocellulosic biomass could be relatively more stable against market fluctuations and could become self-sustaining in the long run, even though government subsidies will be necessary in the early stages. With petroleum prices expected to increase, second-generation ethanol will likely become more competitive in cost of production, and advances in technology for lignocellulosic ethanol generation will further reduce costs. In the medium to long term, second-generation ethanol production costs are expected to be highly competitive compared with molasses ethanol.

Feedstock production and collection may currently only bring limited economic benefits, but they have considerable potential to produce second-generation biofuels if infrastructure, feedstock cultivation, handling skills, and logistics are developed (Eisentraut, 2010). Once second-generation biofuels become commercially viable, a domestic industry can be built upon existing infrastructure and feedstock sources, thus significantly reducing overall investment costs. Even without an eye to producing second-generation biofuels, the acquired skills and improved infrastructure would allow for other domestic bioenergy options to become feasible and would help promote overall development.

Considering that the cultivation of biomass as fuel stock on agricultural land is not a feasible option in the Indian context, selling unutilised agricultural residues for bioethanol production can create additional income for farmers. Farmers cultivating marginal areas for biodiesel feedstock (e.g., Jatropha), however, do stand to benefit from the additional income they can obtain through selling oil seeds and oil cake. The major competition for lignocellulosic agricultural residues, especially those discussed in earlier Chapters of this report, comes from its use in pulp and paper manufacturing. There is further competition for these resources for farmers' own applications at the source, such as roof thatching, fodder for cattle, household fuel and heating. There are also other minor applications where the residues are used in areas such as packaging and handicrafts.

The recent WEO 2013 report notes that India has remained the country with the largest population without electricity access, estimated at 306 million people in 2011, and approximately two-thirds of the population (818 million people), rely on traditional biomass (IEA, 2013). Globally, demand for bioenergy in the power sector increases most in absolute terms, accounting for approximately half the total increase in bioenergy during 2011 to 2035. The number of people without access to electricity globally is projected to decline by more than one-fifth to approximately 970 million in 2030, or 12 percent of the global population. In the projections, India will see a significant improvement. Its electrification rate will rise from 75 percent today to approximately 90 percent, but in 2030 the country will still have the largest number of people without access to electricity of any single country, at nearly 150 million people.

Despite having a large supply potential for many feedstocks, particularly agricultural residues, India is struggling to ramp up the collection of feedstocks to meet the strong growth in domestic demand for bioenergy for both power sector applications and biofuel production. In the IEA projections, India looks set to become a significant importer of solid biomass for power generation, where the demand for solid biomass will reach 37 Mtoe, nearly triple current levels, requiring some 100 million tonnes of dry biomass feedstocks. While a similar order of magnitude of agricultural residues is available, the IEA concludes that it will be difficult to collect and transport a high proportion of these residues to power plants at reasonable costs (IEA, 2013).

7.2 Social impact

The biofuel sector has the potential to create substantial employment for both skilled and unskilled labour. The sugar industry is the source of livelihood for 45 million farmers and their dependents, comprising 7.5 percent of the rural population. Another 500,000 people are employed as skilled or semi-skilled labourers in sugarcane cultivation (Gonsalves, 2006). With second-generation biofuel industries becoming more established, there is greater potential to generate both direct and indirect jobs. These jobs may not be in the primary agricultural sector because the proposed feedstocks are by-products of agriculture. However, jobs will be generated in the collection and transport of residues, biomass pre-processing, and the generation of bioethanol and related by-products.

Compared with current-generation biofuels, the new technologies demand more highly skilled workers because the quality of feedstock and process technologies is more complex for thermo-chemical or bio-chemical conversion technologies compared with first-generation biofuels. India has highly skilled engineers due to the country's lengthy experience in energy industries, and the need for having skilled labour should not complicate the establishment of a second-generation biofuel industry with regard to human resources for second-generation biofuel production.

Of prime importance, a number of studies indicate that farmers benefit from engaging in feedstock production when the enabling environment (via tax incentives, land titles, subsidies, and land right policies) is profitable, equitable, and there are built-in measures to diversify. Furthermore, providing incentives (e.g., seeds and tax breaks) and expanding the existing infrastructure create opportunities for agents along the value chain (ECOFYS, 2012).

Unlike fuel-free technologies (e.g., wind and solar PV), which mainly create jobs distant from their point of application, biofuel production is more labour intensive at the point of feedstock growth and production (IRENA 2011). For developing countries or even developed countries that seek to promote investment in rural areas, this characteristic of biofuels is of value. Important in the development context, although labour productivity is evolving through time, studies have shown that renewable energy technologies are currently more labour intensive than fossil fuel technologies (IRENA 2011).

A large part of India's population, mostly in rural areas, still does not have access to energy services. The enhanced use of renewables (mainly biofuels) in rural areas is closely linked to poverty reduction and improved health because greater access to energy services can a) facilitate access to pumped drinking water; b) reduce the time spent by women and children on basic survival activities, such as gathering firewood, fetching water, and cooking; c) allow the lighting of rural households; and d) reduce deforestation and indoor pollution caused by firewood use (Eisentraut, 2010). Considering that approximately 300 million people in India are without access to electricity (IEA, 2013), developing access to modern decentralised energy technologies, particularly renewables (including biofuels), is an important element of effective poverty alleviation policies. A programme that develops energy from raw materials grown in rural areas can go a long way in providing energy security to rural people (Gonsalves, 2006). Smallholders stand to benefit directly from the additional income generated by selling residues and from cropping marginal lands/wastelands for second-generation biofuel feed stock cultivation. Farmers' cooperatives, self-support groups, and NGOs can assemble smallholders, impart training when needed, and organise support activities to ensure a competitive market position for these groups.

7.3 Environmental impacts

Environmental impact assessment studies have not been performed for biofuels in India and information on the exact dimensions of the environmental impact is not available. However, in the debate of the environmental sustainability of biofuels the following general issues are of main concern: GHG emission reductions; biodiversity; the identification of areas of high conservation value; impacts on water; impacts on air; and impacts on soil (Fischer and Schrattenholzer, 2001. Cherubini et al. 2009; Rowe et al. 2009; UNEP, 2009; Fischer et al. 2010; Wu and Liu, 2012. Caldeira-Pires et al. 2013; Leal et al. 2013; Kendall and Yuan, 2013; Mohr and Raman, 2013).

Regarding GHG emissions, second-generation biofuels are thought to provide a clear benefit over first-generation options. Biofuels produced from crop residues are estimated to result in emissions of 11 gCO_{2e}/MJ_{fuel} whereas the first-generation conversion of cereals to ethanol emissions is estimated at 37-64 gCO_{2e}/MJ_{fuel} (ECOFYS, 2012). Sugarcane to ethanol conversion, often rated highest among first-generation options in terms of economic and environmental sustainability, is estimated to produce emissions of 10-13.4 gCO_{2e}/MJ_{fuel} whereas second generation conversion is estimated to produce emissions of 12.3-12.4 gCO_{2e}/MJ_{fuel} in different biofuel settings[14] (Franke et al., 2013). In case of sugarcane to ethanol conversion there is no significant improvement in emissions in the first and second-generation route. Emissions from vegetable oil to biodiesel conversion fall within the range of 43-50 gCO_{2e}/MJ_{fuel} (ECOFYS, 2012) whereas Jatropha biodiesel produce emissions of 21.5-82.3 gCO_{2e}/MJ_{fuel} in different biofuel settings (Franke et al., 2013). The second generation conversion of rice and wheat straw to ethanol emissions is estimated at 21.6-23.1 gCO_{2e}/MJ_{fuel}. Therefore, emissions from second-generation biofuels would be roughly one-fifth the emissions of biofuel production based on the first-generation conversion of cereals or vegetable oils.

When considering the risks of biofuel production concerning land with a high conservation value and biodiversity, the risks associated with the use of residues are small compared with dedicated feedstock plantations because no additional land is required. Nevertheless, some negative impacts might occur in the form of nutrient extraction that leads to degradation of the soil with negative impact on its productivity.

