Sustainable biomass potential for biofuels – A spatial assessment for Brazil and India

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Summary

There is a large interest in biofuels in Brazil and India as a substitute to fossil fuels, with a purpose of enhancing energy security and promoting rural development. The critical question is whether there is adequate spare land available in Brazil and India that is suited for biofuel feedstock production.

For these reasons, Daimler AG launched a project in co-operation with the International Institute for Applied System Analysis (IIASA) and the Technical University of Berlin to assess the biomass potential for biofuels employing the following sustainability criteria: The production of biofuels i) must exclude competition with food and feed supply; ii) does nor directly nor indirectly result in deforestation; iii) does not encroach in protected areas; iv) does not cause in biodiversity loss; v) does not compete for scarce fresh water resources and vi) will not cause land degradation due to inappropriate management; vii) must not contribute to GHG emissions and climate change as result of increased fertilizer use for crop production intensification or of conversion from crop production to biofuel. Applying the sustainability criteria outlined above this thesis aims for a spatially detailed assessment of biomass and biofuel potentials in promising future vehicle markets Brazil and India.

A new land resources database for Brazil has been created for a 30 arc-second (about 1 km^2) grid-cell resolution comprising of land intensities of seven major land cover categories. This study combines available recent geographic land use data derived from remote sensing analysis with statistical information from Brazil's latest agricultural Census and with forest data from FAO's Forest Resource Assessment. Spatial allocation algorithms were applied to obtain spatial distributions for i) cropland, ii) pasture, iii) forest, iv) built-up land required for urban, industrial and infrastructure, v) barren and sparsely vegetated land, and vi) water. The remaining unused share in each grid-cell was termed vii) residual land areas. Residual land was further categorized according to its legal protection status, biodiversity value, and whether it belongs to the territory of the Amazon biome. Some 44% of the latter or 37 Mha is not located in the Amazon or in protected areas or in areas of high biodiversity value and could be earmarked for biofuel production. About 62 billion litres of bioethanol from miscanthus, followed by 34 billion litres and 31 billion litres from sugarcane and cassava respectively could be produced from residual land. Potential biodiesel production amounts to about 18 billion litres when residual land is used for jatropha cultivation or 7 billion litres for soybeans. In comparison current domestic demand for bioethanol is around 23 billion litres and 3 billion litres biodiesel.

In contrast to Brazil where significant extents of residual land exist the spare land for biofuel production in India is very limited. India launched a large program to promote biofuel production, particularly on wastelands: its implications has been studied intensively considering the fact that India is a large developing country with high population density and large rural population depending upon land for their livelihood. The study for India presents an assessment of biofuel production potentials on Indian wasteland, which combines available statistical information from the agricultural survey and specific statistical data of wastelands from the Wasteland Atlas with geospatial information for wasteland suitability for biofuel feedstocks obtained from the Global Agro-ecological zones (GAEZ) assessment, which was carried out for the purpose of this study. An iterative sequential downscaling procedure has been implemented to estimate culturable wasteland shares and suitability for biofuel feedstocks. Of the total land area of India (327 Mha), about 14% is wasteland of this total approximately 13 Mha would be suitable for growing biofuel feedstocks. The production potential of culturable wastelands amounts 12 billion litres in the case of miscanthus, followed by 4 billion litres bioethanol from sugarcane. Potential biodiesel production amounts about 7 billion litres biodiesel in the case of jatropha. In comparison 7 billion litres

bioethanol and 18 billion litres biodiesel would be required considering the biofuel blend of 20% targeted by the Indian government.

Results for Brazil and India provide biophysical potentials of residual land or culturable wasteland expressed in biomass (t/ha) and biofuel equivalents (l/t). Biofuel feedstocks production potentials have been equated to energy output (GJ), GHG saving potential (ton CO_2eq) and replacement potentials of fossil transport fuels and. In addition the maximum possible amount of biofuels produced from residual land or culturable wasteland was determined by selecting the highest yielding biofuel feedstocks in terms of biofuel energy output (GJ/ton biomass). Further, key factors, which determine potential future uses of residual land or wasteland and its impact on biofuel production has been analysed.

Zusammenfassung

In den Ländern Brasilen und Indien herrscht großes Interesse an Biokraftstoffen. Zum einen sieht man in Biokraftstoffen die Chance die zukünftige Energieversorgung sicherzustellen und zum anderen ländliche Regionen mit einem hohen Anteil an Landwirtschaft durch den Anbau von Pflanzen für die Biokraftstoffproduktion zu unterstützen. Entscheidend ist hierbei, ob in diesen Ländern bisher ungenutzte Flächen existieren und ob diese für den Anbau von Pflanzen für die Biokraftstoffproduktion geeignet sind.

Aus diesem Grund hat die Daimler AG in Kooperation mit dem Internationalen Institut für angewandte Systemanalyse (IIASA) und der Technischen Universität Berlin ein Projekt initiiert, mit dem Ziel der geodatenbasierten Berechnung des nachhaltigen Biomassepotentials für die Erzeugung von Biokraftstoffen. Dabei wurden die folgenden Nachhaltigkeitskriterien berücksichtigt: Die Produktion der Biokraftstoffe darf i) nicht in Konkurrenz zur Nahrungs- und Futtermittelerzeugung stehen; ii) darf weder direkt, noch indirekt zu Entwaldung führen; iii) darf nicht auf geschützten Flächen erfolgen; iv) darf nicht auf Flächen mit hoher Biodiversität erfolgen; v) tritt nicht in Konkurrenz zu Frischwasserressourcen; vi) verursacht keine Landdegradierung aufgrund unangemessener Bewirtschaftung; vii) darf keine zusätzlichen Treibhausgas-Emissionen verursachen z.B. als Folge von vermehrtem Düngemitteleinsatz. Unter Berücksichtigung der o.g. Nachhaltigkeitskriterien zielt diese Arbeit auf eine räumlich detaillierte Bewertung von Biomasse – und Biokraftstoffpotentialen auf ungenutzten Landflächen in Brasilien und Indien.

Für Brasilien wurde eine neue geodatenbasierte Landflächennutzungs-Datenbank mit einer Rasterauflösung von 30 Bogensekunden (ca. 1 km^2) generiert. Dabei wurden verfügbare Statistiken zur Landnutzung und Waldflächen mit geodatenbasierten Landnutzungsinformationen kombiniert. Es wird zwischen sieben Landüberdeckungsarten unterschieden: i) Ackerland, ii) Weideland, iii) Waldflächen, iv) Nutz- und Reservefläche für städtische und industrielle Infrastruktur, v) Ödland und spärlich bewachsenes Land und vi) Wasserflächen. Die nicht i) bis vi) zuzuordnenden Anteile jedes Rasters wurden zusammengefasst als vii) restliche Landflächen sog. „residual land". Die restlichen Landflächen wurden weiter kategorisiert gemäß ihres rechtlichen Schutzstatus, ihrer Biodiversität und ob sie dem Amazonas zugewiesen sind. 44% des „residual land" etwa 37 Millionen Hektar sind weder dem Amazonas-Gebiet noch Schutzgebieten bzw. Gebieten mit besonderer Biodiversität zuzuordnen. Diese Fläche steht für den potentiellen Anbau von Pflanzen für die Biokraftstoffproduktion zur Verfügung. Zirka 62 Milliarden Liter Bioethanol aus Miscanthus (auch als China-Schilf bekannt), gefolgt von 34 Milliarden Litern aus Zuckerrohr bzw. 31 Milliarden Litern aus Cassava könnte auf „residual land"- Flächen erzeugt werden. Das Potential für die Biodieselerzeugung liegt bei 18 Milliarden Litern, wenn diese Flächen für den Jatrophaanbau verwendet würden bzw. 7 Milliarden Litern bei entsprechender Bewirtschaftung mit Soja. Der aktuelle nationale Bedarf liegt bei 23 Milliarden Liter Bioethanol und 3 Milliarden Liter Biodiesel.

Im Unterschied zu Brasilien, wo ein signifikantes Flächenpotential besteht, sind diese zur Biokraftstoffproduktion geeigneten freien Landflächen in Indien stark limitiert. Indien hat ein ausgeweitetes Programm zur Unterstützung der Biokraftstoffproduktion ins Leben gerufen, hierbei steht die Nutzung von Ödlandflächen sog. „wasteland"-Flächen insbesondere im Fokus. Die geodatenbasierte Berechnung des nachhaltigen Biomassepotentials für die Erzeugung von Biokraftstoffen für Indien kombiniert verfügbare Statistiken zur Landnutzung und „wasteland"-Flächen mit Geoinformationen über die Tauglichkeit zur landwirtschaftlichen Nutzung. Dabei wurde eine sequenzielle Downscalingprozedur angewendet, um das Potential von kultivierbaren „wasteland"-Flächen abzuschätzen und deren Tauglichkeit für den Pflanzenanbau für die Biokraftstoffproduktion zu prognostizieren. Ungefähr 14% der 327 Millionen Hektar Gesamtfläche Indiens sind „wasteland". Schätzungsweise 13 Millionen Hektar wären tauglich zum Anbau von Pflanzen für die Biokraftstoffproduktion. Das Produktionspotential der

kultivierbaren „wasteland“- Flächen beträgt 12 Milliarden Liter Bioethanol beim Anbau von Miscanthus gefolgt von 4 Milliarden Liter bei Verwendung von Zuckerrohr. Das Potential für die Biodieselerzeugung liegt bei 7 Milliarden Litern, wenn diese Flächen für den Jatrophaanbau verwendet würden. 7 Milliarden Liter Bioethanol und 18 Milliarden Liter Biodiesel würden in Indien benötigt um eine 20% Beimischung von Biokraftstoff in Benzin oder Diesel zu erreichen.

Die Potentiale der Rohstofferzeugung für Biokraftstoffe wurden für Brasilien und Indien in Bezug auf die Energieausbeute (GJ) und das Einsparpotential von Treibhausgasen (Tonnen CO2 –Äquivalent) gegenübergestellt. Zusätzlich wurde der maximale Ertrag an Energie aus Biokraftstoffen ermittelt, unter der Annahme des Anbaus desjenigen Rohstoffs mit der höchstmöglichen Energiedichte (GJ/Tonne Biomasse). Um die zukünftige Verfügbarkeit von „residual land“ oder „wasteland“-Flächen zu untersuchen wurden landwirtschaftliche Bedarfs- und detaillierte Weidelandproduktivitätsuntersuchungen hinzugezogen.

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Author's Declaration

I prepared this dissertation without illegal assistance. This work is original except where indicated by special reference in the text and no part of the dissertation has been submitted for any other degree. This dissertation has not been presented to any other University for examination, neither in Germany nor in another country.

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List of Abbreviations

AGB	Above Ground Biomass
Census	Annual agricultural survey
CO_2eq	Carbon dioxide equivalent
CRU	Climate Research Unit
DACNET	Department of Agriculture and Cooperation
DM	Dry Matter
DW	Dry Weight
E5	5% blend of ethanol in gasoline
E10	10% blend of ethanol in gasoline
E100	Pure ethanol (100%)
EBP	Ethanol blending program
EC	European Commission
EJ	Exa Joules (10^{18} Joules)
EMBRAPA	The Brazilian Agricultural Research Corporation
FAO	Food and Agriculture Organization
FAOSTAT	Statistics of the Food and Agriculture Organization
FFV	Flex-Fuel Vehicles
FRA	Forest Resource Assessment from Food and Agriculture Organization
g	gram
GAEZ	Global Agro-Ecological Zones
GAUL	Global Administrative Unit Layers
GHG	Greenhouse Gas
GIS	Geographic Information System
GJ	Giga Joules (10^9 Joules)

GK$,	Geary–Khamis Dollars
GLC	Global Land Cover Database
GLCCD	Global Land Cover Characterization Database
GPCC	Global Precipitation Climatology Centre
ha	Hectare
HWSD	Harmonized World Soil Database
IBGE	Brazilian Institute of Geography and Statistics
IFPRI	International Food Policy Research Unit
IIASA	International Institute for Applied System Analysis
ISRIC	International Soil Reference and Information Centre
ISSCAS	Institute of Soil Science Chinese Academy of Science
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
l	Litre
LCCS	Land Cover Classification System
LUC	Land Use Changes
LUT	Land Utilization Types
MAPA	Ministry of Agriculture, Livestock and Supply
Mha	Million hectares
MMA	Brazilian Ministry of the Environment
MS	Moderately suitable (40–60% of maximum achievable yield)
ms	Marginally suitable (20–40% of maximum achievable yield)
Mt	Million tonnes
NBM	National Biodiesel Mission
NBSC	National Biofuel Steering Committee
NS	Not suitable (less than 5% of maximum achievable yield)

PJ	Peta Joules (10^{15} Joules)
PPAC	Petroleum Planning and Analysis Cell
PROBIO	National biodiversity database by Brazilian ministry of the environment
RED	Renewable Energy Directive
RFA	Renewable Fuels Agency
RTFO	Renewable Transport Fuel Obligation
S	Suitable (60–80% of maximum achievable yield)
SI	Suitability Index
SRTM	Shuttle Radar Topography Mission
t	Tonnes
TERI	The Energy and Resource Institute
Umbrella crop	Combining production potential and suitability results of ten crops on the basis of maximum output value in a grid-cell into one so-called umbrella crop.
UNEP	United Nations Environment Program
VmS	Very marginally suitable (5-20% of maximum achievable yield)
VS	Very suitable (80–100% of maximum achievable yield)
WAC	Wasteland Atlas Category
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen
WCMC	World Conversion Monitoring Center
WDPA	World Database on Protected Areas
YSSP	Young Scientist Summer Program

Chapter I Introduction

1 Importance of biofuels, sustainability criteria's

The transport sector is a critical sector of the socio-economy as it enhances societal cohesion through human mobility and it contributes to economic growth through effective and efficient movement of goods and services. Demographic changes and economic growth over the next half century will cause a more than a doubling of world transport capacity and substantially increased fuel demand, particularly in the developing countries (OFID-IIASA 2009). The automotive industry has made considerable progress regarding alternative motorization systems like electric/hybrid vehicles and fuel cell cars. But these mobility concepts will not be available in the short term. The challenges associated with range, infrastructure, recharging time, and uniform service station docking standards must be overcome before electric mobility becomes a practical everyday option (Daimler 2009). The combustion engine will continue to be the dominant engine system for many years to come, especially for freight transport. As a consequence, the automotive industry is interested in alternative fuels for its combustion engines and biofuels in particular. The key issues center around finding a sustainable source of biofuel production for the future that will keep the fuel costs at acceptable level. In addition, the use of biofuels should provide environmental benefits and endow the automobile industry potentially with CO_2 credits (Riegel 2009).

A critical assessment of the biofuel potential is urgently required. Such an assessment, however, cannot be accomplished easily. Biomass production places characteristic demands on the physical environment with biofuel feedstocks showing temporally and spatially varying habitats, geographical extensions and yield ranges depending on factors such as local climate, terrain, soil conditions, and fresh water supply (Riegel 2009). Furthermore, an increased cultivation of agricultural feedstocks for liquid fuel production competes for scarce land, water and nutrients with food and feed production.

To produce biofuels, considerable amounts of biomass have to be provided, which will require an analysis of existing and potential biomass (OECD-IEA 2010). Recent studies have assessed the technical global biomass potential. There are ranging between 30 EJ (Hoogwijk et al. 2003) and 1,300 EJ (Smeets et al. 2007) in 2050, or between 8% and 350% of current global energy consumption (OECD-IEA 20014). A major cause for such large differences relates to the crucial factors of future land availability and yields, both being very uncertain. Particularly in developing regions, these global estimations indicate considerable potential for the cultivation of dedicated energy crops. Countries with favourable climatic conditions (such as wet tropical climates) or countries where modernization and intensification of agricultural production could free large tracts of land would be most promising for future biofuel production (OECD-IEA 2010).

However a fair amount of uncertainty results from the fact that most studies are either demand driven (focusing on the demand for bioenergy) or supply driven (focusing on the sources of bioenergy) and use a top-down approach (Berndes et al. 2003, Hoogwijk et al. 2003, Smeets et al. 2007). Secondly, most studies pay limited attention to quality and relevance of the data used, to the impact of the various factors that determine the bioenergy production potential (e.g. food consumption patterns, yields and the applied level of technology) and to the question, how an expanding bioenergy sector would interact with other land uses (e.g. food and feed production, biodiversity, soil and environmental conservation). Therefore, the availability of land that can be dedicated to energy crops for the production of biofuels may be limited and requires careful assessment; more research on availability of land resources is clearly needed (OECD-IEA 2010).

Recently, doubts have been raised about the actual benefits of biofuels regarding the mitigation of greenhouse gas (GHG) emissions (Searchinger et al. 2008). There are also questions about potential environmental, social and economic impacts, such as competition with food supply, risks of reducing biodiversity, impacts on water quality and water availability, and lack of benefits to those directly affected by large scale introduction biofuels production (Walter et al. 2011).

For these reasons, Daimler AG launched a project in co-operation with the International Institute for Applied System Analysis (IIASA) and Technical University of Berlin to assess the biomass potential for biofuels in promising future vehicle markets Brazil and India employing the following sustainability criteria:

The production of biofuels i) must exclude competition with food and feed supply; ii) does nor directly nor indirectly result in deforestation; iii) does not encroach in protected areas; iv) does not cause in biodiversity loss; v) does not compete for scarce fresh water resources and vi) will not cause land degradation due to inappropriate management; vii) must not contribute to GHG emissions and climate change as result of increased fertilizer use for crop production intensification or of conversion from crop production to biofuel.

2 Focus region Brazil

Brazil is the world's second largest producer of fuel ethanol (EIA 2014), after the USA, that surpassed Brazil in 2004, and the world's largest exporter (OECD-IEA 2010). In 2013 Brazil produced 28 billion litres fuel ethanol, representing nearly a third of global production (F.O. Lichts 2013). Brazil exported 2.9 billion litres in 2013 (USDA 2014a), with the United States and South Korea as main destinations. Current regulations in Brazil enforce a 25% blend of ethanol with fossil gasoline used for vehicles (USDA 2014a). Internal use has grown continuously since the introduction of flex-fuel vehicles (FFVs) in 2003. FFVs can be fuelled by both, gasoline and ethanol, which substantially increased consumer flexibility in response to price hikes. In recent years, almost 90% of the new cars sold in Brazil were FFVs (Walter et al. 2011). Brazil has been the world’s leading producer and consumer of sugarcane based bioethanol. The majority of biofuel is used for the domestic transport sector. Brazil is also a key player in ethanol trade, yet trade barriers in the United States and the European Union currently limit export. However, as of 2012, the 54% import tariff for ethanol to the United States was abolished. Brazilian sugarcane based bioethanol production in 2011 and 2012 was 23 billion litres down from a peak of 28 billion litres in 2010 (USDA 2014a).