The use of residues is bound by different constraints because biomass is taken away from the site rather than added. Using secondary residues as feedstock (e.g., bagasse, rice husks) is expected to have only a small negative impact on the environment because these residues are usually not returned to the field. The use of primary residues, however, could lead to nutrient extraction that has to be balanced with synthetic fertilisers to avoid decreasing productivity (Eisentraut, 2010).

Agricultural systems need to maintain soil health to be sustainable in the long term. In large scale farming, however, the emphasis is generally on boosting production with management practices that include choice of high yielding varieties combined with tillage, use of heavy machinery, fertilisers, herbicides, pesticides, and irrigation.

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[14] "Setting" is defined as a generic representation created by combining fuel chains ("life-cycles") with socioeconomic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) categories (Franke et al., 2013).

Excessive use of these inputs may result in soil erosion, loss of organic matter, loss of biodiversity, a negative impact on microbial population, soil contamination, groundwater pollution, salinity, and acidity. Crop production is also spread over soils of varying vulnerabilities, climatic conditions, sensitive ecosystems (e.g., wetlands and tropical forests), and marginal lands (e.g., steep slopes and shallow soils). Thus, the negative impacts noted above are likely to vary with site conditions. The concern that biofuel markets may have negative impacts on soil health is based on the premise that increased demand for biofuel feedstocks will encourage the expansion of related cropping area, a shift from diversity to monoculture, and an increased use of inputs. The connection appears logical, but there are no studies establishing a direct link between biofuels and soil health (ECOFYS, 2012).

Water quantity and quality are factors that determine the extent to which bioenergy can contribute to the overall energy mix. For example, in a world already facing water stress, largely due to over 70% of freshwater being consumed by the agricultural sector, bioenergy development is likely to add to this – through feedstock production and conversion processes - and hence increase the pressure (UNEP, 2012). Moreover, access to fresh water is a growing concern in rapidly developing countries such as China, India, South Africa, etc. Therefore, in countries like India, feedstock sources such as agricultural and forestry residues that do not require irrigation or additional land should be given priority, and water requirements during the biofuel production process (e.g., 4-8 litres of water per litre of ethanol for cellulosic ethanol) need to be considered carefully. Extreme weather events (inundation, droughts) due to climate change might increase uncertainty in terms of available water resources (UNEP, 2009). In addition to exacerbating water scarcity, the intensification of agricultural production induced by growing non-food biomass demand and the associated application of agro-chemicals may increase the risks of water pollution and related threats to human health and aquatic ecosystems. At the same time, there are opportunities to harness bioenergy development to help increase access to water by leveraging the introduction of efficient water management techniques, by increasing soil absorption capacity in dry areas, by selecting appropriate crops, by providing energy for water pumping and cleaning water (UNEP, 2012).

The possible soil impacts of increasing biomass demand and of intensifying the utilisation of crop residues can be grouped into four main categories. First, it will likely result in a more complete removal of vegetative biomass, which in turn could lead to the extraction of nutrients and a loss of soil fertility if not balanced with a judicious application of fertilisers. Second, the removal of crop residues might increase the area with bare soils between cultivation cycles due to a lack of mulching material and might increase degradation risks due to wind and water erosion. Third, the need to collect and transport large amounts of biomass from the field to the biofuel production sites will increase the use of machinery, in number and size, which may enhance soil compaction and affect soil properties. Fourth, the demand for and reliance on certain types of crop residues could increase mono-cropping and thereby affect biodiversity and add to soil-borne diseases. Careful management and best practices, designed to optimise production while ensuring resource conservation, may minimise the most common risks, which means that although there may be a potential for degradation, in actuality it may not be taking place or may not be serious (ECOFYS, 2012).

Proper crop rotation (e.g., cereals with legumes), cover crops, minimum tillage, and residue management along with a proper amount of fertilisers can help maintain soil conditions and productivity (e.g., FAO, 2000; Sullivan, 2001). In addition, degraded lands can be improved with proper management, including the use of deep rooting leguminous cover crops and soil amendments (e.g., Fairhurst and McLaughlin, 2009). On the other hand, poor management may degrade even the best of lands. Thus, the practices adopted by a farmer could well be more significant than the original state of the land.

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8. Conclusions

The importance of developing a strong biofuel industry to tackle the challenges of energy security and fuel self-sufficiency has been widely acknowledged in India. The global food crisis in 2008 and the subsequent food versus fuel debate prompted the Indian government to adopt a policy decision not to use any edible feedstock for bio-energy production in India's biofuel production program. The National Biofuel Policy has been designed to harness the possible environmental, social and economic benefits that may arise from the large-scale development of biofuels in the country. However, the success of the program will largely depend on the readiness of the stakeholders to engage with and the government institutions to tackle the variety of social, economic, and environmental challenges the program may face during implementation.

With the ever increasing demand for transportation fuels and rapidly depleting petroleum resources, India has to develop alternative fuels, especially for the transportation sector. It has become apparent that bioethanol production solely based on sugarcane molasses is neither economically viable nor sufficient and sustainable in the long-run. Similarly, the Jatropha-based biodiesel production program is hampered by several obstacles, such as slow progress in planting, problems with processing and marketing infrastructure, and under-developed distribution channels. While favorable government policies and the vigorous participation of local communities and private entrepreneurs can sustain the program in the short term, it is equally important to have a robust and effective long-term vision and strategy. Currently, biomass seems to be the only feasible renewable resource for producing transport fuels, but the lack of cost-effective technologies for biomass conversion to fuel has hindered progress in this direction.

India established an ambitious National Mission policy on biofuels in 2009, but the infancy of the ethanol industry and difficulty in meeting current targets constrains future demand growth in the projections (IEA, 2013). The current course of action is unlikely to be sufficient in the long run, given the present choice of feedstocks, the status of technology, and prevailing policies. A substantial research thrust in the development of second and third generation feedstocks as envisioned in the National Biofuel Policy is still needed to address the future energy needs of the country, particularly to find solutions to meeting future transport fuel requirements.

In the recent WEO 2013 report (IEA, 2013), India is recognised as "a region that, despite having large supply potential for many feedstocks, particularly agricultural residues, struggles to ramp up the collection of feedstocks to meet the strong growth in domestic demand for bioenergy, for both power sector applications and biofuels production". Taking into account feed demand and other uses, our conservative estimates of future crop residue supply suggest that India has the biomass resources to produce some 58 and 65 billion litres of ethanol from second-generation biofuels in 2020/21 and 2031/31, respectively, which will be sufficient to meet the current 20 percent blending target across the country.

India is expected to increase its biofuel consumption several times over by 2035, making it difficult for domestic supply to keep up (IEA, 2013). The assumed development of advanced biofuels at a commercial scale after 2020 affects the biofuel market in several ways. First, it creates a single market for biomass feedstocks for the power and transport sectors. For some regions, this limits the available supply for one or both of these sectors. According to the WEO 2013 scenario analysis, the IEA projects substantial increases of bioenergy uses in India, and the available supplies of crop and forestry residues will become relatively scarce by the end of the outlook period in 2035 due to demand from multiple sectors.

The available data confirm that land in India, in most parts, is already intensively used and scarce water resources are being exploited beyond sustainable levels. With a growing population and rising per capita incomes, food demand in India will continue to substantially increase in the following decades. Consequently, biofuel production will have to rely on feedstocks derived from biomass wastes, crop and forest residues, or mostly rain-fed biomass production harvested from non-food land. To achieve efficiency, biofuel production will have to involve second and third generation conversion processes to create and benefit from a broad base of different biomass feedstocks.

At present, India lacks mature technologies for second-generation biofuel production from lingo-cellulosic biomass, which is an abundant potential source of renewable energy. Crop residues are being produced and can be exploited in most parts of the country. Although biomass itself is cheap, its processing costs are relatively high. Technologies for biomass-to-biofuel conversion are still at various stages of development, and a large-scale proof of implementation is lacking.

Moreover, private investors (especially the petroleum companies) should be encouraged to invest in biofuel programmes, and government policies should be conducive to their participation. Active involvement of the private sector and private-public partnerships could help accelerate the commercialisation of second-generation biofuel technologies, which would be essential to tackle the challenges of India's transport fuel security.

In many developing countries, the framework conditions needed to set up a second-generation biofuel industry are currently insufficient. The main obstacles that need to be overcome include poor infrastructure, lack of skilled labour, and limited financing possibilities. These constraining factors are less severe in countries such as China and India, where skilled labour is available and substantial financial resources exist. In ramping up the collection of feedstocks from crop residues, the establishment of the necessary infrastructure for collection, transport, and handling of large amounts of biomass will be an indispensable step towards boosting biofuel use in India, and this will allow the country to enter second-generation biofuel production once technical and costs barriers have been reduced or eliminated.

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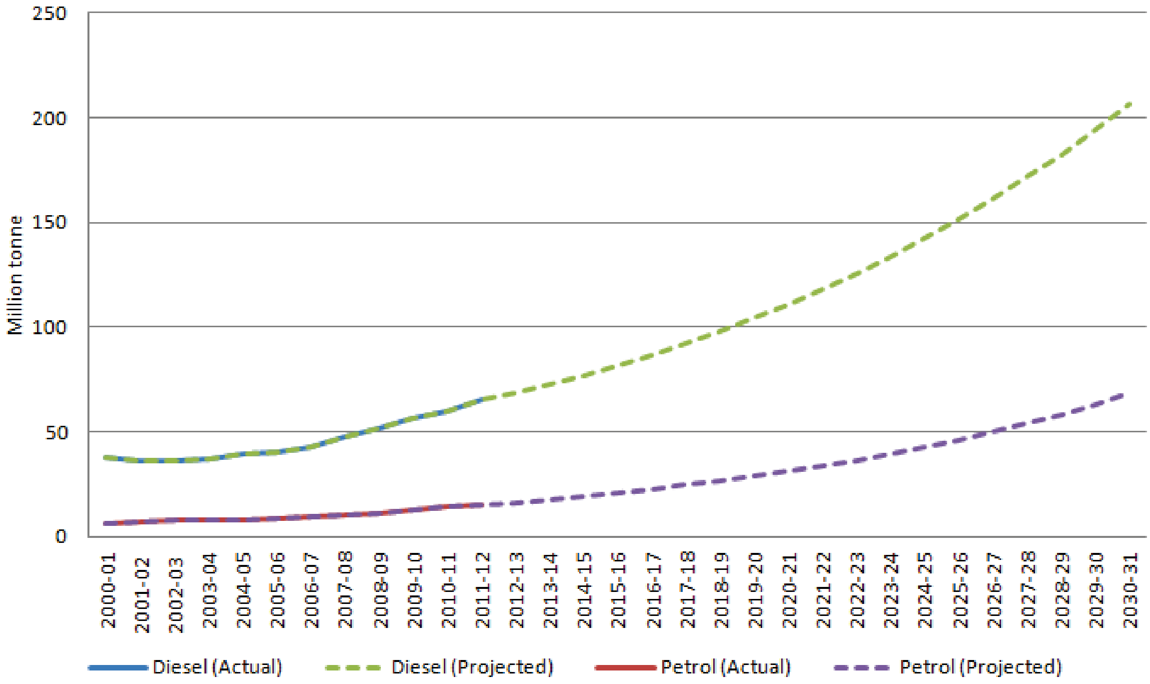
Annexure

Annexure – I: Demand projections for diesel and gasoline use until 2030-31

Figure A.I.1 presents the demand projections for diesel and gasoline. The consumption data of petrol and diesel from 2000-01 to 2011-12 are taken from PPAC (2013). PPAC also provides projections of petrol and diesel use until 2021-22. For projections until 2030-31, we have used 6.2 percent and 8.4 percent growth rates for diesel and petrol (PPAC growth rates for 2021-22), respectively. Diesel consumption will increase by a factor of 3.4 (60.1 Mt in 2010-11 to 206.31 Mt in 2030-31), whereas petrol consumption will increase by a factor of 4.8 from 2010-11 to 2030-31.

Figure A.I.1. Demand projections for diesel and gasoline.



Source: PPAC (2013) and own assumptions

Annexure – II: Availability of land for biodiesel crops

The availability of land and water are the basic requirements for large-scale plantations of biodiesel crops. Several private industries and state governments are exploring the possibility of utilising agricultural land for biodiesel production. Jatropha could be planted on cultivable wastelands, fallow land, forests, and sown areas. One of the often-quoted advantages of Jatropha is that it can grow as a 'wild' crop along railway tracks and on the hedges of cultivated lands. However, the long-term sustainability and yield of such casual plantations is suspect. Additionally, haphazard and dispersed sowings will increase the supply-chain costs. Therefore, such plantings are not expected to contribute significantly to biodiesel production.

Biodiesel plantation on wastelands mainly depends on two factors: the availability of usable wastelands and the climatic suitability of different agro-ecological regions for biodiesel plantations. There have been varying estimates of the extent of India's wastelands, ranging from 38 to 187 Mha, and the ground realities are often different from statistical records (Ramakrishnaiah, 2006). Data from remote-sensing techniques have estimated the wasteland area at 55 Mha (GoI, 2005). As per the 2011 Wastelands Atlas of India prepared by the National Remote Sensing Centre (NRSC, 2011), the total area under wastelands during 2008-09 amounted to 46.7 Mha, of which barren rocky and snow covered/glacial areas accounted for 11.8 Mha.

Table A.II.1. Planning Commission estimates on potential land availability for *Jatropha* plantation

Type of land	Total area (Mha)	Area for Jatropha plantation (Mha)	Assumptions
Forest cover	69	3	14 Mha of forest is under the Joint Forest Management scheme, of which 20 percent would be easily available for Jatropha plantation.
Agricultural land	142	3	It is assumed that farmers will prefer to put a hedge of approximately 30 Mha around their crops for protection.
Agro-forestry		2	Considerable land is held by absentee landlords who will be attracted to Jatropha plantation, as it does not require looking after.
Cultivable fallow lands	24	2.4	10 percent of the total area is expected to come under Jatropha plantation.
Wastelands under watershed development and other MoRD poverty alleviation programmes		2	---
Public lands along railway tracks, roads and canals		1	---

Source: GoI (2003)

The Planning Commission, Government of India, has estimated that with appropriate extension and availability of planting stocks, it would be possible to cover 13.4 Mha of land with *Jatropha* by the year 2012 (GoI, 2003) to meet the emerging blending requirements. The estimation details are given in Table A.II.1. However, *Jatropha* plantations have been slow to take off due to the lack of good quality planting materials and ownership issues regarding community or government wastelands and other factors (Kureel, 2007).

Agriculture being a state subject, the responsibility for the promotion of *Jatropha* plantation rests with the state governments. The biofuel plantation programme is in dire need of an integrated approach across various states. While the authority for the transfer or leasing of government land rests with the district collector, the nodal agency for the processing of application differs in each state. The type of land made available for plantation also varies across different states (Table A.II.2).

Table A.II.2. Initiatives taken by some states for Jatropha plantations

State	Nodal agency	Type of land made available
Rajasthan	Department of Agriculture	Wastelands and ravine lands
Andhra Pradesh	Department of Rain and Shadow Area Development	Irrigated and rain-fed lands
Tamil Nadu	Watershed Development Agency & Watershed Development Corporation	Wastelands and degraded forest lands
Chhattisgarh	Biofuel Development Authority	Wastelands or ravine lands
Gujarat	Agro Industrial Corporation	Hilly areas and barren lands

Source: Saxena (2007)

Annexure – III: Area, production and yield of major crops in India

We use a simple linear regression model to estimate the area and production of major crops in the near future. Figure A.III.1 presents the time variation of area and production for rice. It can be noted that rice production increased from 20.6 Mt in 1950-51 to 105.3 Mt in 2011-12. During the same period, the rice yield increased by a factor of 3.6, whereas the area under rice cultivation increased from 31 Mha to 44 Mha. Similarly, Figure A.III.2 presents the time variation of the area and production for wheat. It can be noted that wheat production increased from 6.5 Mt in 1950-51 to 95 Mt in 2011-12. During the same period, the wheat yield increased by a factor of 4.8, whereas the area under wheat cultivation increased from 9.8 Mha to 29.9 Mha.