Brazil started biodiesel production in 2006. Installed production capacity increased rapidly in response to envisioned mandates. In 2010, the biodiesel use mandate has been set at 5%; recently since end of 2014 a 7% mandate has been set. In 2013 Brazil marketed 3.5 billion litres of biodiesel transport fuel representing a 6% share in the total diesel market. Soybean is by far the most important source for biodiesel production (72%) followed by animal fats (24%) and cotton seed (2%) (USDA 2014a). Current biofuel production is about 65% and 40% of installed capacity for bioethanol and biodiesel respectively making a rapid expansion possible in case of increased demand and availability of sufficient feedstock. Total production capacity is 40 billion litres bioethanol from 490 bio-refineries and 8.2 billion litres biodiesel from 64 biodiesel plants (USDA 2014a). The biodiesel industry has largely been driven by the renewable fuel obligation (OECD-IEA 2010). Around 92% of the biofuel plants authorised for commercialisation have the “Social Fuel” seal, a certificate, which requires purchasing a minimum amount of feedstock from small farmers. This program aims at stimulating the cultivation of a variety of oil crops for biodiesel production, including castor bean and oil palm, which can be grown respectively in the North-East and North of Brazil. However, in practice 72% of the national biodiesel production is being produced from soybean oil, planted in the South (Lapola et al. 2009). Although the government projects a three-fold increase in the biodiesel production up to 2015, it is still unclear which oil crops will be used.

Brazilian agriculture covering about one-fourth of the countries territory has expanded substantially during recent decades and is expected to expand further in response to growing demand for food, feed and biofuel feedstocks (OECD-FAO 2009). Today the vast majority of energy crops, primarily sugarcane for fuel ethanol production is grown in the favourable climatic conditions of Brazil's South-East and Central-East regions. In view of the envisaged expansion of sugarcane, the Brazilian government conducted a broad study identifying areas suitable for sugar cane production. In addition new guidelines have been proposed for favouring energy crop feedstock production in underused or degraded pasture and from land under rain-fed cultivation (OECD-IEA 2010). However, expansion of cultivated land in Brazil has directly or indirectly caused deforestation and loss of biodiversity. This is raising concerns regarding environmental sustainability of biofuel feedstock production (Lapola et al. 2010, Sparovek et al. 2009). Brazil's potential to sustainably produce biofuels for domestic demand and the world market is one of the key factor for mobilizing resources for the bio-based economy. The suitability for biofuel production strongly depends on local biophysical conditions and management regimes, especially in large countries with a wide range of agro-ecological conditions (Fischer et al. 2010). Any regional planning for biofuel feedstock expansion or intensification must account for the spatial (and temporal) variations of crop suitability and productivity in order to maximize energy return and GHG effectiveness per land area (Lapola et al. 2009).

3 Focus region India

India is the world's fourth largest primary energy consumer and fourth largest petroleum consumer (EIA 2014). Rapid economic expansion of around 9% (OECD-IEA 2012b) in recent years has increased primary energy demand from 13 EJ in 1990 to 29 EJ in 2010, which is expected to more than double by 2035 (OECD-IEA 2012a). The highest growth rate occurs in the transport sector (WEO 2007), which is driven by road traffic with annual growth rates during recent years of 7 to 10% (USDA 2012). The current 2 EJ (year 2010) energy demand of the transport sector is expected to more than quadruple by 2035 (OECD-IEA 2012a). Diesel and gasoline cover more than 95% of the national transportation fuel requirement. This sector consumes 50% of India's oil which is for 75% imported (OECD-IEA 2012b). Volatile oil prices and the uncertainty about sustained oil supplies have led the Indian Government to search for alternatives to fossil fuels and promote energy security. Biofuels are considered as a promising option, Biofuels (biodiesel or bioethanol) can be produced locally and can used as substitutes for fossil diesel and gasoline in the transportation sector. The National Biofuel Steering Committee (NBSC) under the Prime Minister had announced a target of substituting 20% of fossil fuel consumption by biodiesel and bioethanol by 2017 (USDA 2014b). The key challenge is to find sustainable feedstocks production systems and to develop sustainable biofuel supply chains for biofuel provision at acceptable costs. The use of biofuels should stimulate rural development through increased employment opportunities, should provide environmental benefits and support the automobile industry with CO_2 credits (Riegel 2009).

In India sugar molasses, a by-product of the sugar industry, is the main feedstock for bioethanol production. India has an important sugar cane industry based on 5 Mha of cultivated land with a production potential of 342 Mt in the year 2011 (FAO 2011) Most of the sugarcane production is located in Maharashtra, where more than one-thirds of sugarcane is being produced (DACNET 2007). Further sugarcane is grown in Uttar Pradesh (30%), Tamil Nadu (10%) and Karnataka (7%) states. Part of this production is used for bioethanol (1.2–1.8 Mt per year) (OFID-IIASA 2009) which can be produced from 330 distilleries (USDA 2014b). Support for fuel bioethanol production started in 2003, when India's government mandated that nine states and four Union territories were required to sell E5, a 5% blend of ethanol in gasoline through its ambitious Ethanol Blending Program (EBP) (USDA 2014b). However, in view of supply constraints from the sugar industry, the original proposal was downsized to only 4 States and later fully suspended OFID-IIASA 2009). The recovery in sugar and molasses output during 2005/2006 generated renewed interest in the ethanol program. In October 2008 the government introduced an E10 mandate (10% blend of ethanol in gasoline) (F.O. Lichts 2008). Bioethanol and alcohol production in India depends largely on availability of sugar molasses.

Since sugarcane production in India is cyclical, bioethanol production also varies with sugar and sugarcane production and therefore does not assure optimum supply levels needed to meet the demand at any given time. Lower sugar molasses availability and consequent higher molasses prices affect the cost of production of bioethanol, thereby disrupting the supply of bioethanol for the blending program at pre-negotiated fixed bioethanol prices (USDA 2014b). Currently bioethanol consumption is restricted to the transportation sector only (Pisces 2011). India produces conventional bioethanol from sugar molasses; production of advanced bioethanol like sweet sorghum and miscanthus is in a nascent phase (research and development) (USDA 2014b).

In the case of biodiesel, India's commercial production is almost non-existent. Due to high vegetable oil prices in the domestic market, it is not economically feasible to produce biodiesel. The Government of India had launched the National Biodiesel Mission (NBM) after identifying jatropha as the most non-edible tree-borne oilseed for biodiesel production. There are various advantages of growing jatropha as biofuel feedstock especially on marginal land. Jatropha is useful for soil conservation, tolerates marginal soils with low nutrient content, can grow without irrigation in a broad spectrum of rainfall regimes and is reported fairly resistant to pests and diseases (Achten et al. 2008). Yet, so far jatropha productivity is reported to be highly variable. Experiences with jatropha plantation show high uncertainty about the yield (the average being less than half of what was expected) and some ended in failure (Euler and Gorriz, 2004). Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of jatropha are not available. The development of jatropha sector hinges on how effectively cultivars performs these tasks and thus helps overcome main constraints, namely mobilisation of land, development of suitable plant varieties and suitable cultivation/harvesting techniques and creation of incentives for the stakeholders.

The Planning Commission of India set an ambitious target of planting 11.2 to 13.4 Mha of land to jatropha by the end of 2012 (USDA 2014b). Even though the central government and several state governments provide fiscal incentives in support of planting jatropha and several public institutions are supporting the biofuel mission (USDA 2014b) today, only small quantities of jatropha and other non-edible oilseeds are crushed for oil, mainly used for lighting. By 2008 more than 700,000 ha of land was brought under jatropha plantation, of which the majority comprises new plantations that are not yet productive (Biswas et al. 2013). As the result, the deadline for blending target of 20% for biodiesel has been postponed from 2011–2012 to 2006–2017 (OFID-IIASA 2009). However, currently, India is one of the largest cultivators of jatropha globally (Upham et al. 2012). Presently, commercial production and marketing of jatropha-based biodiesel in India is small, with estimates varying from 140 to 300 million litres per year (USDA 2012). There are about 6 biodiesel plants with a capacity of 480 million litres in India that produce biodiesel (USDA 2014b).

The critical question is whether there is adequate spare land available in India that is suited for biofuel feedstock production.

Although India comprises only 2.4% of the world's land area, it supports world’s second largest population of 1.24 billion in 2012 (WDI 2014). India consists of 30 states with a total land area of 327 Mha, of which 54% is agricultural area including 168 Mha cropland and fallow land, and 10 Mha pasture (DACNET 2007). The high population density of nearly 380 persons per km^2 and an annual population growth rate of 1.3% (WDI 2014) highlight scarce land availability for food, feed and biofuel production. Limited availability of agriculture land, slow agricultural productivity growth, increasing land demand by growing population, risks of acute food shortages and consequential price rises have prompted India policymakers to launch a large program which promotes biofuel feedstock to be grown on those wastelands that are otherwise unsuited to food or feed production, avoiding possible conflicts of fuel- versus food security and deforestation (USDA 2012). Although wasteland areas are readily available and its land prices are generally low, extent in which wasteland areas may be used for biofuel feedstock production requires a critical and a priori assessment of production potentials of India’s wastelands.

4 Objective and research questions

The production of biofuels i) must exclude competition with food and feed supply; ii) does nor directly nor indirectly result in deforestation; iii) does not encroach in protected areas; iv) does not cause in biodiversity loss; v) does not compete for scarce fresh water resources and vi) will not cause land degradation due to inappropriate management; vii) must not contribute to GHG emissions and climate change as result of increased fertilizer use for crop production intensification or of conversion from crop production to biofuel.

Applying the sustainability criteria outlined above this study aims for a spatially detailed assessment of biomass potentials from spare land (wasteland or otherwise residual land) for biofuel production in Brazil and India. These areas exclude all forests, all cropland and pastures currently used for agricultural production as well as all land in use for urban, industrial or infrastructure purposes. The analysis includes consideration of legally protected areas and areas with high biodiversity value. An iterative sequential downscaling procedure has been implemented to estimate these lands. The framework combines land evaluation methods with socioeconomic and multiple-criteria analysis to evaluate spatial and dynamic aspects of biomass potentials from spare land.

Furthermore the assessment aims to assess potential productivity of selected biofuel feedstocks on derived extents and locations of available spare land. For these areas the suitability and productivity of biofuel feedstocks is estimated and its suitability for biofuel feedstocks including estimates on (i) biophysical production potentials of biofuel feedstocks, (ii) attainable yield and production per district or micro-regions and states, calculated in terms of biomass (t/ha), biofuel equivalent (l/ha) and energy (GJ/ha), (iii) maximum possible amount of biofuels produced from culturable spare land in a grid-cell was determined by optimizing biofuel feedstocks yields in terms of biofuel energy output (GJ/t biomass), (iv) concentration of spare land with prime or good quality land for best performing feedstock and (v) the volume of GHG emissions saved (in CO2 equivalent) due to replacement of fossil transport fuels with biofuels from residual land.

In addition the study aims to identify key factors, which determine potential future uses of culturable spare land and its impact on biofuel production.

Based on the overall objectives a number of research questions are posed:

- Is there adequate spare land available in Brazil and India that is suited for biofuel feedstock production?
- Which biofuel feedstocks are suitable to be introduced in these areas?

- Which biofuel feedstock yields can be attained, taking into account respective biophysical characteristics of land?
- What are biofuel feedstock potentials of spare land?
- What are biofuel potentials vis-à-vis different biofuel feedstock scenarios?
- How much fossil fuels could be replaced?
- How big is the amount of GHG emissions, which could be saved due to replacement of fossil transport fuels with biofuels from spare land?
- Which are the key factors, which determine potential future uses of spare land and its impact on biofuel production?

5 Structure of the thesis

The thesis is organized in to five chapters (I-V). After introducing the importance of biofuels sustainability criteria's, the current Biofuel situation in Brazil and India, research subject and questions in chapter I, chapter II and chapter III presents the results for Brazil.

Chapter II presents (i) data, methodology and results of the spatially detailed analysis of Brazil's downscaled land balances for major land categories; ii) presents quantification of Brazil's residual land, iii) presents an assessment of the quality of this residual land and iv) discusses key factors, which determine potential future uses of residual land and its impact on biofuel production.

The focus in chapter III is on (i) introducing selected biofuel feedstocks, sugarcane, cassava, miscanthus, soybean and jatropha and its biophysical requirements; (ii) presenting results for biofuel potentials in terms of biomass and biofuels and (iii) discussing potential for reducing GHGs and replacing fossil transport fuels when biofuels are grown on residual land.

Results for India are presented in chapter IV. This chapter presents (i) data and methodology applied for the spatial assessment of biomass yield potentials on culturable wasteland; (ii) results for biofuel potentials for sugarcane, miscanthus and jatropha in terms of biomass and biofuels and (iii) discusses the potential for reducing GHGs and replacing fossil transport fuels when biofuels are grown on culturable wasteland.

Finally, chapter V synthesises the results of the three preceding chapters and provides recommendations for future research.

Additionally, appendix A, B and C provides tables with results for biomass and biofuel potentials of different feedstocks at state, micro-region and district level for Brazil and India.

Chapter II

Brazil's current and future land balances: Is there residual land for bioenergy production?[1]

Abstract

A new land resources database for Brazil has been created for a 30 arc second (about 1 km^2) grid-cell resolution comprising of land intensities of seven major land cover categories being consistent with year 2006 Census agricultural statistics at micro-region level and forest data from the forest resource assessment 2010 by Food and Agriculture Organization at biome level. Spatial allocation ('downscaling') algorithms were applied to obtain spatial distributions for i) cropland, ii) pasture, iii) forest, iv) built-up land required for urban, industrial and infrastructure, v) barren and sparsely vegetated land, and vi) water. The remaining unused share in each grid-cell was termed vii) residual land areas. Some 44% of the latter or 37 Mha is not located in the Amazon or in protected areas or in areas of high biodiversity value. This *residual-III land* equates to 50% of Brazil's current cropland and is earmarked for potential biofuel feedstock production. Almost one-third of these areas would be very suitable or suitable for crop production. Agricultural demand projections combined with detailed pasture productivity calculations suggest that until 2030 current pasture land areas would be sufficient for both providing feed for Brazil's increasing cattle herd and land areas for expanding croplands. In this case the 37 Mha residual land could be used for biofuel feedstock production.

Keywords: Brazilian land balance, residual land, sequential downscaling, sustainability criteria

1 Introduction

As demand for biofuel on the world market has been increasing, Brazil, today the largest producer and consumer of sugarcane bioethanol, is considered as a major potential supplier of biofuels. Large land endowments and technologically advanced sugarcane agro-industries developed since the 1970s place Brazil in a leading position for producing cheap biofuels with substantial potentials for mitigating human greenhouse gas (GHG) emissions.

Food security and promotion of renewable energy including modern uses of biomass as a source of energy are key goals in developing countries. This has raised the important question whether these concurring goals are conflicting interests impossible to reconcile or whether it is possible to integrate them into a common strategy for sustainable land use.

The availability of land that can be dedicated to agricultural land expansion for bioenergy crop production may be limited and requires careful assessment; more research on availability of land resources is clearly needed (OECD-IEA 2010). Doubts have been raised about the actual benefits of biofuels regarding the mitigation of GHG emissions due to indirect land use changes (Searchinger et al. 2008). There are also questions about potential environmental, social and economic impacts, such as competition with food supply, risks of reducing

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[1] Lossau S, Fischer G, Tramberend S, van Velthuizen H, Kleinschmit B, Schomäcker R. Brazil's current and future land balances: Is there residual land for bioenergy production? Biomass and Bioenergy 2015; 81:452-461. ISSN 0961-9534. doi: http://dx.doi.org/10.1016/j.biombioe.2015.07.024

biodiversity, impacts on water quality and water availability, and lack of benefits to those directly affected by large scale introduction biofuels production (Walter et al. 2011).

These challenges for Brazil endowed with significant land resources and land use change hot spot have both a local and global dimension (Jonas et al. 2014). Brazilian agriculture covering about one-fourth of the countries' territory has expanded substantially during recent decades and is expected to expand further in response to growing demand for food, livestock feed and biofuel feedstocks (OECD-FAO 2009). At the same time maintaining environmental conservation of biodiversity rich ecosystems and avoiding GHG emissions from deforestation are essential for achieving sustainable land use locally and globally.

Securing food production involves both to meet the increasing demand locally for a rapidly growing middle class and to serve the growing markets for export of agricultural commodities. Brazil is spearheading the development of sugarcane derived bioethanol serving the country's growing fleet of flex-fuel vehicles (FFVs) and increasing demand from the world market. Today the vast majority of biofuel feedstocks, primarily sugarcane for fuel ethanol production, are grown in the favourable climatic conditions of Brazil's South-East and Central-East regions. In view of the envisaged expansion of sugarcane, the Brazilian government conducted a broad study identifying areas suitable for sugarcane production (CGEE 2012). In addition new guidelines have been proposed for favouring energy crop feedstock production in underutilized or degraded pasture land and from land under rain-fed cultivation (OECD-IEA 2010).

Land suitability for biofuel production strongly depends on local biophysical conditions and management regimes. Regional planning for biofuel feedstock expansion or intensification must account for the spatial (and temporal) variations of crop suitability and productivity in order to maximize energy return and GHG effectiveness per land area (Lapola et al. 2009).

For these reasons, Daimler AG launched a project in co-operation with the International Institute for Applied System Analysis (IIASA) and Technical University of Berlin to assess the biomass potential for biofuels taking into consideration the following sustainability criteria:

The production of biofuels i) must exclude competition with food and livestock feed supply; ii) does neither directly nor indirectly result in deforestation; iii) does not encroach in protected areas; iv) does not cause biodiversity loss; v) does not compete for scarce fresh water resources and vi) will not cause land degradation due to inappropriate management; vii) must not contribute to GHG emissions and climate change as result of increased fertilizer use for crop production intensification or of conversion from crop production to biofuel.