Figure A.III.1. Time variation of area and production of rice in India

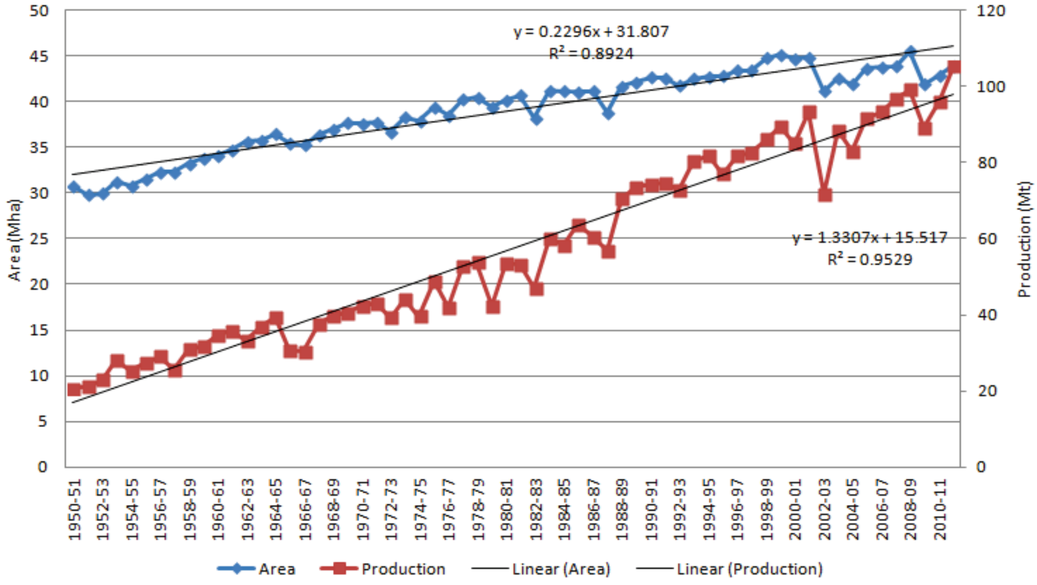


Figure A.III.2. Time variation of area and production of wheat in India

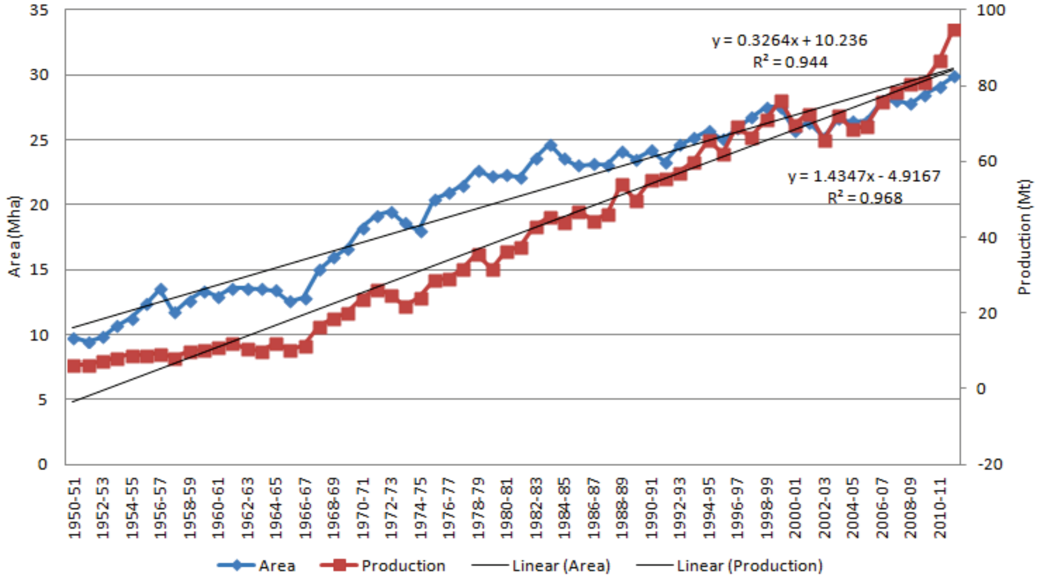


Figure A.III.3 presents the time variation of area and production for maize. Maize production increased from 1.73 Mt in 1950-51 to 21.76 Mt in 2011-12. During the same period, the maize yield increased by a factor of 4.53, whereas the area under maize cultivation increased from 3.16 Mha to 8.78 Mha.

Figure A.III.3. Time variation of area and production of maize in India

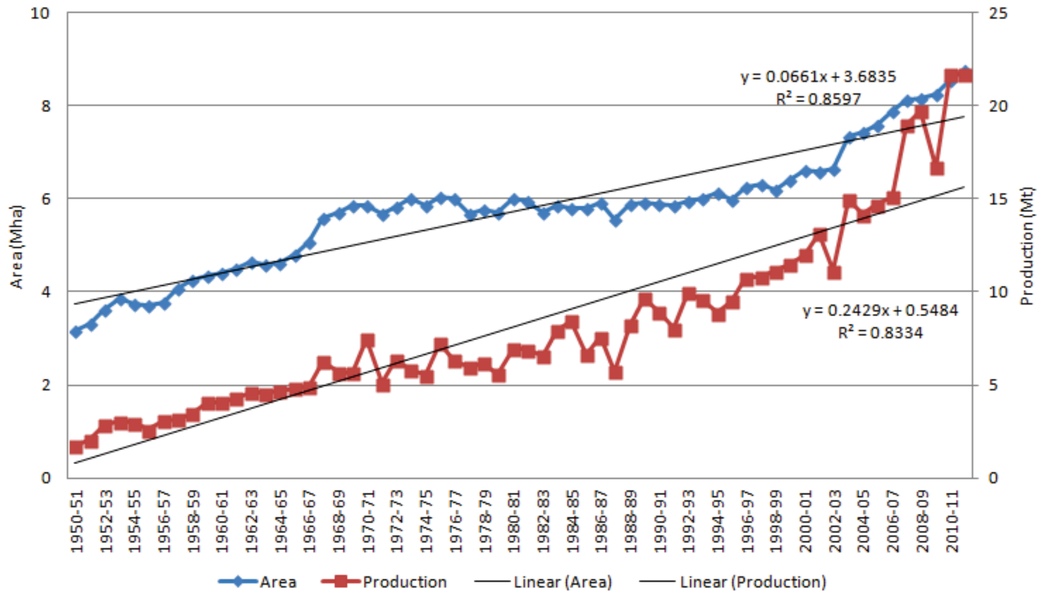


Figure A.III.4 presents the time variation of area and production for lentil (masur) in India. Lentil production increased from 0.37 Mt in 1970-71 to 0.95 Mt in 2010-11. During the same period, the lentil yield increased by a factor of 1.2, whereas the area under maize cultivation increased from 0.75 Mha to 1.6 Mha.

Figure A.III.4. Time variation of area and production of lentil (masur) in India

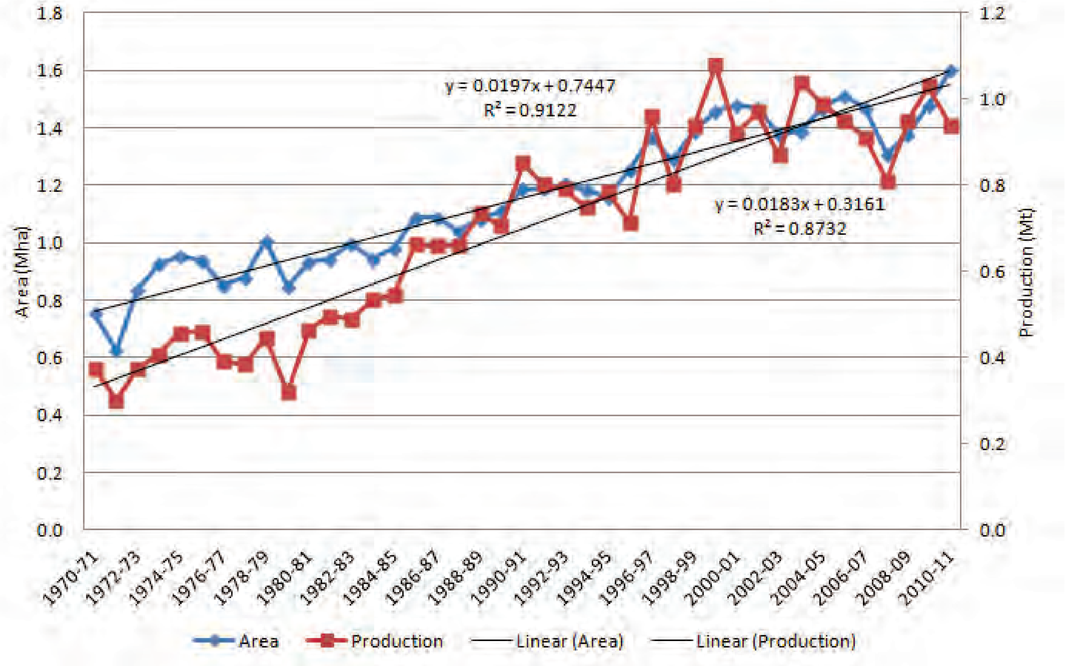
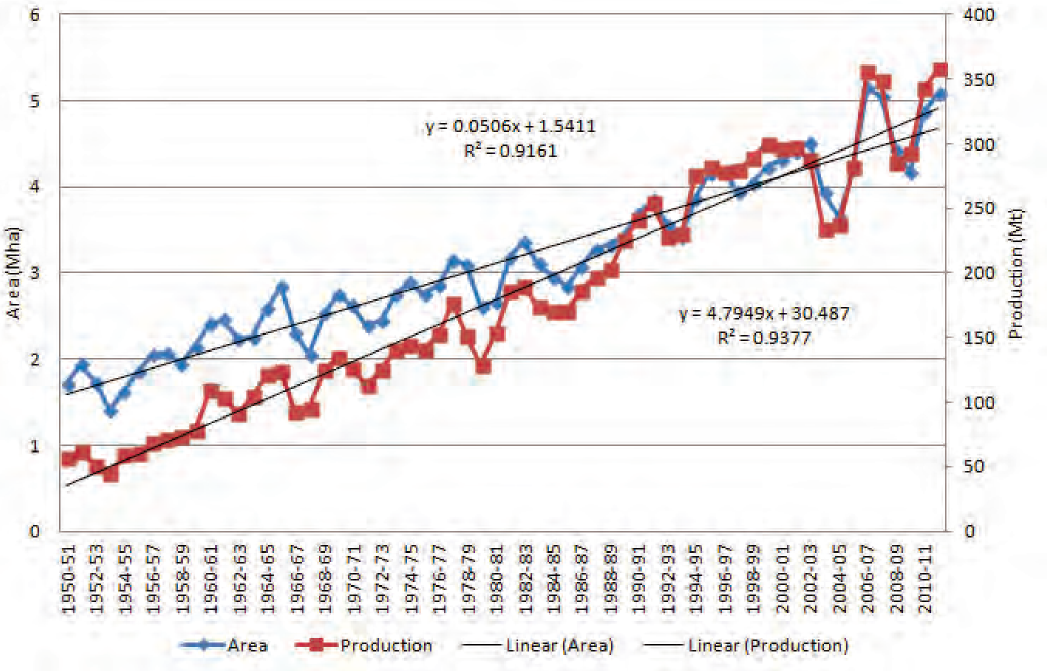


Figure A.III.5 presents the time variation of area and production for sugarcane in India. Similarly, the area and production of other crops is projected based on the data from 1950-51 to 2011-12 (MoA, 2013).

Figure A.III.5. Time variation of area and production of sugarcane in India



Annexure – IV: Agro-ecological zone assessment

The International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) have been jointly developing a global Agro-Ecological Zone (AEZ) methodology for assessing agricultural resources and their sustainable production potential. Rapid developments in information technology have produced increasingly detailed and manifold global databases, which made the first global AEZ assessment possible in 2000. Since then, global AEZ assessments have been performed every few years, with the data being published on CD or DVD. With each system update, the number of issues addressing the size of the published datasets and the numbers of the results have multiplied. GAEZ v3.0, launched in May 2012, was the most ambitious assessment to date, and the goal was to make the entire database and all results of this assessment publicly available (GAEZ Data Portals of IIASA and FAO at <www.gaez.iiasa.ac.at> and http://gaez.fao.org, respectively). GAEZ has been tested and applied in many applications and is an integral part of the ecological-economic modelling framework of IIASA in studying the development of the world's food and agricultural system.

Methodology

The adequate quality and availability of land and water resources, together with important socio-economic and institutional factors, is essential for food security. The crop cultivation potential describes the agronomically possible upper limit for the production of individual crops under given agro-climatic, soil, and terrain conditions for a specific level of agricultural inputs and management conditions. The AEZ approach is based on principles of land evaluation (FAO 1976, 1984 and 2007) to identify sound and sustainable land use options. In addition to evaluating land production potentials, the current GAEZ v 3.0 incorporates two important new global data sets, namely, "Actual Yield and Production" and "Yield and Production Gaps" between potential and actual yield and production.

Geo-referenced global climate, soil, and terrain data are combined into a land resource database, commonly assembled on the basis of global grids and at 5 arc-minute and 30 arc-second resolutions. The climatic data comprise monthly values of precipitation, temperature, wind speed, sunshine hours and relative humidity, which are used to compile various agronomically meaningful agro-climatic indicators, including quantified thermal and moisture regimes in space and time. The application of matching procedures to identify crop-specific limitations of the prevailing climate, soil, and terrain resources along with comprehensive simulations with AEZ crop models under assumed levels of inputs and management conditions, provides the maximum potential and agronomically attainable crop yields for basic land resource units under different agricultural production systems.

Actual yields and production are derived through downscaling agricultural statistics of the main food and fibre crops for all rain-fed and irrigated cultivated areas for the year 2000 (and, in the case of India, for 2010-11 as well). The sequential rebalancing procedures developed within the framework of GAEZ v3.0 rely on appropriate optimisation principles (Fischer et al., 2006a, 2006b), e.g., cross-entropy maximisation, and they combine the available samples of real observations at locations with other "prior" hard (statistics, accounting identities) and soft (expert opinion, scenarios) data. The results are presented as (i) crop production value and (ii) crop area, production, and yields for major commodities. The comparison of simulated potential yields and production with the observed yields and production of crops currently grown (year 2000) provides estimates of apparent yield and production gaps.

In summary, GAEZ generates large databases of (i) natural resource endowments relevant for agricultural uses, (ii) spatially detailed results of suitability and attainable yields, (iii) spatially detailed results of estimates/actual yields of the main food and fibre commodities for all rain-fed and irrigated cultivated areas, and (iv) spatially detailed yield and production gaps for the main food and fibre commodities. The results are commonly aggregated for current major land use/cover patterns and by administrative units, land protection status, or broad classes reflecting infrastructure availability and market access conditions.

Overview of AEZ procedures

The AEZ methodology uses a land resource inventory to assess, for specified management conditions and levels of inputs, a comprehensive range of agricultural land-use options and to quantify the anticipated production of cropping activities relevant in the specific agro-ecological context.

The calculation procedures for establishing crop suitability estimates in AEZ include five main data processing steps:

(i) Climate data analysis and compilation of general agro-climatic indicators;

(ii) Crop-specific agro-climatic assessment and water-limited biomass/yield calculation;

(iii) Yield-reductions due to agro-climatic constraints;

(iv) Edaphic assessment and yield reductions due to soil and terrain limitations, and

(v) Integration of agro-climatic and agro-edaphic results into crop-specific grid-cell databases of agro-ecological suitability and yields.