For complying with the first four of these sustainability criteria an important first step is to assess the availability and quality of available land resources in Brazil. Research presented in this paper contributes here by developing (i) spatially detailed land balances to identify "residual" land; (ii) assess the quality of residual land; (iii) and analyse potential land competition of residual land use for food, livestock feed and bioenergy production.

2 Methodology and data

2.1 Assessment of land balances and residual land

For the estimation of Brazil's residual land areas an as accurate as possible current land use data base is of critical importance. This study combines available recent geographic land use data derived from remote sensing analysis with statistical information from Brazil's latest agricultural Census of the year 2006 (IBGE 2006) and with forest data from FAO's Forest Resource Assessment (FRA) 2010 (FAO 2010a). Table II-1 summarizes the applied geographic and statistical data sources.

Data	**Description**	**Scale**	**Source**
Geographical Data Sources			
Administrative Unit Layer	Administrative unit layer for Brazil provided by Brazilian Institute of Geography and Statistics (IBGE)	polygon (transferred to 30 arc second grid-cell resolution)	(IBGE 2011a)
Biome Layer	Biome boundary layer for Brazil provided by Brazilian Ministry of the Environment (MMA).	polygon (transferred to 30 arc second grid-cell resolution)	(MMA-IBGE 2011)
FRA 2000	The World Forest Database 2000, developed by Food and Agriculture Organisation (FAO) based on AVHRR satellite data.	30 arc second grid-cell resolution	(FAO 2001)
GLC 2000	Global Land Cover Characteristics Database 2000 (GLCC 2000), developed by European Joint Research Centre (JRC) based on SPOT satellite data. FAO land cover classification system (LCCS) for South America with 74 categories for forest, cropland, pasture and others	30 arc second grid-cell resolution	(JRC 2006)
HWSD 2009	Harmonized World Soil Database 2009, with spatial information for over 16000 different soil mapping units and respective soil attributes (eg. organic carbon, pH, water storage capacity, soil depth etc.). Developed by FAO, in cooperation with JCR, IIASA; International Soil Reference and Information Centre (ISRIC) and Institute of Soil Science Chinese Academy of Science (ISSCAS)	30 arc second grid-cell resolution	(FAO et al. 2012)
IFPRI 2000	World Land Use- Land Cover Database 2000, with over 40 land categories for cropland, pasture, forest and others. Developed by International Food Policy Research Institute (IFPRI), derived from a reinterpretation of the Global Land Cover Characterization Database (GLCCD) ver. 2.0 based on AVHRR satellite data.	30 arc second grid-cell resolution	(IFPRI 2002, EDC 2000)
Irrigation Layer	Global map of irrigation areas, with information about the amount of area equipped for irrigation at the end of the 20th century as a percentage of the total area on a raster. Developed by FAO in cooperation with Goethe University, Germany.	5 arc minute resolution (scaled to 30 arc second grid-cell resolution)	(FAO 2007)
Population Layer	Layer developed by IIASA, based on statistical population data for Brazil and per capita land requirements applied to a spatially detailed population layer for the year 2000 developed by FAO and based on the Landscan global population distribution database.	30 arc second grid-cell resolution	(ORLN 2000)
PROBIO 2006	National Biodiversity Database 2006 developed by Brazilian Ministry of the Environment (MMA) providing spatial identification of areas with high biodiversity.	polygon (transferred to 30 arc second grid-cell resolution)	(MMA 2004)
Spatial Climate Inventory	Geo-referenced climate database developed by IIASA using climate data from Climate Research Unit (CRU) of East Anglia University and the VASCLimO global precipitation data from the Global Precipitation Climatology Centre (GPCC)	5 arc minute resolution (scaled to 30 arc second grid-cell resolution)	(FAO-IIASA 2012, Mitchell and Jones 2005, New et al. 2002, Beck et al. 2004)
SRTM	Digital Elevation Database providing terrain slope information and aspect data derived from high resolution elevation data available from Shuttle Radar Topography Mission (SRTM)	30 arc second grid-cell resolution	(CGIAR-CSI 2008)

Protected Area Layer	A legally protected areas layer at 30 arc second grid-cell resolution was derived from the protected areas layer of the GAEZ, which is based on the World Database of Protected Areas (WDPA). World Database on Protected Areas including nationally and internationally protected areas developed by World Conversion Monitoring Center of the United Nations Environment Program (UNEP-WCMC) in cooperation with International Union for Conservation of Nature (IUCN)	30 arc second grid-cell resolution	(FAO-IIASA 2012, UNEP 2010)
Statistical Data Sources			
Census 2006	Statistical survey data for cropland, pasture and livestock at micro-regional level collected by IBGE	559 micro-regions	(IBGE 2006)
FRA 2010	Statistical forest data derived from FAO forest survey 2010	6 biomes	(FAO 2010b)
FAOSTAT 2008	Statistical crop production data for the year 2008 derived from FAOs land resource statistics.	country level	(FAO 2011)

Table II - 1 Summary of the geographical and statistical data sources

An iterative sequential downscaling procedure (Fischer et al. 2006) has been implemented to estimate land cover shares for major land use categories in individual 30 arc second grid-cell resolution longitude/latitude grid-cells (about 1 km^2). The resulting land balance comprises of seven major land use categories i) cropland, ii) pasture, iii) forest, iv) built-up land required for urban, industrial and Infrastructure, v) barren / sparsely vegetated, and vi) water. Remaining unused area in each grid-cell was termed vii) residual land. Table II-2 summarizes sequence and data sources applied in the sequential downscaling procedure.

No.[a]	Land use category	Statistical data source	Geographic data sources
1	Built-up land	not applicable	Population layer (ORLN 2000)
2	Water	not applicable	GLC 2000 (JRC 2006), HWSD (FAO et al. 2012)
3	Cropland	Census 2006 (IBGE 2006) for 559 micro-regions	Combined land cover of GLC 2000 (JRC 2006), IFPRI (IFPRI 2002), FRA 2000 (FAO 2001) and Irrigation layer (FAO 2007)
4	Pasture[b]	Census 2006 (IBGE 2006) for 559 micro-regions	Combined land cover
5	Forest	FRA 2010 (FAO 2010a) for 6 biomes and allocated evenly to micro-regions	Combined land cover
6	Barren	not applicable	GLC 2000 (JRC 2006)
7	Residual land	Calculated as remainder in each grid-cell	

a lists the sequence in downscaling

b the Census pasture categories managed pasture and natural pasture were combined into one pasture category

Table II - 2 Data sources applied for downscaling of major land use categories

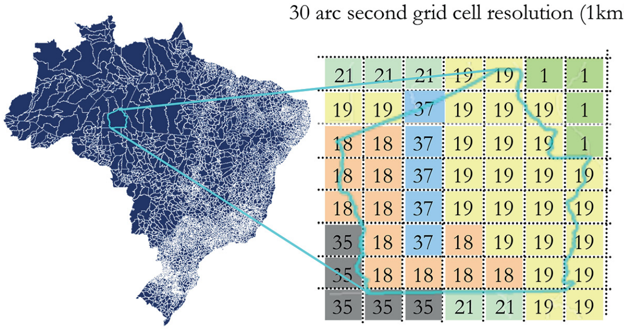
First built-up land intensities required for urban and infrastructure land were calculated based on an estimated relationship of per capita land requirements and applied to a year 2000 spatially detailed population layer at 30 arc second (about 1 km^2) grid-cell resolution developed by FAO and based on the Landscan global population distribution data (ORLN 2000).

Second, land cover data and additional soil data from the Harmonized World Soil Database (HWSD) (FAO et al. 2012), was used to delineate inland water bodies.

After excluding built-up land shares and water grid-cells, agricultural land and forest area were allocated in accordance with statistical data and geographic land cover distributions. Brazil's 559 micro-regions reported in the agricultural census 2006 (IBGE 2006) include extents of total farmland, and the sub-categories cropland and several pasture land uses. Forest area statistics reported in FRA 2010 (FAO 2010a) for six biomes were evenly allocated to micro-regions. For estimating cropland, pasture and forest intensities GLC 2000 (JRC 2006) was used as the prime land use database. The IFPRI (IFPRI 2002), FRA 2000 (FAO 2001) and the irrigation layer (FAO 2007) spatial land cover datasets were integrated into a combined new data layer of 42 land cover classes at 30 arc second grid-cell resolution. The spatial allocation procedure applies defined ranges of weights for each of the combined land cover classes separately for farmland (sum of cropland and pasture), cropland, and forest (Table II-3). These have been defined first, where possible, by quantitative land cover class delineation included in the GLC 2000 (JRC 2006) classification using the FAO land cover classification system (LCCS). Second, expert judgment's plausibility of the presence of cropland, pasture or forest land in individual combined land cover categories. The adjustment of the individual land cover shares in the iterative procedure is controlled by a parameter file, which specifies three levels of increasingly wider intervals within which the weights are adjusted (Table II-3). Box II-1 shows an example for cropland allocation. In this way total farmland and cropland was allocated to grid-cells. The difference between farmland and cropland refers to a combined pasture category. Next forest was allocated to grid-cells again applying the combined land cover database. When GLC 2000 reports barren or sparsely vegetated land remaining shares of those grid-cells were allocated to the category barren land. Finally any unallocated share of a grid-cell was termed residual land. The sum of the seven shares in each grid-cell is 1, i.e. there is consistency without double counting or leakage.

Brazil

Land cover of one micro-region
30 arc second grid cell resolution (1km²)



21	21	21	19	19	1	1
19	19	37	19	19	19	1
18	18	37	19	19	19	1
18	18	37	19	19	19	19
18	18	37	19	19	19	19
35	18	37	18	19	19	19
35	18	18	18	18	19	19
35	35	35	21	21	19	19

Reference weights applied for cropland downscaling

Count km²	Land Cover Class GLC , IFPRI, FRA	Weight Intervals w -3	w-2	w-1	w0	w1	w2	w3
4.5	37 water	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.8	18 crop + others	0.20	0.30	0.50	0.70	0.90	0.95	1.00
15.2	19 crop + pasture	0.10	0.20	0.40	0.60	0.80	0.90	1.00

Allocation of cropland

Step1:	9.8 km² x 0.7 (w0) + 15.2 km² x 0.6 (w0) = 13 km²	Census = 15.4 km² < 13 km²
Step2:	9.8 km² x 0.9 (w1) + 15.2 km² x 0.6 (w0) = 15 km²	Census = 15.4 km² < 15 km²
Step3:	9.8 km² x 0.95 (w2) + 15.2 km² x 0.6 (w0) = 15.4 km²	Census = 15.4km² = 15.4 km²
Left over:	9.8 km² x 0.05 + 15.2 km² x 0.4 = 4.8 km²	

Box II - 1 Example for allocation of cropland using land cover reference weights

Table II - 3 Weights applied in the spatial downscaling procedure for different combined land cover classes

Class	Combination of different land cover sets[a]			Land cover weights to allocate cropland[g]							Land cover weights to allocate forest							Land cover weights to allocate farmland						
	GLC2000[b]	**IFPRI[c]**	**FRA2000[d]**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
	Trees																							
1	closed forest		forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	open forest	forest	forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10
3	open forest	agriculture		0,00	0,00	0,00	0,00	0,05	0,10	0,30	0,60	0,75	0,90	0,95	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,05	0,10	0,35
4	open forest	grass and pasture		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,60	0,70	0,80	0,95	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,10	0,35
5	open forest	bare, sparsely or undefined		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,40	0,50	0,75	0,95	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,10	0,35
	Shrubs																							
6	closed shrubs	forest	forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,10	0,15	0,20	0,30	0,40	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	closed shrubs	trees		0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,05	0,10	0,20	0,30	0,40	0,00	0,00	0,00	0,00	0,00	0,05	0,15
8	closed and open shrubs	agriculture		0,00	0,00	0,00	0,00	0,05	0,15	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25	0,50
9	closed and open shrubs	grass and pasture		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25	0,50
10	closed and open shrubs	bare, sparsely or undefined		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25	0,50
	Herbaceous																							
11	herbaceous	forest	forest	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,10	0,15	0,20	0,25	0,30	0,40	0,05	0,10	0,20	0,40	0,60	0,70	0,85
12	herbacous	trees		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,00	0,05	0,10	0,15	0,20	0,30	0,05	0,10	0,20	0,40	0,60	0,80	1,00
13	herbacous and open grassland	agriculture		0,00	0,00	0,00	0,00	0,05	0,15	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,15	0,25	0,50	0,65	0,80	1,00
14	herbacous and open grassland	grass and pasture		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,15	0,25	0,50	0,65	0,80	1,00
15	herbacous and open grassland	bare, sparsely or undefined		0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,15	0,25	0,50	0,65	0,80	1,00
	Crops																							
16	pure crop land	forest		0,05	0,15	0,35	0,60	0,80	0,90	1,00	0,00	0,00	0,00	0,10	0,15	0,20	0,40	0,15	0,50	0,65	0,80	0,90	1,00	1,00
17	pure crop land	trees		0,10	0,20	0,40	0,60	0,80	0,90	1,00	0,00	0,00	0,00	0,05	0,10	0,15	0,30	0,15	0,50	0,65	0,80	0,90	1,00	1,00
18	pure crop land	agriculture		0,20	0,30	0,50	0,70	0,90	0,95	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,50	0,70	0,90	0,95	1,00	1,00
19	pure crop land	herbacous		0,10	0,20	0,40	0,60	0,80	0,90	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,50	0,70	0,90	0,95	1,00	1,00
20	pure crop land	bare, sparsely or undefined		0,10	0,20	0,40	0,60	0,80	0,90	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,50	0,70	0,90	0,95	1,00	1,00
	Mosaic with crop and trees																							
21	crop and trees	forest		0,00	0,10	0,20	0,30	0,40	0,50	0,70	0,10	0,15	0,20	0,25	0,40	0,50	0,75	0,05	0,15	0,25	0,40	0,50	0,60	0,85
22	crop and trees	trees		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,05	0,10	0,15	0,20	0,35	0,45	0,70	0,05	0,15	0,25	0,40	0,50	0,60	0,85
23	crop and trees	agriculture		0,05	0,15	0,30	0,50	0,60	0,70	0,85	0,05	0,10	0,15	0,20	0,30	0,40	0,60	0,05	0,20	0,35	0,50	0,60	0,75	0,95
24	crop and trees	herbacous		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,00	0,05	0,10	0,15	0,25	0,40	0,60	0,05	0,20	0,35	0,50	0,60	0,75	0,95
25	crop and trees	bare, sparsely or undefined		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,00	0,05	0,10	0,15	0,25	0,40	0,60	0,05	0,20	0,35	0,50	0,60	0,75	0,95
	Mosaic with crop and others																							
26	crop and woddy shrubs	forest	forest	0,00	0,10	0,20	0,30	0,40	0,50	0,70	0,00	0,00	0,05	0,10	0,25	0,35	0,50	0,05	0,15	0,30	0,40	0,50	0,65	0,90
27	crop and woddy shrubs	trees		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,00	0,00	0,00	0,05	0,10	0,15	0,25	0,05	0,15	0,30	0,40	0,50	0,65	0,90
28	crop and woddy shrubs	agriculture		0,05	0,15	0,30	0,50	0,60	0,70	0,85	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,20	0,35	0,50	0,60	0,75	0,95
29	crop and woddy shrubs	herbacous		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,20	0,35	0,50	0,60	0,75	0,95
30	crop and woddy shrubs	bare, sparsely or undefined		0,00	0,15	0,25	0,40	0,50	0,60	0,80	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,20	0,35	0,50	0,60	0,75	0,95
	Wetlands																							
31	wetland (trees)		forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
32	wetland (trees)		no forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
33	wetland (shrub/herbacous)			0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,50
34	mangroves			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Non vegetated areas																							
35	bare,snow and ice			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
36	artificial surfaces			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
37	water			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Areas with no population[e]																							
38	Trees			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,80	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
39	Shrubs			0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,35
40	Herbaceous 3			0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25	0,50	0,75
41	Herbaceous 4			0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25	0,50	0,75
	Irrigated Areas[f]																							
42	Irrigated Areas			1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

a GLC2000 was used as the prime database, the IFPRI, FRA 2000 and Irrigation layer spatial land cover datasets were integrated into a combined new data layer of 42 land cover classes at 30 arc-seconds resolution

b Regional classification for South America of the global land cover characteristics database for the year 2000 (GLC2000) based on SPOT satellite data

c The International Food Policy Research Institute (IFPRI) global land cover categorization derived from a reinterpretation of the Global Land Cover Characterization Database (GLCCD) ver. 2.0

d The geographical layer of the FAO Forest Resource Assessment 2000 (FRA 2000)

e A population layer at 30 arc-second for the year 2000 developed at FAO and based on the Landscan global population distribution data were used to idenitify classes with no population with respective weights.

f Irrigation Layer

g The adjustment of the individual land cover shares in the iterative procedure is controlled by a parameter file, which specifies three levels of increasingly wider intervals within which the weights are adjusted

2.2 Allocation of residual-I, II and III land

The spatial inventory of residual land was further categorized according to its legal protection status, biodiversity value, and whether it belongs to the territory of the Amazon biome. Applying these criteria led to three increasingly restrictive definitions of residual land, which we termed respectively *residual-I, II and III land*, as explained below and shown in Table II-4.

Types	**Description**	**Spatial allocation**
Residual-I land	is defined as the remaining fraction of land, so as to avoid direct competition of plantations with existing food and livestock feed production, grazing of ruminant livestock as well as of direct contribution to deforestation.	The land shares in each pixel, which are not forests and not reported in the last agricultural census as being used for crops or pasture, not built-up land required for housing and infrastructure, not barren or sparsely vegetated and not inland water bodies.
Residual-II land	is defined as remaining fraction of *residual-I* land safeguarding legally protected areas and areas with high biodiversity value.	*Residual-II* land was obtained from *Residual-I land*, when excluding grid-cells with legally protected areas derived from the WDPA (UNEP 2010) database and grid-cells classified by a layer from PROBIO (MMA 2004) as high biodiversity value.
Residual-III land	is defined as remaining fraction of *residual-II* land that is outside the Amazon biome.	*Residual-II land* was obtained , excluding grid-cells occurring in the Amazonas biome derived from the IBGE layer for Brazilian biomes (MMA-IBGE 2011).