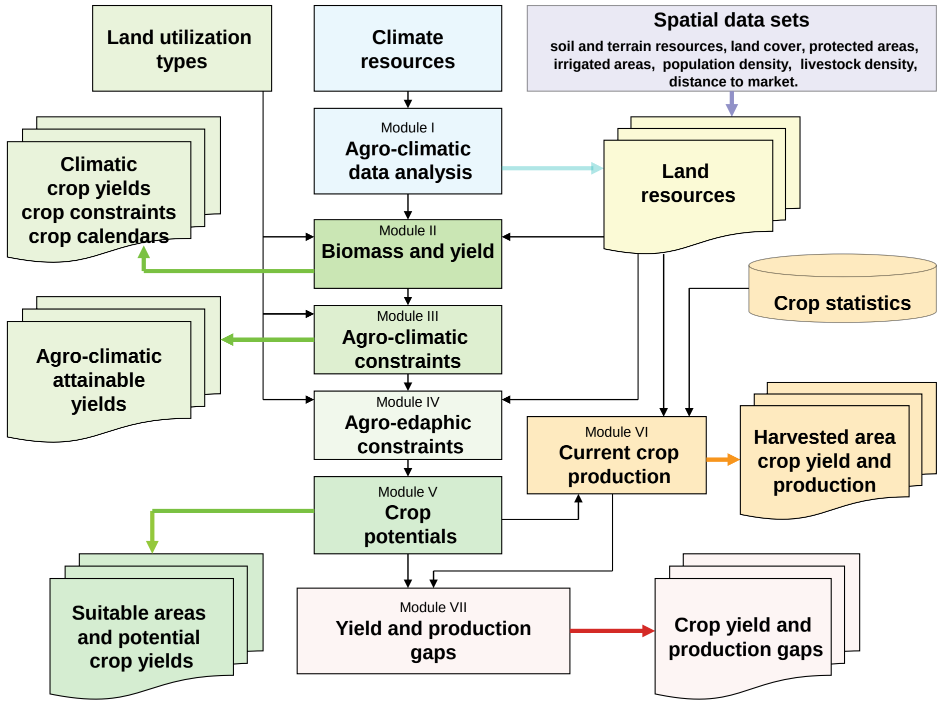
To attribute statistical data to spatial land units, i.e., to obtain the grid-cell level area, yield, and production of the prevailing main crops, two main activities are involved:

(vi) Estimation of shares of rain-fed and irrigated cultivated land in each grid-cell and estimation of harvested area, yield and production of the main crops in the rain-fed and irrigated cultivated land shares.

Finally, inventories of apparent yield gaps are compiled through:

(vii) Quantification of achievement ratios separately for rain-fed and irrigated cultivated land shares between downscaled current crop yield statistics and potential attainable crop yields.

The overall AEZ model structure is schematically shown below.



Overall structure of AEZ Model

Climate data analysis and compilation of general agro-climatic indicators

This AEZ component calculates for each grid cell a variety of climate-related variables and indicators. Spatial grids of historical (1961-2000), baseline (1961-1990 average), and projected future climates are processed to create layers of agro-climatic indicators relevant to plant production. Temporal interpolations are used to transform monthly data to daily estimates required for characterising thermal and soil moisture regimes. The latter includes the calculation of reference potential and actual evapotranspiration through daily soil water balances.

Thermal regime characterisation includes thermal climates, thermal zones, temperature growing periods, temperature sums (for average daily temperatures above 0°C, 5°C, and 10°C), and the quantification of temperature profiles, i.e., distributions of location specific average daily temperatures within a calendar year. The soil water balance calculations determine the potential and actual evapotranspiration for a reference crop; number of growing period days (LGP, days), including LGP quality (P/PET), dormancy periods, and cold brakes; and begin and end dates of one or more LGPs. Various agro-climatic indicators are used for multiple-cropping zone classifications for rain-fed and irrigated conditions separately.

Crop-specific agro-climatic assessment and potential water-limited biomass/yield calculation

Water-limited biomass and yields of approximately 280 crop and pasture types are assessed, each at three assumed levels of inputs and management. At low input levels, traditional crop varieties are considered, which may have different qualities that are preferred but may have low yield efficiencies and, because of management limitations, are grown in relatively irregular stands with inferior plant densities. In contrast, high input level high-yielding varieties are deployed with advanced field management and machinery to provide optimum plant densities.

The calculation of maximum attainable biomass and yield as determined by radiation and temperature regimes precedes the computation of crop water balances and the establishment of optimum crop calendars for each of these conditions. Crop water balances are used to estimate actual crop evapotranspiration, the accumulated crop water deficit during the growth cycle, and attainable water limited biomass and yields for rain-fed conditions. A window of time is determined when conditions permit cultivation. The growth of each crop type is tested for the days during the permissible window of time with separate analysis for irrigated and rain-fed conditions. The growth cycle duration and calendar producing the best yields define the crop calendar of each crop-type in individual grid-cells.

The results include temperature/radiation defined maximum yields, yield reduction factors accounting for sub-optimum thermal conditions for yield impacts due to soil water deficits, estimated soil water deficits, potential and actual LUT evapotranspiration, temperature sums during each crop cycle, and crop calendars.

Yield reduction due to agro-climatic constraints

Grid cell specific multipliers are calculated and used to reduce yields for various agro-climatic constraints. This step estimates the effect of limitations due to soil workability, pests and diseases, and other constraints. Five groups of agro-climatic constraints are used:

(a) Yield adjustment due to year-to-year variability of soil moisture supply (this factor is applied to adjust yields calculated for average climatic conditions)

(b) Yield losses due to the effect of pests, diseases, and weed constraints on crop growth

(c) Yield losses due to water stress, pests, and disease constraints on yield components and yield formation of produce (e.g., affecting the quality of produce)

(d) Yield losses due to soil workability constraints (e.g., excessive wetness causing difficulties in harvesting and handling of produce)

(e) Yield losses due to the occurrence of early or late frosts.

The obtained agro-climatic constraints are yield reduction factors of different constraints and severities by crop and by level of inputs. Due to a paucity of empirical data, constraint ratings have been based on recorded expert opinions.

Yield reduction due to soil and terrain limitations

Crop-specific yield reduction due to limitations imposed by soil and terrain conditions are determined from soil attribute data from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009). Soil nutrient availability, soil nutrient retention capacity, soil rooting conditions, soil oxygen availability, soil toxicities, soil salinity and sodicity conditions, and soil management constraints are estimated on a crop by crop basis and are combined into a crop and input specific suitability rating.

The soil evaluation algorithm for soil types and slope classes assesses the match between crop soil requirements and the respective soil qualities as derived from the soil attributes of the HWSD. Thus, the rating procedures result in a quantification of suitability for all combinations of crop types, input levels, soil types, and slope classes.

Integration of climatic and edaphic evaluation

The final step in the GAEZ crop suitability and land productivity assessment combines the results of the agro-climatic evaluation for biomass and yield calculated for different soil classes, and it uses the edaphic rating produced for each soil/slope combination. The algorithm steps through the grid cells of the spatial soil association layer of the Harmonized World Soil Database and determines for each grid cell the respective make-up of land units in terms of soil types and slope classes. Each of these component land units is separately assigned the appropriate suitability and yield values, and the results are accumulated for all elements.

The processing of soil and slope distribution information takes place in 30 arc-second grid cells. One hundred of these cells produce the edaphic characterisation at 5 arc-minutes, the resolution used for providing the GAEZ results.

Cropping activities are the most critical in causing topsoil erosion because of their particular cover dynamics and management. The terrain-slope suitability rating used in the GAEZ study accounts for factors that influence production sustainability and is achieved through: (i) defining permissible slope ranges for the cultivation of various crop types and setting maximum slope limits; (ii) accounting for likely yield reduction due to the loss of fertiliser and topsoil for slopes within the permissible limits; and (iii) distinguishing among a range of farming practices, from manual cultivation to fully mechanised cultivation. In addition, the terrain-slope suitability rating is varied according to the amount and distribution of rainfall, which is quantified in GAEZ by means of the Fournier index.

Application of the procedures in the modules described above results in an expected yield and suitability distribution regarding rain-fed and irrigation conditions for each 5-minute grid cell and each crop/LUT. Land suitability is described in five classes: very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (mS), and not suitable (NS) for each crop type. Large databases are created, which are used to derive additional characterisations and aggregations. Examples include the calculation of land with cultivation potential, the tabulation of results by ecosystem type, the quantification of climatic production risks by using historical time series of suitability results, the impact of climate change on crop production potentials, and irrigation water requirements for current and future climates.

Actual Yield and Production

This GAEZ module estimates actual yields and production from downscaling year 2000 statistics of the main food and fibre crops (statistics derived mainly from FAOSTAT and the FAO study AT 2015/30). The results are presented as (i) crop production value and (ii) crop harvested area, production, and yields for major commodities.

Two main activities were involved in obtaining grid-cell level area, yield, and production of prevailing main crops:

(i) estimation of shares of rain-fed or irrigated cultivated land by 5' grid cells and

(ii) estimation of area, yield, and production of the main crops in the rain-fed and irrigated cultivated land shares

Estimation of cultivated land shares

Land cover interpretation schemes were devised that allow a quantification of each 5-arc-min grid cell into seven main land use cover shares. Shares of cultivated land, subdivided into rain-fed and irrigated land, were used for allocating rain-fed and irrigated crop production statistics.

Allocation of agricultural statistics to cultivated land

Agricultural production statistics are available at the national scale from FAO. Various layers of spatial information are used to calculate an initial estimate of location-specific crop-wise production priors. These priors are adjusted in an iterative downscaling procedure to ensure that crop areas and production are consistent with aggregate statistical data, are allocated to the available cultivated land, and reflect available ancillary data, e.g., selected crop area distribution data (Monfreda et al., 2008) and the agronomic suitability of crops estimated in AEZ.

Yield and Production Gaps

Yield and production gaps have been estimated by comparing potential attainable yields and production (estimated in GAEZ v3.0) and actual yields and production from downscaling year 2000 statistics of the main food and fibre crops (statistics derived mainly from FAOSTAT and the FAO study AT 2015/30). For the main commodities, the yield and production gaps were estimated by comparing actual achieved yields and production with the potential attainable yields and production of the same 'observed' land use.

Annexure – V: Land utilisation in India

Table A.V.1. Patterns of land utilisation (2009-10)

		Classification of reported area							('000 hectare)
							Fallow land		
Year/State/ Union Territory	Reporting area for land utilisa-tion statistics (col.3 to 10)	Forests	Not avail-able for culti-vation	Permanent pastures & other gra-zing lands	Land under misc. tree crops & groves	Cultu-rable waste land	Fallow land other than curr.fallows	Current fallows	Net area sown
1	2	3	4	5	6	7	8	9	10
2009-10	**305611**	70042	42954	10149	3351	12857	10484	15753	140022
State:									
Andhra Pradesh	**27505**	6210	4808	566	295	647	1627	3361	9991
Arunachal Pradesh	**5660**	5154	64	18	38	64	70	40	212
Assam *	**7850**	1853	2626	160	196	77	50	79	2811
Bihar *	**9360**	622	2121	16	244	45	122	858	5332
Chhattisgarh	**13790**	6349	1012	859	1	351	262	272	4683
Goa	**361**	125	37	1	1	53	..	12	132
Gujarat *	**18810**	1913	3528	690	4	1976	16	379	10302
Haryana	**4371**	40	574	28	12	29	5	133	3550
Himachal Pradesh *	**4550**	1103	1123	1500	68	136	18	60	542
Jammu & Kashmir	**1757**	2023	580	120	63	149	26	84	735
Jharkhand	**7970**	2239	1332	110	93	336	1045	1564	1250
Karnataka	**19050**	3072	2174	914	288	413	484	1301	10404
Kerala	**3886**	1082	501	(a)	4	98	45	77	2079
Madhya Pradesh	**30756**	8689	3432	1338	24	1147	608	547	14972
Maharashtra *	**30758**	5215	3172	1242	250	917	1189	1373	17401
Manipur *	**2010**	1742	27	1	6	1	(a)	(a)	233
Meghalaya	**2229**	946	231	..	162	394	155	58	283
Mizoram	**2101**	1585	95	5	39	7	181	66	123
Nagaland	**1621**	861	89	..	107	43	101	59	361
Orissa	**15571**	5813	2138	494	342	375	229	606	5574
Punjab	**5033**	295	528	4	5	3	4	37	4158
Rajasthan	**34270**	2735	4268	1697	17	4475	2048	2055	16974
Sikkim *	**693**	584	11	..	8	3	4	5	77
Tamil Nadu	**13033**	2127	2666	110	253	326	1542	1117	4892
Tripura *	**1049**	606	134	..	27	1	1	1	280
Uttarakhand	**5672**	3485	441	198	383	309	80	34	741
Uttar Pradesh	**24170**	1662	3295	65	360	431	537	1232	16589
West Bengal	**8684**	1174	1820	6	55	31	20	323	5256
Union Territory:									
A. & N. Islands *	**757**	717	9	4	4	3	3	3	15
Chandigarh *	**6**	..	5	..	..	..	(a)	(a)	1
D. & N. Haveli*	**49**	20	4	1	-	(a)	2	2	20
Daman & Diu *	**4**	..	..	..	..	..	..	..	4
Delhi	**147**	1	93	(a)	1	10	8	12	22
Lakshadweep*	**3**	..	..	..	..	..	..	..	3
Puducherry	**49**	..	19	(a)	1	4	3	3	19

Source: Directorate of Economics and Statistics, Ministry of Agriculture

(a) Below 500 hectares

* The figures are taken from the latest forestry statistics publication and agriculture census and are estimated based on the latest available yearly data received from the States/Uts.

Note: The figures classified under different columns for different categories of land use do not always add up in the sub-totals and, as a whole, to the area totals at the state and all India levels due to rounding off of the figures.

Figure A.V.1: Share of net sown area and current fallow land in total reported land utilisation of districts in 2006-07

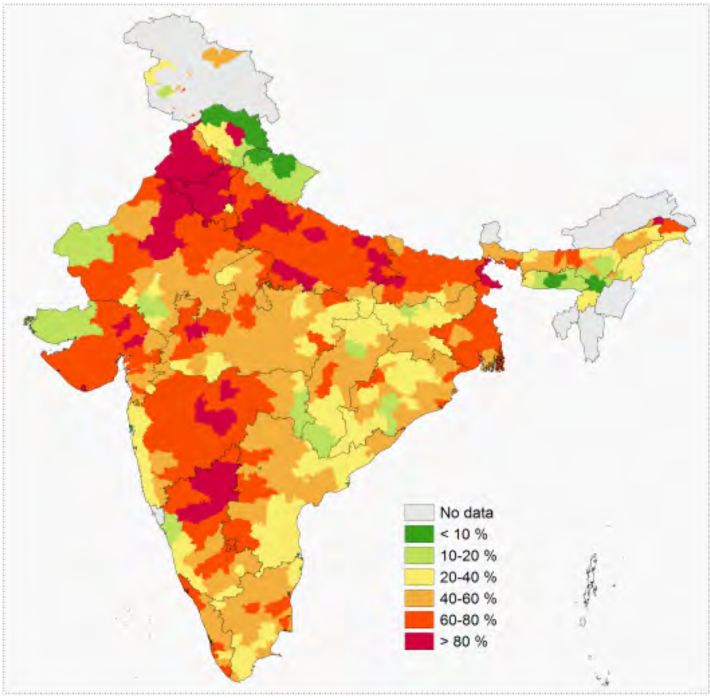
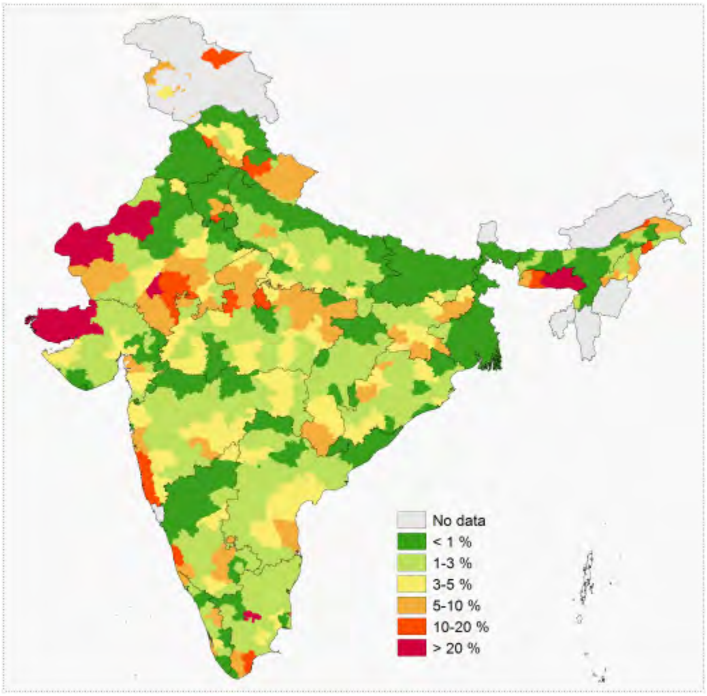


Figure A.V.2: Share of culturable wasteland in total reported land utilisation of districts in 2006-07



Annexure – VI: Cost of agricultural residues

Agricultural residues are produced as a by-product along with the main crops. Thus, they are normally assumed to be available at "no cost" to the user, which may not be a valid assumption. As long as the agricultural residues are used by the owners themselves, their costs may not be explicitly determined. However, when critically analysing the various factors responsible for the overall cost of residues (from their production and handling from the farm to the point of their utilisation), it is found that the cost of agricultural residues may be substantial. As mentioned earlier, the estimation of the cost of an agricultural residue to the user is somewhat involved. However, as a first approximation, it may be assumed that the costs of crop production, harvesting, collection, transportation, and storage of the residues would be the primary contributors towards their cost. A simple approach to estimating the cost of agricultural residues, taking into account the above factors, was developed by Tripathi et al. (1998), is discussed in the following sub-sections.