Table II - 4 Definition of residual land applied in this study

A legally protected areas layer at 30 arc second grid-cell resolution was derived from the protected areas layer of the GAEZ-v3.0 (FAO-IIASA 2012), which is based on the World Database of Protected Areas (WDPA) (UNEP 2010). In addition, high biodiversity areas have been considered according to a GIS layer from PROBIO (MMA 2004). All grid-cells delineated as protected or of high biodiversity value were excluded from *residual-I land* and aggregated to *residual-II land*. The Amazon biome was derived from a biome layer of the Brazilian Ministry of Environment (MMA) and the Brazilian Institute of Geography and Statistics (IBGE) (MMA-IBGE 2011) and converted to 30 arc second grid-cell resolution. *Residual-III land* is defined as *residual-II land* not located in the Amazon biome.

2.3 Assessment of land quality

The FAO/IIASA Global Agro-ecological Zoning modelling framework (GAEZ) (FAO-IIASA 2012) was applied for the assessment of crop suitability and productivity for *residual-III land* and biomass productivity of pasture land. For assessing quality of the *residual-III land*, potential productivity of ten major crops was estimated, namely for: maize, wheat, sorghum, cassava, beans, soybeans, oil palm, sugarcane, coffee and cotton. In 2008 these crops amounted for 89% of Brazil's total harvested area (Table II-5).

The *residual-III land* quality assessment included the following steps:

1) The GAEZ modelling framework was used to quantify for each of the ten major crops brazil-wide the suitability and agronomical attainable yields for rain-fed crop production potentials assuming a high level inputs management regime (i.e. market oriented production, use of available highest-yield cultivars, fully mechanized, adequate application of nutrients and pest, disease and weed control)
2) Combining production potential and suitability results of ten crops on the basis of maximum output value in a grid-cell into in one so-called umbrella crop.
3) Quantification of land productivity within *residual-III land* by means of the agricultural quality for the umbrella crop. Aggregating of 30 arc second grid-cell resolution cell results to micro-region and state level.

Nr	**Name**	**Harvested Area [b] 1000 ha**	**Production 1000 ton**	**Share of harvested Areas %**
	Grain crops			
1	Maize	14,444	58,933	22
2	Wheat	2,364	6,027	4
3	Sorghum	831	2,004	1
	Root crops			
4	Cassava	1,889	26,703	3
	Pulses			
5	Beans [a]	3,826	3,486	6
	Oil crops			
6	Soybeans	21,057	59,242	32
7	Oil palm	66	660	0
	Sugar crops			
8	Sugarcane	8,140	645,300	12
	Cash crops			
9	Coffee	2,222	2,796	3
10	Cotton	1,064	3,983	2
	10 Major Crop Total	55,903	809,134	86
	Brazil Total	65,366	881,026	100

a Pulses in FAOSTAT include: Dry beans, Dry broad beans, Dry peas, Chick-peas, Cow peas, Pigeon peas, Lentils, Bambara beans, other pulses
b FAOSTAT Data of the year 2008 (FAO 2011)

Table II - 5 Share of harvested area and production of ten major crops

GAEZ Methodology

The GAEZ procedures calculate grid-cell productivity and suitability for individual crops and grasses. The GAEZ modelling framework and database include the following basic elements:

- Land Utilization Types (LUT) database of agricultural productions system describing crop-specific environmental requirements and adaptability characteristics, including input level and management conditions.
- GAEZ land resource data base which is composed of:
  i. Results of a detailed agro-climatic analysis of geo-referenced climate data from Climate Research Unit (CRU) of East Anglia University (Mitchel et al. 2005, New et al. 2002) and the VASCLimO global precipitation data from the Global Precipitation Climatology Centre (GPCC) (Beck et al. 2004),
  ii. Soil data available from the Harmonized World Soil Database (HWSD) (FAO et al. 2012) and
  iii. Terrain slope and aspect data derived from high resolution elevation data available from the Shuttle Radar Topography Mission (SRTM) (CGIAR-CSI 2008).
- Mathematical procedure for matching crop LUT requirements with GAEZ land resources data and estimating potential biomass and yields by grid-cells with a resolution of 30 arc second grid-cell resolution

- Mapping and aggregation of grid-cell results providing average yields per administrative unit as well as distributions of land by suitability in terms of six suitability classes:

VS or very suitable (80–100% of maximum achievable yield in Brazil);

S or suitable (60–80%);

MS or moderately suitable (40–60%);

mS or marginally suitable (20–40%);

VmS or very marginally suitable (5-20%), and

NS or not suitable (less than 5%)

Characterizing aggregate land productivity for an umbrella crop

Nr	Name	Produce	Unit	Price (GK$[a]/t)[b]
	Grain crops			
1	Maize	grain	tons	125
2	Wheat	grain	tons	155
3	Sorghum	grain	tons	130
	Root crops			
4	Cassava	root	tons	75
	Pulses			
5	Beans[c]	grain	tons	235 - 500
	Oil crops			
6	Soybeans	grain	tons	250
7	Oil palm	fruits	tons	75
	Sugar crops			
8	Sugarcane	stalk	tons	20
	Cash crops			
9	Coffee	beans	tons	1,000
10	Cotton	seed, lint	tons	525 , 1430

a Geary-Khamis dollar (GK$): International price weights compiled by the FAO for aggregation of physical quantities of production and trade, i.e., the original units of production (in tonnes) were converted to an equivalent amount in GK$ (Bruinsma 2003)
b GK$ refers to harvested weights from the year 2000, achieved at FAOSTAT (FAO 2011)
c Pulses in FAOSTAT include: Dry beans, Dry broad beans, Dry peas, Chick-peas, Cow peas, Pigeon peas, Lentils, Bambara beans, other pulses (FAO 2011)

Table II - 6 Geary –Khamis dollars (GK$) a for different crops

Production potential and suitability for the ten major crops were aggregated to an umbrella crop for describing aggregate quality of *residual-III land*. International price weights of the year 2000 were used (Geary–Khamis prices compiled by FAO (Bruinsma 2003)) for aggregation of physical quantities of different crops. Original units (t/ha) were converted to an equivalent value by applying an international price weight, the Geary–Khamis dollars (GK$). Table II-6 highlights GK$ values per hectare for the ten crops. For constructing the umbrella crop, a choice was made in each grid-cell by comparing crops in terms of output value and a suitability index (SI) defined as follows:

SI = (0.9*VS+0.7*S+0.5*MS+0.3*mS+0.1*VmS)

Then the crop with the highest SI was chosen to represent grid-cells output characteristics. The crop with highest output volume was selected.

For estimating the agricultural quality of *residual-III land* a computational procedure was applied to match a grid-cell’s suitability class with the respective land cover shares of the land balance results. It is assumed that the most suitable part of a grid-cell will be assigned in the following sequence land cover classes present in a grid-cell: 1) cropland and built-up land; 2) pasture land in use for livestock grazing, 3) forest land, 4) residual land, 5) barren and sparsely vegetated land.

In practice it means that the better land will be first allocated to cultivated cropland and built-up land, when any of this better land is left then this is than allocated in sequence first to pasture land then to forest etc. (Box II-2). Potential suitability and productivity of residual land has in this way been estimated and refers to farming with appropriate management, adequate fertilization etc. and full mechanization.

3 Results and discussion

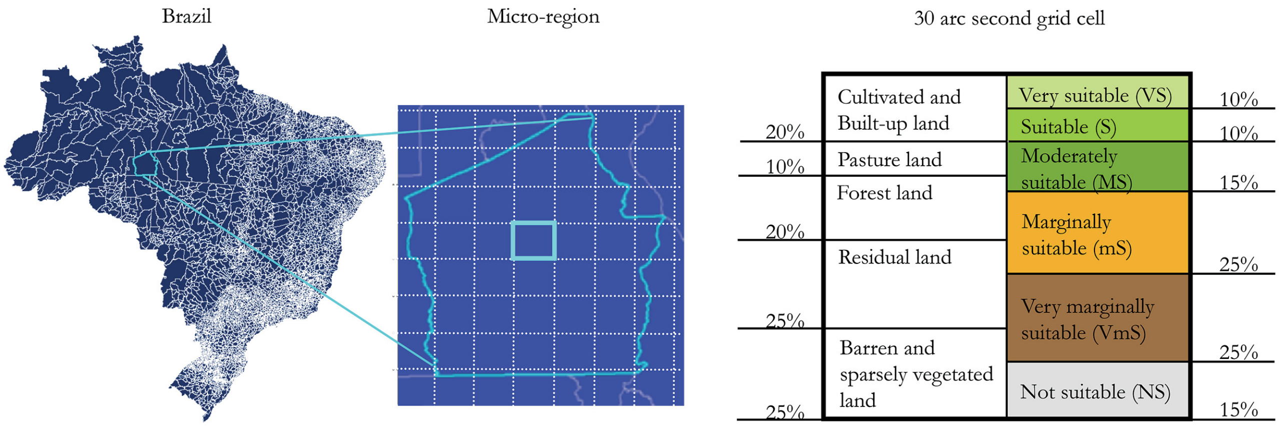
3.1 Land balance and extents of residual land

A land resources database for Brazil has been created for 30 arc second (about 1 km²) grid-cell resolution comprising of land intensities of seven major land cover categories. Figure II-2 presents a comprehensive map showing selected shares of all seven land cover categories. The category 'mixed land use' represents grid-cells where none of the seven land cover categories is above 50%.

Forest is dominating in the North and North-East of Brazil while cropland and pasture are mainly located in the South and South-East of the country. In the Central-East heterogeneous landscapes include forest, cropland, and pastures with no specific land cover class dominating. Some residual land is found across Brazil. However, a concentration of residual land occurs in the South-East, North-East and Central-East. A very noticeable area of residual land, i.e. non-forest land not recorded as being in agricultural use, exists in the state of Roramia, in the northern Amazon biome (Figure II-2). A primary objective of this study was to determine residual land extents, which have further been characterized by protection status, value for biodiversity and its location in the Amazon biome.

Table II-7 summarizes Brazil's major land categories and the three types of residual land (see Table II-3) aggregated by state based on the 30 arc second (about 1 km²) grid-cell resolution land balance data. Figure II-3 maps distribution and intensity of residual land. Figure II-4 highlights whether or not residual land is located in legally protected areas (UNEP 2010) and areas classified as high biodiversity value (MMA 2004). In addition the map delineates the Amazon biome.

Brazil comprises of 26 states grouped in five main regions (Figure II-1) and has a total land area of 852 Mha, of



Box II - 2 Example for suitability allocation for residual land which 528 Mha is forest. Agricultural area includes 61 Mha cropland and 157 Mha pasture. *Residual-I land* accounts up to 85 Mha almost 10% of the country. About half of *residual-I land* is found in areas either protected or classified as having a high biodiversity value. The remaining *residual-II* land outside protected and biodiverse areas amounts to 41 Mha. About 10% of this land is located in the Amazon biome, which is in this study subtracted with the intention of safeguarding tropical rainforests. Finally, *residual-III land*, i.e. residual land outside the Amazon, not protected and not biodiverse, amounts to 37 Mha (4.4% of Brazil) and is considered to be potentially available for biofuel production. Almost half of *residual-III land* occurs in the South-East where it occupies nearly 19% of land. Further *residual-III land* is found in the North-East with 8 Mha (5% of land), Central-East with 7 Mha (4% of land), South with 3 Mha (5% of land) and North with 2.5 Mha (1% of land). At state level highest occurrences of *residual-III land* are found in Minas Gerais with 12.5 Mha (21 % of state), Bahia with 4.2 Mha (7% of state), Goiás with 3.4 Mha (10% of state), São Paulo with 3.3 Mha (13% of state) followed by Tocantis with 2.5 Mha (9% of state).

3.2 Quality of residual land

The crop suitability and productivity assessments for *residual-III land* based on the GAEZ (FAO-IIASA 2012) modeling framework suggests that for Brazil as a whole about 28% of the *residual-III land* (10.6 Mha) is very suitable (VS) or suitable (S) prime agricultural land. Some 41% is moderately suitable (MS), marginal suitable (mS) or very marginally suitable (VmS) for rain-fed crop production. The remaining 31% are not suitable (NS) for any of the ten crops making up the umbrella crop group (Table II-8). Figure II-5 highlights the spatial distribution of the quality of *residual-III land* by showing both *residual-III land* shares and suitability of individual grid-cells. In Minas Gerais, the state with the largest extents of *residual-III land*, 22% of this land is assessed as very suitable (VS) and suitable (S) for crop production with a maximum attainable output value of 3397 GK$/ha. About 33% is moderately suitable (MS), marginal suitable (mS) or very marginal suitable (VmS). The remaining 45% is not suitable. In the states with highest occurrences of *residual-III land*, 44% of the *residual-III land* are of the category VS and S in Bahia, 28% in Goiás and 47% in São Paulo. The best *residual-III land* is found in the region Central-East where 32% of the 6,756 ha *residual-III land* are of the category VS and S with a maximum attainable output value of 3,364 GK$/ha. In this state about 53% is MS, mS or VmS and only 15% NS.

Figure II - 1 Administrative regions Brazil

in 1000 ha	Total Land Area	Crop land	Pasture	Forest	Urban area	Water	Baren areas	*Residual-I land*[a]	*Residual-II land*[b]	*Residual-III land*[c]
North	**386,233**	**4,273**	**26,417**	**327,211**	**574**	**6,166**	**248**	**21,342**	**5,660**	**2,550**
Rondônia	23,893	495	4,810	17,758	65	76	8	681	362	-
Acre	16,512	164	1,039	15,240	27	-	-	43	39	-
Amazonas	156,935	743	928	149,242	122	3,443	141	2,315	388	-
Roraima	22,574	103	731	17,378	21	69	1	4,270	167	-
Pará	124,289	1,945	10,713	103,350	243	2,269	91	5,677	1,880	-
Amapá	14,099	62	267	12,691	19	57	7	997	49	-
Tocantins	27,931	761	7,929	11,552	77	252	-	7,359	2,775	2,550
North-East	**155,815**	**15,199**	**30,472**	**84,000**	**1,630**	**1,922**	**4,005**	**18,587**	**8,479**	**8,074**
Maranhão	32,977	2,430	5,720	18,837	231	725	211	4,823	2,284	1,879
Piauí	25,318	1,361	2,683	17,497	135	105	156	3,380	1,138	1,138
Ceará	14,984	1,918	2,611	9,434	238	71	418	293	176	176
Rio Grande do Norte	5,311	676	1,203	2,376	95	74	657	230	128	128
Paraíba	5,682	660	1,681	2,531	110	30	435	236	173	173
Pernambuco	9,872	1,697	1,976	4,692	209	91	735	472	236	236
Alagoas	2,791	904	872	631	77	78	180	49	27	27
Sergipe	2,197	318	943	566	54	75	141	101	46	46
Bahia	56,683	5,235	12,783	27,436	481	673	1,072	9,003	4,271	4,271
South-East	**92,837**	**13,302**	**27,363**	**22,735**	**1,637**	**1,052**	**37**	**26,713**	**17,425**	**17,425**
Minas Gerais	58,931	5,495	17,739	14,942	651	473	2	19,629	12,547	12,547
Espírito Santo	4,623	750	1,342	1,184	89	10	-	1,248	794	794
Rio de Janeiro	4,374	367	1,265	1,055	236	27	16	1,410	779	779
São Paulo	24,909	6,690	7,017	5,554	661	542	19	4,426	3,305	3,305
South	**56,351**	**15,004**	**15,693**	**19,552**	**723**	**616**	**66**	**4,696**	**2,994**	**2,994**
Paraná	19,932	6,430	4,741	6,533	278	242	16	1,692	1,306	1,306
Santa Catarina	9,523	1,717	1,701	5,011	141	12	17	924	576	576
Rio Grande do Sul	26,896	6,857	9,251	8,008	304	362	33	2,080	1,112	1,112
Central-East	**161,479**	**13,604**	**57,124**	**74,643**	**522**	**1,309**	**10**	**14,269**	**7,283**	**6,756**
Mato Grosso do Sul	35,859	2,864	20,263	9,797	112	474	4	2,347	1,427	1,427
Mato Grosso	90,853	6,505	21,603	56,903	150	626	2	5,064	2,362	1,835
Goiás	34,185	4,138	15,178	7,804	221	203	4	6,637	3,482	3,482
Distrito Federal	582	97	80	139	39	6	-	221	12	12
Total Brazil	**852,715**	**61,382**	**157,069**	**528,141**	**5,086**	**11,065**	**4,366**	**85,607**	**41,841**	**37,799**

a *Residual-I land*: is defined as the remaining fraction of land, so as to avoid direct competition of plantations with existing food and livestock feed production, grazing of ruminant livestock as well as of direct contribution to deforestation

b *Residual-II land*: is defined as remaining fraction of *residual-I land* safeguarding legally protected areas and areas with high biodiversity value

c *Residual-III land*:is defined as remaining fraction of *residual-II land* that is outside the Amazon biome

Table II - 7 Major land use and residual land categories at state level calculated from Brazilian land resources database (30 arc second grid-cell resolution)

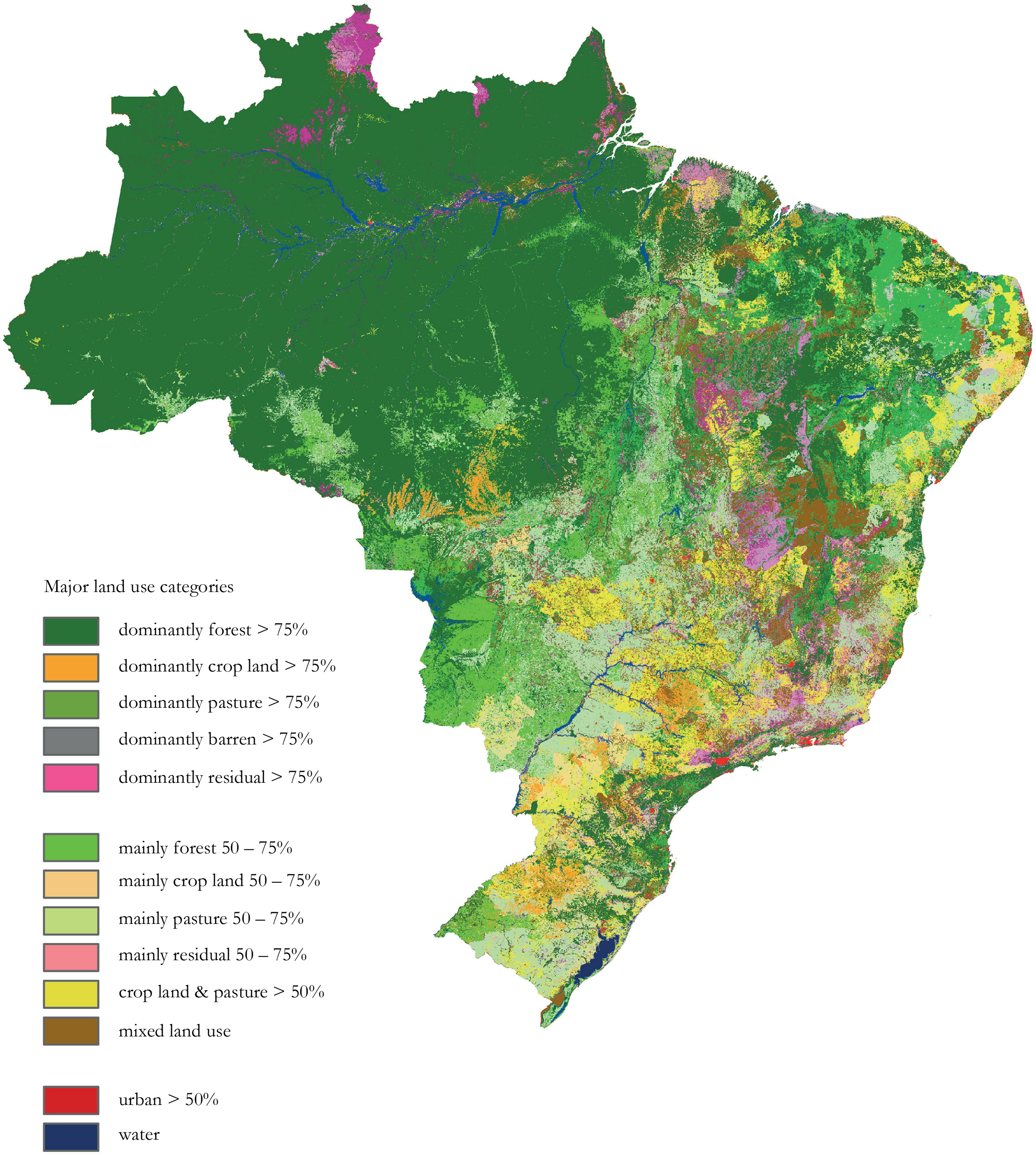


Figure II - 2 Brazilian land resources database with land intensities (30 arc second grid-cell resolution)

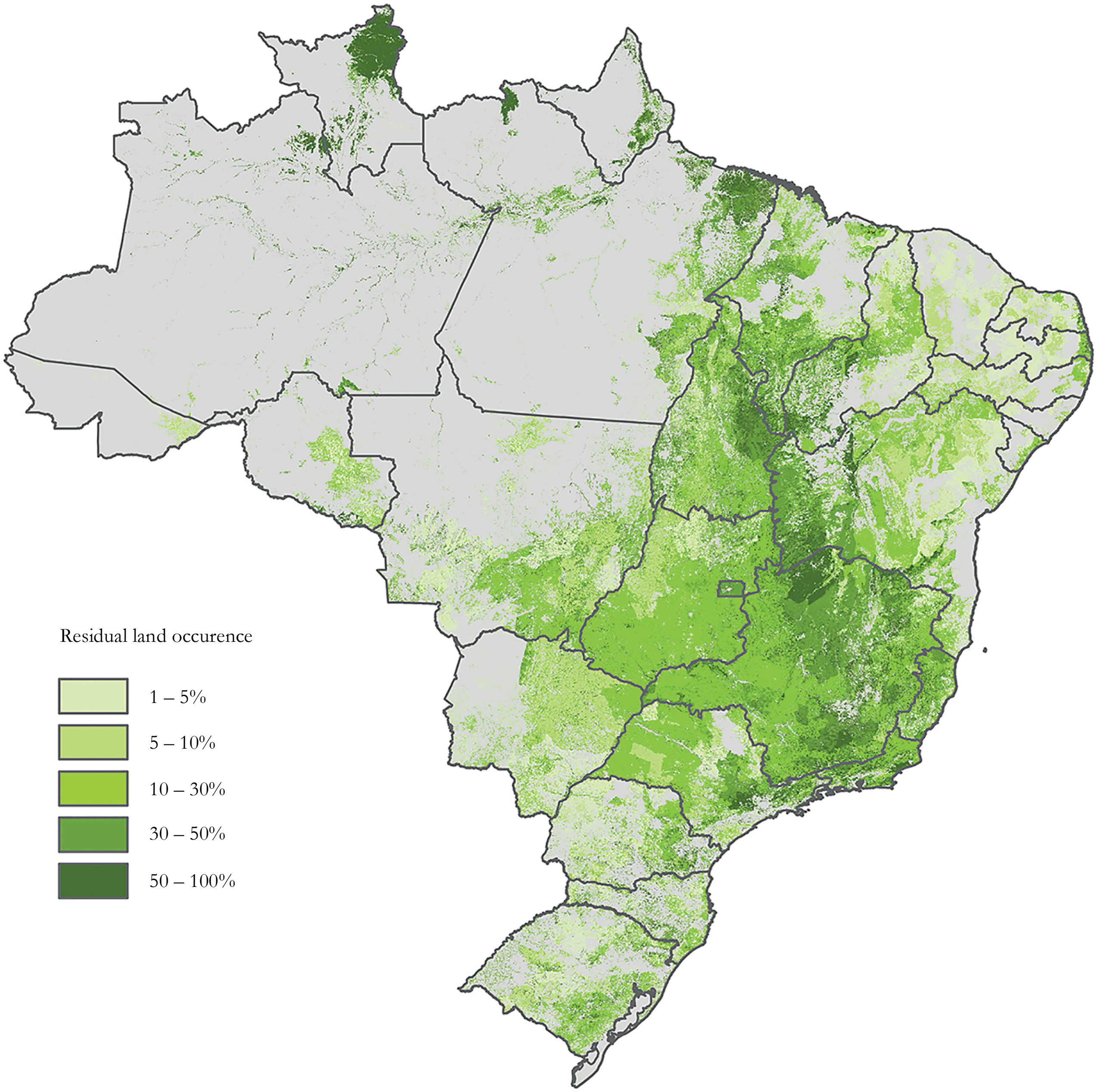


Figure II - 3 Distribution and intensity of residual land (30 arc second grid-cell resolution)

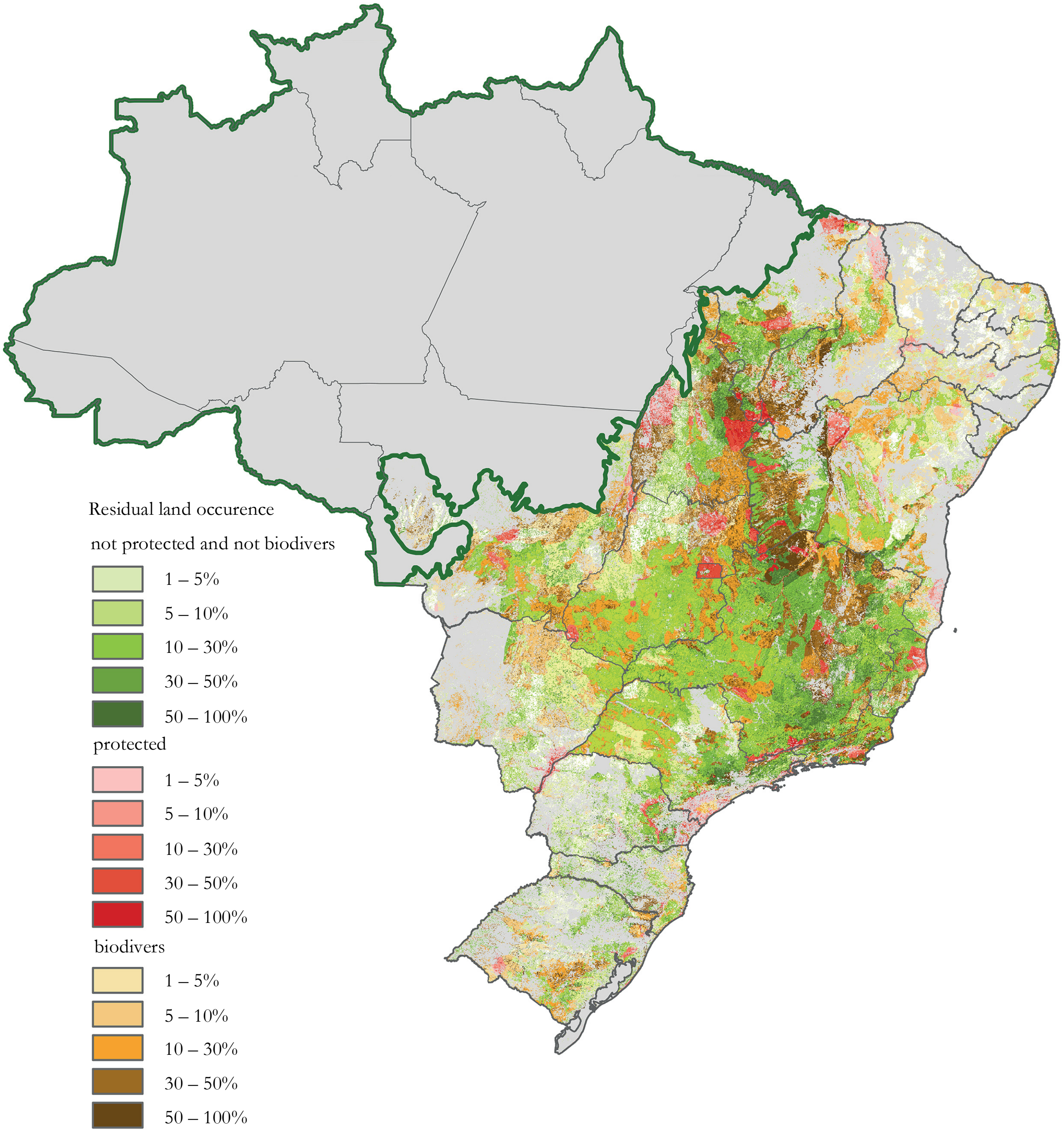


Figure II - 4 Distribution and intensity of residual land and its occurrence on protected or biodiverse areas (30 arc second grid-cell resolution)

high level inputs/ advanced management[e]	***Residual-III land***[a] **(1000 ha)**	**Suitability profiles for *residual-III land***[b] **(1000 ha)**						**Potential Yields for umbrella crop**[c] **(GK$/ha)**[d]					
		VS	**S**	**MS**	**ms**	**vmS**	**NS**	**Ymax**[e]	**S**	**MS**	**ms**	**vmS**	**NS**
North	**2,550**	**32**	**476**	**247**	**41**	**1,473**	**280**		**2,086**	**2,224**	**1,591**	**1,002**	**89**
Rondônia	-	-	-	-	-	-	-	-	-	-	-	-	-
Acre	-	-	-	-	-	-	-	-	-	-	-	-	-
Amazonas	-	-	-	-	-	-	-	-	-	-	-	-	-
Roraima	-	-	-	-	-	-	-	-	-	-	-	-	-
Pará	-	-	-	-	-	-	-	-	-	-	-	-	-
Amapá	-	-	-	-	-	-	-	-	-	-	-	-	-
Tocantins	2,550	32	476	247	41	1,473	280	2,719	2,086	2,224	1591	1,002	58
North-East	**8,074**	**824**	**1,611**	**2,293**	**340**	**1,192**	**1,813**		**17,408**	**15,025**	**11,253**	**6,618**	**1,117**
Maranhão	1,879	2	220	560	109	434	554	2,798	2,117	1,969	1430	1,122	37
Piauí	1,138	8	97	336	85	145	467	2,211	1,254	1,068	1123	922	52
Ceará	176	15	58	37	10	32	24	1,890	1,451	1,381	1018	545	40
Rio Grande do Norte	128	1	30	39	3	40	14	2,185	1,489	1,307	1378	629	83
Paraíba	173	21	59	20	18	24	32	3,208	2,801	2,154	1450	610	213
Pernambuco	236	8	24	67	20	34	83	3,213	2,587	1,776	948	484	243
Alagoas	27	4	1	1	1	10	10	2,689	2,116	1,957	1334	807	214
Sergipe	46	-	9	11	8	10	8	2,487	1,828	1,940	1310	749	111
Bahia	4,271	765	1,113	1,222	86	463	621	3,232	1,765	1,473	1262	750	124
South-East	**17,425**	**1,427**	**3,135**	**3,936**	**772**	**737**	**7,417**		**8,485**	**6,945**	**5,184**	**3,247**	**1,214**
Minas Gerais	12,547	1,030	1,708	2,739	631	714	5,724	3,397	2,132	1,604	1335	682	126
Espírito Santo	794	60	113	62	9	5	545	2,389	2,125	1,946	1246	932	513
Rio de Janeiro	779	67	30	144	17	6	515	2,945	2,128	1,626	1323	914	376
São Paulo	3,305	270	,284	991	115	12	633	2,830	2,100	1,769	1280	719	199
South	**2,994**	**383**	**534**	**764**	**127**	**111**	**1,077**		**4,674**	**4,236**	**2,826**	**1,943**	**117**
Paraná	1,306	49	289	398	56	54	461	2,470	1,743	1,376	992	704	21
Santa Catarina	576	1	56	191	38	16	274	1,969	1,544	1,524	945	675	80
Rio Grande do Sul	1,112	333	189	175	33	41	342	2,377	1,387	1,336	889	564	16
Central-East	**6,756**	**742**	**1,403**	**1,912**	**159**	**1,525**	**1,015**		**9,094**	**7,976**	**5,625**	**3,391**	**292**
Mato Grosso do Sul	1,427	340	180	875	10	1	22	2,875	2,170	1,847	1355	769	168
Mato Grosso	1,835	119	532	375	23	612	173	3,171	2,383	2,077	1587	991	35
Goiás	3,482	277	691	662	126	906	820	3,364	2,307	1,776	1498	860	61
Distrito Federal	12	6	-	-	-	6	-	3,098	2,234	2,276	1185	771	28
Total Brazil	**37,799**	**3,408**	**7,159**	**9,152**	**1,439**	**5,038**	**11,602**		**41,747**	**36,406**	**26,479**	**16,201**	**2,829**

a *Residual-III land* is defined as that land currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome, with the intention to safeguarding tropical rainforest at high risk in this area.

b Suitability classes are defined at LUT level, when the yield of a chosen LUT in a given grid-cell falls in the ranges 80%-100%, 60%-80%, 40%-60%,20%-40%,5%-20% and < 5%, the suitability class of that grid-cell is determined as respectively very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (ms), very marginally suitable (vmS) and not suitable (NS)

c Combining production potential and suitability results of ten crops on the basis of maximum output value in a grid-cell into in one so-called "umbrella crop". The suitability and yields reflect the best-performing crop of ten major crops in rain-fed Brazilian agriculture namely: maize, wheat, sorghum, cassava, beans, soybeans, oil palm, sugarcane, coffee and cotton.

d Geary-Khamis dollar (GK$) (Bruinsma 2003) : International price weights compiled by the FAO for aggregation of physical quantities of production and trade, i.e., the original units of production (in tonnes) were converted to an equivalent amount in GK$. GK$ refers to harvested weights from the year 2000, achieved at FAOSTAT (FAO 2011)

e The farming system is market oriented; commercial production is the main management objective; production is based on currently available best-yielding cultivars, is fully mechanized with low labor intensity, and provides adequate applications of nutrients and chemical pest, disease and weed control

Table II - 8 Suitability and productivity of *residual-III land* for the umbrella crop

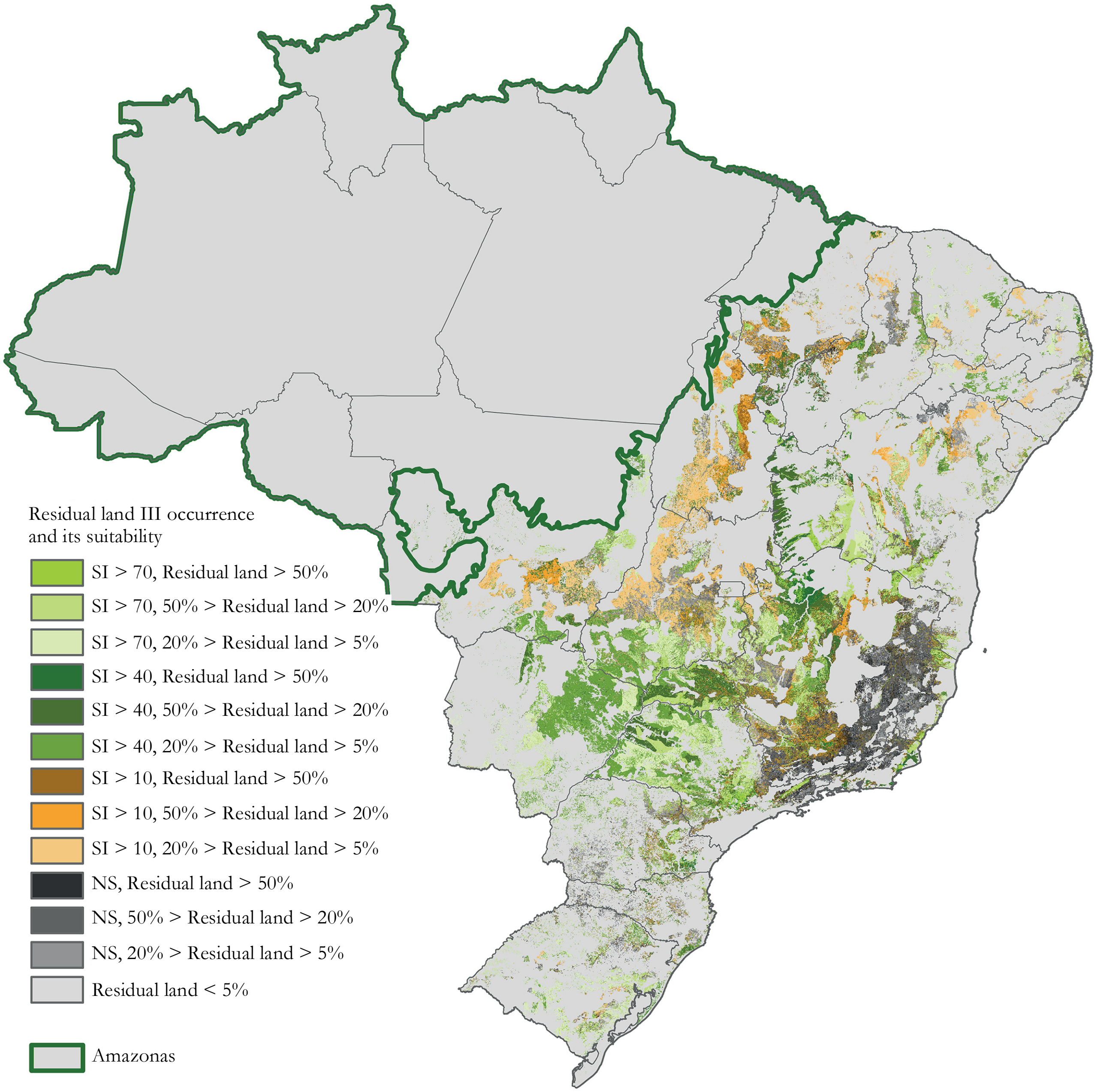


Figure II - 5 Suitability and productivity of *residual III land* for the umbrella crop (30 arc second grid-cell resolution)

3.3 Residual land for food, livestock feed or biofuel feedstock production?

The above described spatial land balance analysis calculates 87 Mha residual land, of which less than half of this area or 41 Mha are neither protected nor classified as having a high biodiversity value. Further subtracting the Amazon biome suggests 37 Mha of residual land (here termed *residual-III land*) potentially available for sustainable expansion of biofuel feedstock production. This compares with current cropland and pasture area extents of 61 Mha and 157 Mha (IBGE 2006) respectively.