Production cost

It is assumed that a certain fraction of the cost of crop production is attributed to the cost of residue production. The production cost of agricultural residues (PC_{ar}) can be determined as

$$PC_{ar} = CCP\xi_r \quad \text{(A.VI.1)}$$

where ξ_r is a certain fraction of the cost of crop production (CCP) attributed to the cost of agricultural residue production.

Harvesting cost

Conventionally, the cost of crop production includes the harvesting cost as well. Thus, for most of the agricultural residues harvested along with the crop, the contribution of harvesting is taken into account in equation (A.VI.2). However, in the case of maize and cotton stalks, the crop is harvested first, followed by a separate harvesting of the residues. In such cases, the costs incurred in harvesting the residues should also be considered for estimating the costs of the agricultural residues. It is assumed that harvesting is performed manually. Therefore, the harvesting cost of residues (HC_{ar}) can be estimated as

$$HC_{ar} = \frac{W_{ul}}{h_{cl}} \quad \text{(A.VI.2)}$$

where W_{ul} is the daily wage rate of unskilled labour (in $ per day) and h_{cl} is the harvesting capacity (in tons per day) of the labour per day.

Collection cost

The agricultural residues must be collected at a single point in a farm/agro-industry for stacking before transportation. The collection cost of agricultural residues depends upon the agricultural wage rate and time required for their collection in a particular area. The collection cost, CC_{ar}, can be determined by dividing the daily wage rate, W_{ul}, by the carrying capacity, C_c (tons per trip), and the number of trips, N_t, made by a person in a day. Thus,

$$CC_{ar} = \frac{W_{ul}}{C_c N_t} \quad \text{(A.VI.3)}$$

Transportation cost

Agricultural residues are transported from the farm and/or processing unit to the end use point, i.e., at the processing unit/bio-refinery or to the storage place to ensure a regular supply during the off-season. Three common transportation modes, i.e., animal carts, tractor trolleys, and trucks have been considered in the present work. Therefore, the transportation cost (TC_{ar}) can be expressed as

$$TC_{ar} = \left[\frac{\zeta_t \left(\xi_d C_d + W_{sl} \right)}{t_c v_s} \right] \tag{A.VI.4}$$

where ξ_d is diesel consumption per hour of operation, C_d the cost of diesel, W_{sl} is the driver's wage (skilled labour) per hour, ζ_t is the distance of transportation, t_c is the carrying capacity of the transporting mode, and v_s is the transportation speed in km/h.

Storage cost

The storage cost includes the cost of handling and the capital invested in the storage facility. The storage cost could be the rental cost of the space or the cost incurred to cover the residues to protect them from rain. The storage cost of agricultural residues, SC_{ar}, can be determined as

$$SC_{ar} = CCP \xi_s \tag{A.VI.5}$$

where ξ_s is a certain fraction of the cost of crop production (CCP) attributed to the storage cost of the agricultural residues.

The various input parameters used for calculating the total cost of the residues are given in Table A.VI.1. The cost of crop production (CCP) has been taken as the minimum procurement price (Table 15) announced by the Ministry of Agriculture, Government of India, during the year 2010-11 (MoA, 2012). The value of ξ_r is taken as 5 percent (except for cotton stalks, which are taken as 3 percent, as the cotton prices are rather high). Manual harvesting is considered for the harvesting cost, assuming that one labourer can harvest 30 kg of residues per hour (Aggarwal, 1994). Thus, in 8 working hours of a day, 0.24 tons of residues can be harvested by one person. The harvesting cost has been estimated for maize stalks and cotton stalks only (Table A.VI.2) because for other residues separate harvesting is not required. For the storage cost, a fixed value ($1/ton) is used.

Table A.VI.1. Input parameters for estimating total cost of agricultural residues

Parameters	Units	Value
Harvesting cost		
Manual harvesting capacity	tons/person/day	0.2
Wage rate of agricultural worker	$/day	1.5
Collection cost		
Carrying capacity (manual)	tons/trip	0.03
Average distance travelled for collection at one point in one trip	km	0.1
Trips per day	number	50
Transportation cost		
Truck mode		
Average loading capacity per trip	tons	6
Average speed of transportation	km/h	40
Fuel consumption for 100 km	litre	30
Cost of fuel	$/litre	0.74
Wage rate	$/h	0.74
Tractor trolley mode		
Average loading capacity per trip	tons	1.5
Average speed of transportation	km/h	15
Fuel consumption (for a 25 hp tractor)	litre/h	4
Animal cart mode		
Average loading capacity	tons	0.5
Wage rate of cart driver	$/h	0.37
Average speed of transportation	km/h	5

The collection of residues is presumed to be performed manually. It is presumed that a farm worker can carry 30 kg of collected residues in each trip, and the average distance travelled in each trip for the collection of residues is approximately 0.1 km. A worker is assumed to make a maximum of 50 trips per day, and thus, the cost of collection is calculated to be approximately $1 per ton for all other residues. Three modes of freight transport, viz. animal carts, tractor trolleys, and trucks, have been considered for estimating the transportation cost component of the cost of agricultural residues. The initial capital costs of animal carts, tractors, and truck have not been taken into account because these are not primarily bought for the transportation of residues only.

Table A.VI.2. Production, harvesting, and collection costs of agricultural residues

Crop residue	Production cost ($/ton)	Harvesting cost ($/ton)	Collection cost ($/ton)
Rice	9.2	0.0	1.0
Wheat	10.4	0.0	1.0
Jowar	8.3	0.0	1.0
Bajra	8.1	0.0	1.0
Maize	8.1	6.2	1.0
Other cereals	8.1	0.0	1.0
Gram	19.4	0.0	1.0
Tur (Arhar)	27.7	0.0	1.0
Lentil (Masur)	20.8	0.0	1.0
Other pulses	20.8	0.0	1.0
Groundnut	21.3	0.0	1.0
Rapeseed & Mustard	17.1	0.0	1.0
Other oilseeds	17.1	0.0	1.0
Cotton	16.6	6.2	1.0
Cotton	16.6	6.2	1.0
Jute and Mesta	14.6	0.0	1.0
Sugarcane	12.9	0.0	1.0

Information about the project:

UNEP Transport Unit in Kenya, UNEP Risø Centre in Denmark and partners in India have embarked on a new initiative to support a low carbon transport pathway in India. The three-year 2.49 million Euro project is funded under the International Climate Initiative of the German Government, and is designed in line with India's National Action Plan on Climate Change (NAPCC). This project aims to address transportation growth, development agenda and climate change issues in an integrated manner by catalyzing the development of a Transport Action Plan at national level and Low Carbon Mobility plans at cities level.

Key local partners include the Indian Institute of Management, Ahmedabad, the Indian Institute of Technology, Delhi and CEPT University, Ahmedabad. The cooperation between the Government of India, Indian institutions, UNEP, and the Government of Germany will assist in the development of a low carbon transport system and showcase best practices within India, and for other developing countries.

Homepage : www.unep.org/transport/lowcarbon

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