Future bioenergy production potential on residual land depends on overall developments of Brazil's agricultural sector. Linkages between food security, biofuel production and environmental conservation are complex and crucially depend on future changes in production intensity (crop yields and livestock feeding efficiency), trade in agricultural products as well as land use regulations. Competition for land resources may increase prices of land and thereby affect production costs and the competitive position of biofuel feedstock production (Fischer et al. 2009).

Brazilian territorial dynamics have been characterized by the rapid expansion of cultivated land in the North-East and Central-East for soybean and cotton production and in the South-East for sugarcane and coffee cultivation (Piketty et al. 2009). Cattle ranching in the Legal Brazilian Amazon correlates significantly with deforestation (Cederberg et al. 2011, Cohn et al. 2011). These land use changes are closely related to large-scale conversion of pastures in southern Brazil to cropland (Lapola et al. 2010, Sparovek et al. 2009). Recently public policy and interventions in beef and soy supply chains have contributed to a 70% decline in deforestation in the Brazilian Amazon. Since 2009 annual deforestation rates were 0.5 to 0.6 Mha (Nepstad et al. 2014).

Results of this study highlight that 28% of *residual-III land* concentrated in the South-East (4.6 Mha), North-East (2.4 Mha) and Central-East (2.1 Mha) is very suitable or suitable for food and livestock feed crop production (Table II-8) and may thus compete with biofuel feedstock production. About half of *residual-III land* in the North-East (3.8 Mha) and in the Central-East (3.5 Mha) is of lower suitability for crop production. In these lower land quality areas pasture expansion for beef production may compete with biofuel feedstock.

The following discussion presents estimates on future cropland area requirements and livestock production and discusses implications for potential pasture demand and the availability of *residual-III land* for bioenergy feedstock production.

Future cropland area requirements

The Foresight project "Global Food and Farming Futures" includes 2010-2030 perspectives on productive capacity of Brazilian agriculture (Santana et al. 2011). It assumes a continuation of historic trends and applies a non-causal forecasting method consisting of univariante time series models and variables of global economic growth, population growth, commodity price development, productivity, and agricultural trade policies. The Ministry of Agriculture, Livestock and Supply (MAPA) used the same methodology for their study "Projections of Agribusiness Brazil 2009/10 to 2019/20" (MAPA-AGE 2009). Scenario analysis in both studies focused on agricultural production, harvested area, consumption and trade for ten dominant crops in Brazil (soybeans, sugarcane, cassava, coffee, cotton, edible beans, maize, rice, sorghum, and wheat). These crops comprised more than 90 % of the total harvested area in 2010 (FAO 2011). Scenario results of MAPA are similar to those produced by Foresight (Santana et al. 2011).

Foresight suggests that Brazil's total harvested area of the ten crops increases by more than 20% (13 Mha) from 62 Mha in 2010 to 75 Mha in 2030. Harvested area increases are due to a significant expansion of soybeans (almost 40% or. 9.3 Mha) and sugarcane (more than 40% or 3.8 Mha). Assuming that growth rates for other crops follow historic trends by 2030 the additional demand for harvested area would be about 14.2 Mha[2]. Cultivated cropland demand projections depend on the combined effect of developments in harvested area and the multiple cropping practices. Agricultural intensification in Brazil included increased double cropping, intercropping or mixed cropping and shorter fallow periods caused the MCI to increase from 89% in 1990 to 95% in 2009 (FAO 2011). Assuming for 2030 that the MCI remains at the level of 2009 suggests that additional cropland area requirements by 2030 are in the order of 15 Mha.

Livestock production and demand for pasture

The predominant livestock production system is ruminant grazing, relying on year round use of natural and sown pastures (Carvalho 2006, FAO-AGAL 2005). Cattle-rearing is continuously intensifying due to technological developments in animal health, nutrition, breed improvement, introduction of more productive fodder and meadow grasses, improved pasture and livestock management and cattle-rearing systems. In recent years a major trend has been the increasing use of feedlots for finishing cattle before slaughter. Such feeding period takes typically about 70 days. By 2010 some 3 million cattle were finish-fed in feedlots, a four-fold increase over the past two decades (FNP 2011). Another on-going intensification trend is the increase of crop based livestock feed supply, in particular in the dry season. Though, the vast majority or nearly 98% of Brazilian beef production is still based on pasture systems alone.

The Census 2006, reports a cattle herd of 172 million heads and a total utilized pasture area of 157 Mha comprising of three pasture categories, sown pastures (58%), natural pastures (36%) and degraded pastures (6%). As of 2007, the cattle herd size reported in the Census 2006 was adjusted upwards from 172 to 205 million heads in IBGE's annual publications on 'Municipal Livestock Production' (see Table 2 in (IBGE 2011b)) By the end of 2011 Brazil's cattle herd had further increased to 213 million head (IBGE 2011b).

Estimates on future land demand for raising sustainable cattle herds are based on the feasibility of increasing Brazil's stocking rates on pasture areas. Several studies suggest Brazil's sustainable stocking rates can be increased by 2030 to 1.6 (Santana et al. 2011, Sparovek et al. 2012), 1.8 (Princes' Rainforests Project) or up to 2.5 (IMS 2011a, IMS 2011b) cattle heads per hectare. This would be achieved through a combination of the following measures: (i) sowing of highly productive grasses and adopting rotational livestock grazing systems; (ii) reclamation of degraded pastures; (iii) stimulating productive systems with feedlots; (iv) supplementing with additional livestock feed concentrates in dry periods; (v) encouraging integrated crop-livestock systems.

However, accurate stocking rates are difficult to estimate due to differences in reported pasture areas. The 157 Mha pasture land reported in Census 2006 is similar with data from remote sensing analysis provided by the PROBIO project (MMA 2004) quoted with 148 Mha in 2002 (Bustamante et al. 2012). Sparovek et al. report a total pasture land extent of 211 Mha of which 158 Mha is used for beef-cattle production (Sparovek et al. 2012). The scenarios of a recent Worldbank study (de Gouvello 2010) assume 205 Mha in 2008. The Outlook Brazil 2022 (FIESP-ICONE 2012) applies in their projections pasture land extents of 182 Mha in 2011, which is assumed to decline to 176 Mha by 2022. Both studies project similar trends of slightly declining pasture extents based on the assumption that less pasture is required due to anticipated livestock productivity increases. Finally,

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[2] FAOSTAT reports for the year 2010: 65 Mha harvested area for all crops in and 59 Mha harvested area for ten dominant crops (90.7%). 13 Mha * (1+0.907) =14.2 Mha

FAOSTAT's land resource domain reports 196 Mha 'permanent pastures and meadows' for the years 2006 to 2009 (FAO 2011).

In this study the spatially explicit land balance results (i.e. using the 157 Mha pastures reported in Census 2006) together with GAEZ biomass productivity calculations are applied for estimating Brazil's rain-fed biomass production from pastures and compare it with cattle feed demand. We assume reported sown pastures occurring in the more suitable areas and apply high input and advanced management characterized by adequate fertilizer and appropriate grazing management. Pasture areas classified as natural or degraded pastures are assumed to be located in the remaining poorer areas and assessed for low input and traditional management, i.e. representing natural conditions. In this way we estimate a total livestock feed supply potential of 830 Mt consumable biomass (DM), of which three-quarters comes from sown pastures, about one-fifth from natural pastures and some 3% from degraded pastures (Table II-9).

Livestock weights in Brazil's cattle production operations ranges from 180 kg (weaned calves) to approximately 380 kg (steers and yearling bulls) (Millen et al. 2011). Daily ruminant livestock feed requirement equates to approximately 2.5% (USAID-FAO 2014) of live weight. Applying this rate to an assumed average live weight of 300 kg, then this equates to 2.74 tonnes consumable biomass (DM) per head and year. With these assumptions a total of 562 Mt consumable biomass (DM) would feed Brazil's 205 million head cattle herd, i.e. 72% of total supply when their sole feed source is grazing. On the average this means that overall, cattle stocking is within the pastures-based livestock carrying capacity bracket.

Biomass supply and demand	**Consumable biomass (Mt DM^{a})**	**Share in total biomass supply**
Supply (year 2006)		
Biomass productivity of 157 Mha pastures	830	100 %
of which from reported		
Sown pastures: 92 Mha (high input management)	625	75 %
Natural pastures: 57 Mha (low input management)	181	22 %
Degraded pastures: 9.8 Mha (low input management)	24	3 %
Current demand (year 2006)		
Cattle herd requirements (205 million heads)	562	67 %
Future demand (by 2030)		
Cattle herd requirements (248 million heads)	680	82 %
Biomass not required by cattle herd	150	18 %

a Dry Matter
Source: Census 2006 (IBGE 2006), Foresight (Santana et al. 2011) scenario and own calculations for biomass productivity based on agro-ecological zones assessment for Brazil, see text for further details

Table II - 9 Supply of consumable biomass from pasture and biomass demand from Brazils current and future cattle herd

Figure II-6 presents the regional variation of biomass supply and livestock feed demand by state. Half of the surplus biomass is available from just three states, namely Mato Grosso do Sul, Mato Grosso and Rio Grande do Sul. Other states with substantial pasture production surplus include Pará, Bahia, Minas Gerais, São Paulo, Paraná and Goiás. In three States (Rondônia, Alagoas, Pernambuco) the feed demand of current size of cattle herds is at or above pasture feed supply.

The Foresight scenarios apply to a cattle population dynamics model and estimate that in comparison to 2006 an additional 43 million cattle is needed to meet the 2030 beef demand (Santana et al. 2011). The additional 43 million cattle require 118 Mt consumable biomass (DM) if their feed source is from pasture grazing only. This represents 44% of the 268 Mt surplus biomass potential achievable from Brazil's current pastures. Projected expansion of livestock production as envisaged until 2030 is therefore feasible on current pastures when the expanding livestock herd is carefully planned with respect to local livestock carrying capacity. Pasture improvement of natural and degraded pastures could further increase livestock feed supply from pastures.

Synopsis - Residual land for biofuel feedstock production

In summary by 2030 projected cropland expansion is 15 Mha and the future cattle herd of 248 million head would require four-fifth of total consumable biomass when grazing is the major source of feed supply. Assuming no deforestation, additional cropland can only expand into excess pastures or residual land. When Brazil's cattle herd will by 2030 be primarily fed by pasture grazing leaves a 150 Mt of 'unused' pasture biomass. Cropland would likely expand into the better pasture areas with achievable yields of 6.8 t/ha (i.e. the average of sown pastures). Thus the 'unused' pasture areas amount to 22 Mha, i.e. significantly more than the projected 15 Mha cropland expansions.

This suggests that both projected cropland and cattle herd expansion is viable within the current 157 Mha pasture land ecosystems. Utilization of the 37 Mha residual land for biofuel feedstock production remains possible when pastures are carefully used for livestock and cropland expansion. However, it is important to emphasize that food and livestock feed demand higher than those projected would soon exceed Brazil's pasture production capacities. Then at least part of the residual land will be required for the food and livestock feed sector assuming that safeguarding forest ecosystems is a prime objective.

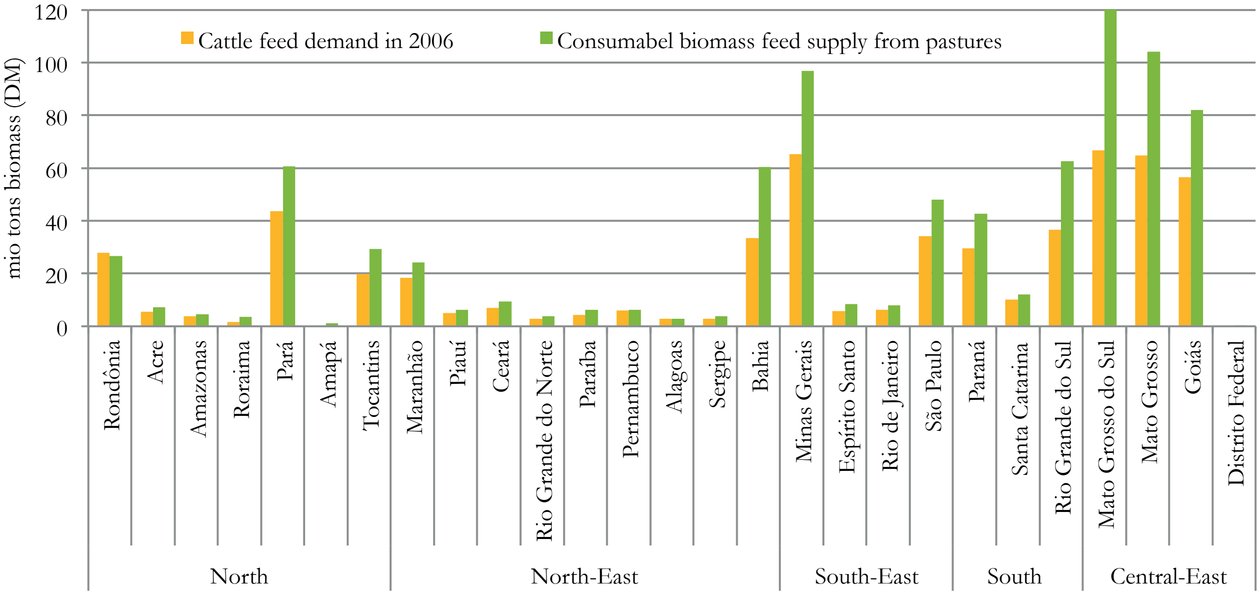

Figure II - 6 Cattle feed demand and supply for Brazil's cattle herd in 2006 by regions

3.4 Environmental conservation concerns

Pastures

It should be noted that the above discussed pasture-fed livestock expansion may be restricted by protection status, occurrence of high biodiversity as well as natural forest regeneration in the Amazon biome. Half of Brazil's pasture is neither protected nor of importance for biodiversity. The other half is occurring in the Amazon biome (12%), designated for both nature protection and importance for biodiversity (11%) or designated for either of the last two (28%). Figure II-7 highlights the designation status of Brazil's pastures by state. In states where biomass supply exceeds current cattle feed demand significant amounts of pastures are designated as protected or of high value for biodiversity. This suggests that sustainable expansion of agricultural production in Brazil must integrate environmental conservation concerns by following well defined agro-diverse sustainable production management systems.

Residual land

From the 85 million ha of *residual-I land* found in this study some 6.6 Mha are located in protected areas and 37.1 Mha in areas classified as having a high biodiversity value. Biodiversity provides and maintains ecosystem services essential to agriculture, including regulation of pests and diseases, nutrient cycling, sequestration and conversion, maintenance of soil fertility and biota by regulating soil organic matter and soil water retention and pollination by bees and other wildlife (OFID-IIASA 2009). Numerous studies indicate that lower plant diversity may lead to increased loss of nutrients from the soil through leaching, and affects ecosystem's productivity in case of pronounced climate variability, in particularly, through recurrent dry-spells and droughts, but also to higher susceptibility to diseases and pests (Tilman 2000).

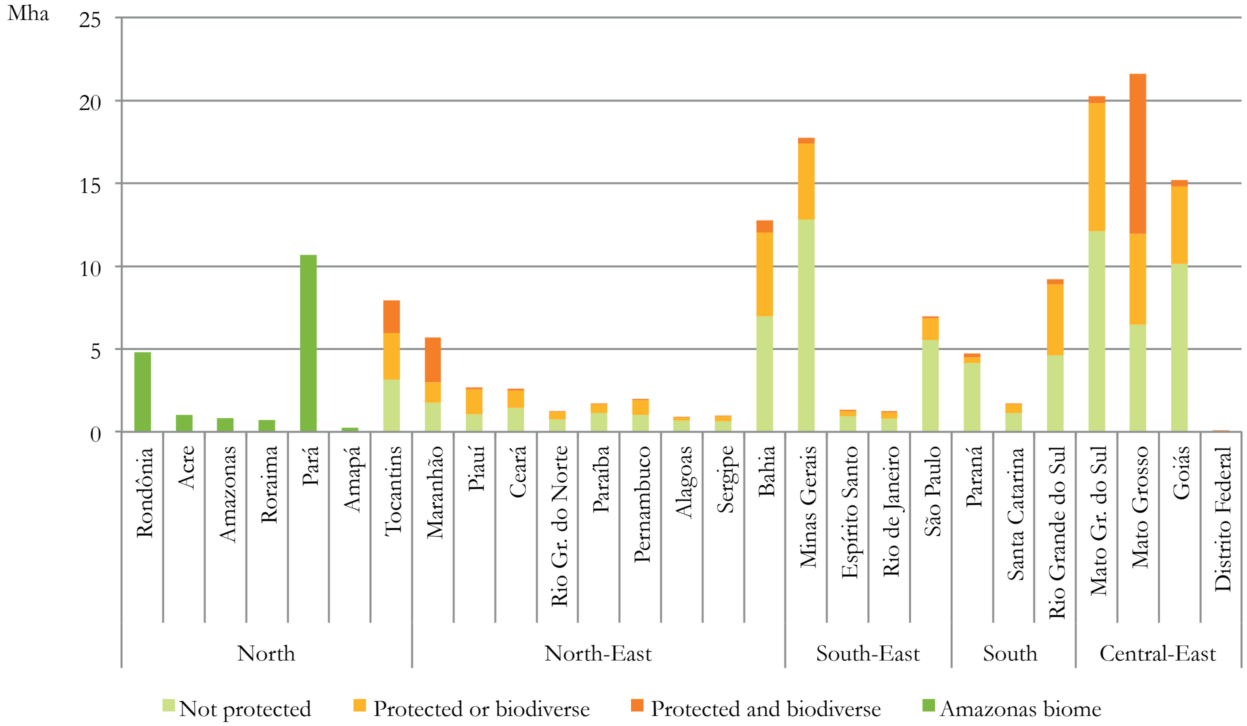

Figure II - 7 Brazil's pastures by protection and importance for biodiversity

When residual land would be used for biofuel feedstock production increasing biofuel production presents both opportunity and challenges from an environmental perspective. The diversity of potential biofuel feedstocks may create an opportunity for large-scale conversion of monoculture production systems (IATP 2008) to diversified agricultural cropping systems generating more environmental benefits from agricultural land, while keeping farmers on the land. Non-traditional feedstocks (cassava, jatropha, miscanthus) are particularly suited for low input production systems. On the other hand current trends in the biofuel industry with conventional biofuel feedstocks grown on large scale monocultures with high levels of fertilizer applications and biocides usage to control weeds or combat pest and diseases may strongly reduce local and regional biodiversity.

4 Scope and limitations of the study

Results need to be considered in the context of the following scope and limitations of the study:

- One of the challenges has been to deal with existing land cover datasets and its lack of consistency on the location and type of current land use. By comparing results of remote sensing products interpretations with Census data, weaknesses and strengths of individual products became apparent and had to be dealt with by using appropriate algorithms developed for this very purpose at IIASA.

- A 30 arc second grid-cell resolution (about 1 km^2) was chosen reflecting the grid-cell size of the remote sensing products. Although 1 km^2 can be considered as a high resolution for a large country such as Brazil, the majority of agriculture fields and parcels are much smaller. Especially cultivated land occurs in heterogeneous land cover associations. Another issue refers to the difficulty to distinguish between cultivated land, pasture land, shrub land, woodland and plantations in remote sensing interpretations (You et al. 2008).

- While the Census 2006 provide the most recent and complete agricultural statistics of Brazil it should be noted that the Census is based on an enumeration at the level of the agricultural holding, i.e., the economic unit dedicated to agricultural production under single management, regardless area size, title, legal form, production purposes or value. The Census data do not account for the remaining non-agricultural part of a micro-region (IBGE 2006).

5 Conclusions

A new land resources database for Brazil has been created for a 30 arc second grid-cell resolution comprising of land intensities of major land cover categories being consistent with year 2006 census agricultural statistics at micro-regions and FRA 2010 forest areas at biome. Spatial allocation ('downscaling') algorithms were applied to obtain spatial distributions of land use categories including a remaining unused share in each grid-cell, termed 'residual land' areas.

Residual-III land, not located in the Amazon or in protected areas or in areas of high biodiversity value, is earmarked for potential biofuel feedstock production. A total of 37 Mha of *residual-III land* (4.4% of Brazil) were found throughout the country. This equates to 60% of Brazil's current cropland and underlines the results of various studies that there is surplus land available in Brazil. Almost half of *residual-III land* occurs in the South-East where it occupies almost 20% of land. Other regions with *residual-III land* include the North-East (8 Mha), Central-East (7 Mha) and South (3 Mha). One third of *residual-III land* is found in one state, Minas Gerais

(12.5 Mha). Land productivity of residual land varies. About 28% of the *residual-III land* is prime agricultural land, 41% is moderate to marginally suitable while the remaining 31% is not suitable for crop production.

Although the current use of residual land is unknown, we assessed competition between food, livestock feed and bioenergy feedstock production. Agricultural demand projections combined with detailed pasture productivity calculations suggest that until 2030 current pasture land areas would be sufficient for both providing feed for Brazil's increasing cattle herd and land areas for expanding croplands. In this case the 37 Mha residual land could be used for biofuel feedstock production.

The analysis emphasizes that increasing stocking density on pastures is to be planned carefully. It is important to highlight that some states are already close to their pasture livestock carrying capacity and would need to rely on additional livestock feed sources such as fodder crops (from cultivated land), crop residues and by-products.

The prevalence and overall quality of residual land across Brazil provide a basis for assessing agronomic potential for specific biofuel feedstocks in different regions. Depending on type of feedstock, land quality and conversion technology, substantial quantities of biofuel feedstocks could be produced on *residual-III land*. However, not all land with identified technical potential of residual land qualifies equally for the practical implementation of biofuel feedstock plantations. Hence, in addition to the quality and suitability of residual land also location-specific investment requirement and transport cost as well as future demand for food, livestock feed and pasture land will play an important role in the discussion of residual land potentials for biofuel feedstocks.

Food and livestock feed demand higher than those projected for 2030 would exceed Brazil's pasture production capacities, then at least part of the residual land will be required for the food and livestock feed sector assuming that safeguarding forest ecosystems is a prime objective.

Further research

The focus of a follow-up research is the assessment of production potentials of key biofuel feedstocks on *residual-III land*. Established feedstocks, in particular sugarcane and soybean, are compared with alternative biofuel feedstocks such as cassava, jatropha and miscanthus.

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Chapter III

Biofuels from Residual Land in Brazil: Agro-ecological assessment for Sugarcane, Cassava, Miscanthus, Soybean and Jatropha[3]

Abstract

A spatially detailed assessment of available residual land in Brazil finds 37 Mha of residual land, of which Legal Amazonia, highly biodiverse ecosystems and protected areas are excluded. This residual land equates to 4.4 % of Brazil's geographical area and compares to about 50% of Brazil's current land used for crop cultivation.

This residual land has been assessed for potential biofuel feedstock cultivation. Potential productivity is expressed in (t/ha) and biofuel equivalents (l/t). Potential performance of the established feedstocks, sugarcane and soybean, has been compared with alternative biofuel feedstocks i.e., cassava, jatropha and miscanthus. Almost three-quarters of residual land is found, to some degree, suitable for biofuel feedstock production. Most productive on residual land is miscanthus (62 billion litres of bioethanol), followed sugarcane and cassava with respectively 34 billion litres and 31 billion litres bioethanol. Production potentials of the same residual land for biodiesel production vary between 18 billion litres for jatropha and 7 billion litres for soybeans. Energy potentials of residual land ranges between 242 PJ (biodiesel from soybeans) to 1,320 PJ (bioethanol from miscanthus). Further, for residual land share in a grid-cell the maximum amount of biofuel energy, was determined by selecting for each grid-cell the best yielding biofuel feedstocks in terms of biofuel energy output. The assessment also addresses greenhouse gas saving potential (ton CO_2eq) and replacement potentials of fossil transport fuels in Brazil.

Keywords: Residual land, GAEZ methodology, Biofuel, Brazil, GHG savings

1 Introduction

1.1 Importance of biofuels, sustainability criteria

The transport sector enhances societal cohesion through human mobility and contributes to economic growth through effective and efficient movement of goods and services. Demographic changes and economic growth will cause a more than a doubling of world transport capacity over the next half century and substantially increase fuel demand, particularly in the developing countries (OFID-IIASA 2009). The automotive industry has made considerable progress regarding alternative motorization systems like electric/hybrid vehicles and fuel cell cars. But these mobility concepts will not be available in the short term. The challenges associated with range, infrastructure, recharging time, and uniform service station docking standards must be overcome before electric mobility becomes a practical everyday option (Daimler 2009). The combustion engine will continue to be the dominant engine system for many years to come, especially for freight transport. Therefore the automotive

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[3] Lossau S, Fischer G, Tramberend S, van Velthuizen H, Kleinschmit B, Schomäcker R. Biofuels from Residual Land in Brazil: Agro-ecological assessment for Sugarcane, Cassava, Miscanthus, Soybean and Jatropha. Forthcoming at Biomass and Bioenergy, Elsevier B.V, Amsterdam, Netherlands

industry is interested in alternative fuels for its combustion engines and biofuels in particular. Key issues center around finding a sustainable source of biofuel production supply chains for the future while keeping the fuel costs at acceptable levels. In addition, the use of biofuels should provide environmental benefits and endow the automobile industry potentially with CO_2 credits (Riegel 2009).

To produce biofuels, considerable amounts of biomass have to be provided, which will require an analysis of existing and potential biomass (OECD-IEA 2010). Recent studies have assessed the technical global biomass potential ranging between 30 EJ (Hoogwiik et al. 2003) and 1,300 EJ (Smeets et al. 2007) by 2050, or between 8% and 350% of current global energy consumption (OECD-IEA 20014). A major cause for such large differences relates to the crucial factors of future land availability and yields, both being very uncertain. Particularly in developing regions, these global estimations indicate considerable potential for the cultivation of dedicated energy crops. Countries with favourable climatic conditions (such as wet tropical climates) or countries where modernization and intensification of agricultural production could free large tracts of land would be most promising for future biofuel production (OECD-IEA 2010).

Recently, doubts have been raised about the actual benefits of biofuels regarding the mitigation of greenhouse gas (GHG) emissions (Searchinger et al. 2008). There are also questions about potential environmental, social and economic impacts, such as competition with food supply, risks of reducing biodiversity, impacts on water availability and quality, and lack of benefits to those directly affected by large scale introduction of biofuels (Walter et al. 2011).

For these reasons, Daimler AG launched a project in co-operation with the International Institute for Applied System Analysis (IIASA) and Technical University of Berlin to assess the biomass potential for biofuels employing the following sustainability criteria:

The production of biofuels i) must exclude competition with food and livestock feed supply; ii) does neither directly nor indirectly result in deforestation; iii) does not encroach in protected areas; iv) does not cause biodiversity loss; v) does not compete for scarce fresh water resources; vi) will not cause land degradation due to inappropriate management; and vii) must not contribute to GHG emissions due to increased fertilizer use for crop production intensification or of conversion from crop production to biofuel.

1.2 Biofuel production in Brazil

As demand for biofuel on the world market has been increasing, Brazil, today the largest producer and consumer of sugarcane bioethanol, is considered as a major potential supplier of biofuels. Large land endowments and technologically advanced sugarcane agro-industries developed since the 1970s place Brazil in a leading position for producing cheap biofuels with substantial potentials for mitigating human GHG emissions.

Brazil has been the world's leading producer and consumer of sugarcane based bioethanol, which is mainly used for the domestic transport sector. Brazil is also a key player in bioethanol trade, yet trade barriers in the United States and the European Union have been limiting export. As a consequence Brazilian sugarcane based bioethanol production in 2011 and 2012 was 23 billion litres down from a peak of 28 billion litres in 2010 (USDA 2014a). However, as of 2012, the 54% import tariff for bioethanol to the United States was abolished the production raised back to 28 billion litres in 2013.

Brazil started biodiesel production in 2006 and since increased its installed production capacity rapidly in response to envisioned mandates. In 2010, the biodiesel use mandate has been set at 5%; recently since

November 2014 a 7% mandate has been set. The increase of the biodiesel blend has been a longstanding request from industry given that industrial capacity is more than two times actual production goals. In 2013 2.9 billion litres of biodiesel transport fuel was marketed, representing 5% of the diesel market in Brazil. Soybean is by far the most important source for biodiesel production (72%) followed by animal fats (24%) and cotton seeds (2%) (USDA 2014a).

The current biofuel production reaches about 65% and 40% of installed capacity for bioethanol and biodiesel respectively, making a rapid expansion possible in response to increased demand and availability of feedstock. Current total biofuel production capacity is 40 billion litres bioethanol from 390 refineries and 8.2 billion litres biodiesel from 64 biodiesel plants (USDA 2014a).

The expansion of cultivated land in Brazil has directly or indirectly caused deforestation and loss of biodiversity. This is raising concerns regarding environmental sustainability of biofuel feedstock production (Lapola et.al. 2010, Sparovek et.al. 2009). Brazil's potential to sustainably produce biofuels for domestic demand and the world market is key for mobilizing resources for the bio-based economy relying on renewable energy sources.

Applying the sustainability criteria outlined above this study contributes by a spatially detailed assessment of biofuel potentials from Brazil's "residual land". These areas exclude all forests, all cropland and pastures currently used for agricultural production as well as all land in use for urban, industrial or infrastructure purposes. The analysis includes consideration of legally protected areas and areas with high biodiversity value. Both are excluded from residual land but details of the amount of residual land legally protected or with high biodiversity value are reported.

Extents of residual land were calculated applying detailed land use balances for the quantification Brazil's residual land shares in each 30 by 30 arc second grid-cell resolution (about 1 km^2) (see Lossau et al. 2015). Total residual land amounts to 37 Mha concentrated in the South-East and to a lesser extent in the North-East and Central-East. All together comprising 4.4% of Brazil's total geographical area or 50% of current cultivated land. Figure III-1 presents a map of Brazil's residual land intensity (i.e. residual land occurrence in individual 30 arc second grid-cells).

Brazil's potential for sustainable expansion of biofuel production depends largely on the suitability of available residual land for biofuel feedstock production, which can be optimized by using a range of biofuel feedstocks with different biophysical requirements and conversion efficiencies, enabling production of maximum biofuel volumes.

The assessment of the suitability and potential productivity of residual land for biofuels production includes estimates of:

(i) biophysical production potentials (in tons) of considered biofuel feedstocks sugarcane, cassava, miscanthus, soybean and jatropha at 30 arc second grid-cell resolution;

(ii) attainable biofuel feedstock yields for micro-regions and states, in (t/ha) and biofuel equivalent (l/ha);

(iii) GHG emission savings (ton CO_2eq) due to replacement of fossil fuels with biofuels and

(iv) key drivers determining potential future uses of residual land and its impact on biofuel production are discussed.

After introducing the selected biofuel feedstocks and biophysical requirements in section 2 , section 3 presents data and methodology of the spatial assessment of biofuel feedstock potentials of residual land. Section 4 presents results for biofuel potentials. Section 5 discusses potential for reducing GHGs and replacing fossil fuels with biofuels from residual land and an estimate of residual land availability by 2030. The final section presents conclusions.

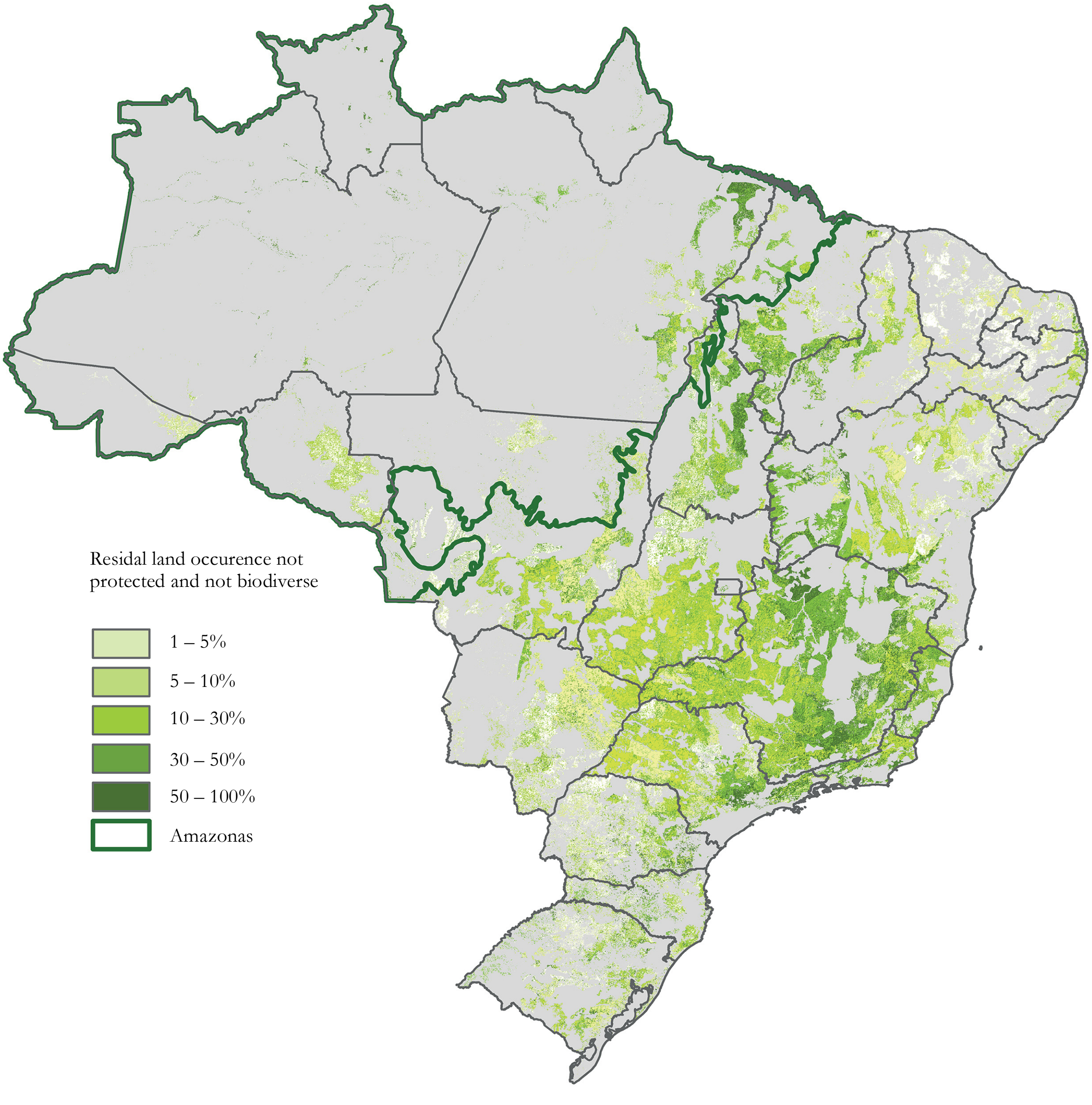

Figure III - 1 Distribution and intensity of residual land shares (30 arc second grid-cell resolution)

2 Considered biofuel feedstocks

Biofuel production is dominated by two types of fuels, bioethanol and biodiesel. Bioethanol is produced from sugar or starch feedstocks, biodiesel from oil feedstocks (OFID-IIASA 2009). Brazil is the world's largest producer of sugarcane (61% of global production) and the second largest of soybean (9% of global production) (FAO 2011). Both crops are used for biofuel production. Alternative biofuel feedstocks, cassava, jatropha and miscanthus are of interest for cultivation on residual land due tolerances to marginal environmental conditions and produce biomass and energy with modest applications of agro-chemicals.

Biofuel production from miscanthus relies on second-generation conversion technologies. This conversion technology is uncertain on the near- and mid-term for commercial-scale application.

Table III-1 presents an overview of biophysical and energy characteristics of the biofuel feedstocks.

Table III-2 presents an overview of argo-ecological characteristics of the biofuel feedstocks.

In the following main features of individual feedstocks are described.

Sugarcane (saccharum officinarum)

Sugarcane processing allows producer's flexibility in allocating to sugar and bioethanol markets (OFID-IIASA 2009). High yield potentials and well-established conversion technologies in Brazil's long-established sugarcane industry have placed Brazilian sugarcane bioethanol as the first renewable fuel to be cost-competitive in the transport sector. Almost half of Brazil's sugarcane production is used for bioethanol production (Lapola et al. 2010). Most of the sugarcane production is located in the South-East, where almost two-thirds of bioethanol is being produced (IBGE 2006). Most sugarcane is grown in São Paulo (54%), Alagoas (11%) and Paraná (6%) states. In view of expansion trends of sugarcane production, the Brazilian government commissioned a national study to identify areas potentially suitable for sugarcane production (OECD-IEA 2010).

Cassava (manihot esculenta)

Cassava is a perennial woody shrub producing an edible root with high starch content. It is also called yucca, manioc, mandioca or tapioca. It is grown in many tropical countries where it is produced mostly by smallholders on marginal or sub marginal lands. It has long been used as a food security crop; cassava roots can be stored in the ground for several months and harvested off-season.

Cassava is an emerging feedstock bioethanol production because: (i) extended harvesting periods support year-round supply for bioethanol production; (ii) high starch productivity; (iii) and requires limited agro-chemical inputs between planting and harvesting. In addition cassava produces a considerable amount of woody, lingo-cellulosic biomass, which could potentially be used as feedstock for future second-generation bioethanol or as supplementary energy source in cassava-processing. In Brazil the majority of cassava is grown in the North-East (54%), followed by North (21%) and South (13%) Brazil (IBGE 2006). Cassava today is primarily used for starch production.

Miscanthus (miscanthus x giganteus)

Miscanthus is a perennial feedstock with a high cellulose yield potential and low input requirements, which makes the plant a leading candidate for second-generation cellulosic bioethanol production (DOE 2006). Miscanthus originates from East Asia (Heaton et al. 2004) where it is used as forage source, for clothing, shelter, etc. (Chou 2009) The miscanthus genotype with the best biomass potential to date is giant miscanthus (*miscanthus x giganteus*), a sterile hybrid of *miscanthus sacchariflorus* and *miscanthus sinensis* parentage (ISU 2010).

Soybean (glycine max)

Soybean is an annual legume cultivated for the production of soybean meal/cake used for livestock feed and soybean oil for human consumption and industry including biofuels. Soybean is Brazil's main agribusiness product in volumes produced and exported. In 2011 soybean complex exports accounted for 26% of total exports in agribusiness and 9.4% of total exports (FIESP-ICONE 2012).

Brazil's harvested soybean areas doubled since the mid-1990s reaching as much as 23 Mha in 2010 (FAO 2011). Soybean is mainly grown in the South (43%) and Central-East (42%) and to a lesser extent in the North-East (7%) (IBGE 2006). Soybean area expansion to date was largely driven by demand for concentrated livestock feeds for both domestic and export markets. Increasing demand for biodiesel adds further momentum. Although the government projects a three-fold increase in the biodiesel production up to 2015, it is highly uncertain

	Bioethanol			**Biodiesel**	
	Sugarcane[a]	**Cassava**[b]	**Miscanthus**[c]	**Soybean**[d]	**Jatropha**[e]
Feedstock (DW)	sugar	root	ligno cellulose	seed	vegetable oil
Biofuel (l/ton feedstock)	677.27	391.43	300.00	221.44	1048.91
Energy yield (GJ/ton feedstock)	14.34	8.29	6.35	7.24	34.51
Heating Value (MJ/l biofuel)	21.17	21.17	21.17	32.68	32.90
GHG savings (kg CO_2eq/GJ)	60.00	40.00	74.00	34.00	58.00
Fossil fuel equivalent (1l fuel/1l biofuel)	0.65	0.65	0.65	0.90	0.92

a sugarcane: 74.5 litre ethanol /ton sugarcane (FAO 2008) / 0,11 ton sugar/ton sugarcane (FAO 1972) = 677,27 litre ethanol /ton sugar * 21.17 MJ/litre ethanol (BMELV-FNR 2009) = 14,34 GJ/ton sugar | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012) -24gCO_2eq/MJ sugarcane bioethanol (RFA-RTFO 2012) = 60g CO_2eq/MJ GHG savings | 1 litre sugarcane bioethanol = 0,65 litre gasoline (BMELV-FNR 2009)

b cassava: 137 litre ethanol/ fresh ton cassava (FAO 2008) = 137* 1/0,35 (65% moisture content) (FAO 1972) = 391,43 litre ethanol/dry ton cassava *21.17 MJ/litre ethanol (BMELV-FNR 2009) = 8,29 GJ/dry ton cassava | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2009) - 44gCO_2eq/Mj cassava ethanol (RFA-RTFO 2012) = 40g CO_2eq/MJ GHG savings | 1 litre cassava bioethanol = 0,66 litre gasoline (BMELV-FNR 2009)

c miscanthus: Hydrolysis ethanol 300 litres ethanol/dry ton (Carriquiry et al. 2010) * 21.17 MJ/litre ethanol (BMELV-FNR 2009)=6,35 GJ/dry ton miscanthus| 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012)-10 g CO_2eq/MJ ligno-cellulosic ethanol (RFA-RTFO 2012) = 74 g CO_2eq/MJ GHG savings | 1 litre miscanthus bioethanol = 0,65 litre gasoline (BMELV-FNR 2009)

d soybean: 0,92 kg oil /litre oil (BMELV-FNR 2012) = 1086,95 litre oil/ton soy oil * 0,19 (19 % oil content per fresh ton) (FAO 1972) * 1/0,9 (10% moisture content) (Gandhi 2009)* 0,965 (biodiesel content) (EC 2008) = 221,44 litre biodiesel/dry ton soybean seed * 32,68 MJ/ litre biodiesel (BMELV-FNR 2009) = 7,24 GJ/dry ton soybean seed | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012) - 50gCO_2eq/MJ soy biodiesel (RFA-RTFO 2012) = 34g CO_2eq/MJ GHG savings | 1 litre soy biodiesel = 0,90 litres diesel (BMELV-FNR 2009)

e jatropha: 0,92 kg oil / litre oil (BMELV-FNR 2009) = 1086,95 litre oil/ton jatropha oil* 0,965 (Biodiesel content) (EC 2008) = 1048,91 litre biodiesel/ ton jatropha oil * 32.9 MJ/litre jatropha biodiesel (BMELV-FNR 2009)= 34,51 | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012) -26 g CO_2eq/MJ jatropha biodiesel (RFA-RTFO 2012) = 58g CO_2eq/MJ GHG savings | 1 litre jatropha biodiesel = 0,92 litre diesel (BMELV-FNR 2009)

Table III - 1 Biophysical and energy characteristics of biofuel feedstocks whether soybean oil will continue to be the main feedstock for such a large increase. Rapid expansion of soybean production has already resulted in several adverse ecological and social impacts due to its large land requirements (which has directly or indirectly contributed to deforestation in the Amazonian region) (Gibbs et al. 2010, Davidson et al. 2012). Soybean provides relative low energy return per area of land, low mitigation of GHG emissions, it also competes with food markets and finally production costs of biodiesel from soybean are high (Lapola et al. 2010).

Jatropha (jatropha curcas)

Jatropha is a perennial deciduous small tree or large shrub native from Central America. It grows up to 30-50 years, can bear fruits after 12 months and reaches its maximum productivity by 5 years (Atabani et al. 2013). As many species of the family Euphorbiaceae, jatropha contains highly toxic compounds and is thus not used for livestock fodder, instead being used for fencing. Jatropha oil is not edible and is traditionally used for manufacturing soap and medicinal applications (OFID-IIASA 2009). Jatropha's seeds contain around 25-40% oil (Moncaleano-Escandon et al. 2013) and yields are estimated to range between 439 - 2,217 litres oil per ha (Jongschaap et al. 2007). Jatropha oil is well suited for biodiesel production and meets American and European standards (Achten et al. 2008).

Based on these interesting properties, potentials and hyped claims, investors, policy makers and clean development mechanism project developers got interested in jatropha as a means to concurrently tackle the challenges of renewable energy supply and GHG emission reduction (Achten et al. 2008).

The cultivation of Jatropha as a biofuel feedstock has started only recently. There is extensive research on the development of new varieties suited for different environments (IREDA 2013). Three-fourth of Latin America's jatropha projects are in Brazil where a total of 15,800 ha is currently cultivated (GEXSI 2008). The Brazilian Agricultural Research Corporation (EMBRAPA) regards jatropha as a promising source for biodiesel production and has recently started an R&D program, on jatropha cultivation (Lapola et al. 2010).

Biofuel feedstock	**Agro-ecological characteristics**
Sugarcane (Saccharum officinarum)	Sugarcane belongs to the crops with a C4 photosynthetic pathway; it is adapted to perform best under conditions of relatively high temperatures. Sugar cane is a perennial with determinate growth habit; its yield is located in the stem as sucrose and the yield formation period is about two-thirds to three-quarters of its cultivated life span. Sugarcane is best adapted to tropical lowland climates; it does particularly well in somewhat drier zones under irrigation, but is sensitive to frost. Ecological requirements of sugarcane include warm, sunny conditions and generous soil moisture supply during most of its cultivation cycle. Sugarcane prefers deep, well drained and well structured and aerated loamy to clayey fertile soils (OFID-IIASA 2009).
Cassava (Manihot esculenta)	Cassava is a C3 crop adapted to perform best in tropical lowland conditions. It produces yields across a range of moisture regimes from semi-arid to per-humid. Ecological requirements of cassava are modest in terms of soil fertility and moisture supply. Cassava can be grown on soils with low fertility. On very fertile soils the vegetative growth of cassava is very luxurious at the expense of the roots. Cassava is very sensitive to salinity, prefers moderately deep soils that are at least moderately well drained. Cassava is sensitive to waterlogging and no flooding should occur (OFID-IIASA 2009).
Miscanthus (Mscanthus x giganteus)	Miscanthus has high yield potential for cellulose fiber production. Its extensive underground rhizome system is a storage organ for nutrients and forms shoots every year (OFID-IIASA 2009). Experience in Europe suggests giant miscanthus being productive over a wide geographic range in temperate, sub-tropical and tropical regions, performs on marginal land, but it is not appropriate for dry regions (Heaton et al. 2011). From its second season onwards giant miscanthus grows to a height of 2.5–3.5 m. It remains productive for over 15 years (up to 25 years) (McKervey et al. 2008) and has low fertilizer

	requirements compared to most agricultural crops. Miscanthus is adapted to a wide range of soil conditions, including marginal low nutrient soils, but is most productive on good soils (optimum soil conditions for miscanthus compare to those of maize) (ISU 2010). Miscanthus does not tolerate prolonged dry periods or periods with stagnant water.
Soybean (Glycine max)	Soybean is a C3 crop adapted to perform under warm to moderately cool conditions. Soybean's wide climatic adaptability spectrum makes it possible for it to be grown across a range of thermal regimes; ranging from tropical to subtropical and temperate zones with warm summers and across moisture regimes ranging from semi-arid to humid. However, high soybean yields require high levels of fertilization and use of agro-chemicals to deal with competition of weeds and combat pest and diseases. Soybean is susceptible to salinity, sodicity, excess calcium carbonate and gypsum, and has low tolerance to waterlogging. Soybean prefers deep, well drained, well structured, loamy to clayey fertile soils (OFID-IIASA 2009).
Jatropha (Jatropha curcas)	Jatropha, also referred to as physic nut, is a C3 plant adapted to perform best under conditions of warm temperatures. There are various advantages of growing jatropha as biofuel feedstock especially on marginal land. Jatropha is useful for soil conservation, tolerates marginal soils with low nutrient content, can grow without irrigation in a broad spectrum of rainfall regimes, from 500 up to 3000 mm per annum and is reported fairly resistant to pests and diseases (Achten et al. 2008). Jatropha is adapted to moist semi-arid conditions, although generally performs better in humid environments. Yet, so far jatropha productivity is reported to be highly variable and its yield performance is largely uncertain when specific varieties are transferred to different ecological circumstances and management (OFID-IIASA 2009). Rotation lengths in plantations are approximately 20 years with maximum yields obtained after four to six years.

Table III - 2 Agro-ecological characteristics of biofuel feedstocks

3 Methodology and data

3.1 Agro-ecological methodology

The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed a spatial assessment tool for estimating production potentials of agricultural crops (Global Agro-ecological Zones modelling framework (GAEZ) (FAO-IIASA 2012).

It provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to crop production and uses environmental matching

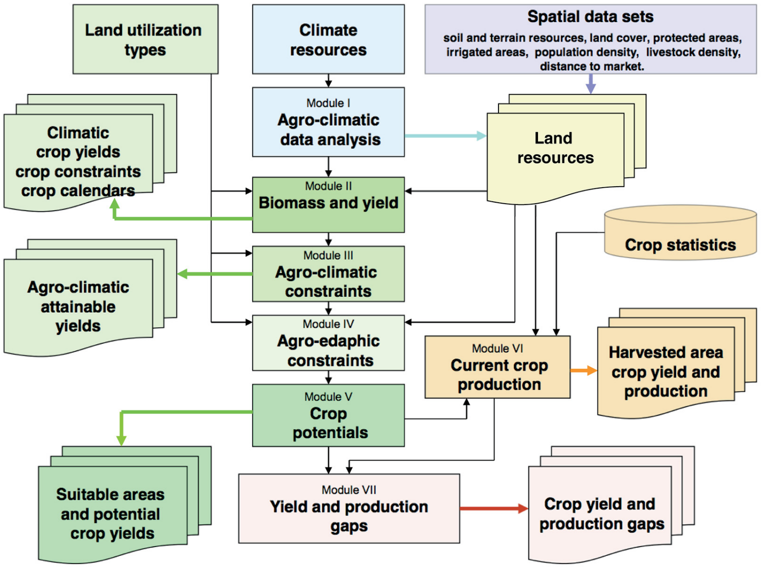

Figure III - 2 Overall structure and data integration of GAEZ procedures to identify limitations of prevailing climate, soil and terrain for crops under specified levels of inputs and management. Figure III-2 presents a schematic overview of the GAEZ methodology as implemented. In this study GAEZ has been applied for the assessment of suitability and productivity of residual land at 30 arc second (about 1km^2) grid-cell resolution for biofuel feedstocks, namely: sugarcane, cassava, miscanthus, soybean and jatropha. Table III-3 provides characterisrtics of assumptions of agricultural inputs and management applied. Three distinct input levels are employed: low, intermediate and high. In addition, a mixed input level has been defined.

3.2 Brazilian land use database

Brazil's land use database (Lossau et al. 2015) records land intensities (percentage of grid-cell) for each 30 arc second grid-cell (about 1 km^2) of major land cover categories consistent with year 2006 Census (IBGE 2006) agricultural statistics at micro-regions and FRA 2010 (FAO 2010b) forest areas and protected areas (UNEP 2010) and areas with high biodiversity (MMA 2004). Spatial allocation ('downscaling') algorithms were applied to obtain spatial distribution for seven land use categories, namely: i) cultivated land, ii) managed pastures, iii) forest, iv) built-up land and land required industrial and infrastructure purposes, v) barren and sparsely vegetated land, and vi) water. The "unused" land in each grid-cell, was termed vii) residual land. Residual land occurring in Legal Amazonia, and residual land that is protected or highly biodiverse has been set apart and is excluded from the productivity assessments.

Management Systems	**Characteristics**
Low-level inputs/ traditional management	The farming system is largely subsistence based and not necessarily market oriented. Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labour intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.
Intermediate-level inputs/ improved management	The farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labor with hand tools and/or animal traction and some mechanization, is medium labor intensive, uses some fertilizer application and chemical pest disease and weed control, adequate fallows and some conservation measures.
High-level inputs/ advanced management	The farming system is mainly market oriented. Commercial production is a management objective. Production is based on improved high yielding varieties, is fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control.
Mixed-level of inputs	Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. The following procedure was applied to individual 30 arc second grid-cells. (1) Determine all land very suitable and suitable at high level inputs (2) Of the balance of land after (1), determine all land very suitable, suitable or moderately suitable at intermediate level of inputs, and (3) Of the balance of land after (1) and (2), determine all suitable land (i.e. very suitable, suitable, moderately suitable or marginally suitable) at low level of inputs.
Source: Global Agro-ecological Zoning modelling framework (GAEZ) (FAO-IIASA 2012)	

Table III -3 Specifications of levels of inputs and management systems used

Assessment of biofuel feedstock potentials on residual land

GAEZ procedures retain sub-grid-cell information (i.e. distributions within a 30 arc second grid-cell) from higher resolution data of terrain (slope, aspect, elevation) and soil information providing soil unit compositions and properties. Suitability and productivity of individual biofuel feedstocks has been estimated for grid-cell shares pertaining to residual land.

Mapping and aggregation of grid-cell results for biofuel feedstocks

Spatial maps at 30 arc second grid-cell resolution were produced for biofuel productivity under rain-fed conditions for biofuel feedstocks on residual land. Biofuel productivity is expressed in terms of crop yields (kg/ha) and suitability class defined as follows:

Figure III - 3 Administrative regions Brazil

VS or very suitable (80–100% of maximum achievable yield in Brazil);

S or suitable (60–80%);

MS or moderately suitable (40–60%);

mS or marginally suitable (20–40%);

vmS or very marginally suitable (5-20%) and

NS or not suitable (less than 5%)

The suitability profile of residual land in individual grid-cells has been expressed by means of suitability index SI.

SI = (0.9*VS+0.7*S+0.5*MS+0.3*mS+0.15*VmS)

Potential biomass and yield have as well been expressed into biofuel and energy output equivalents.

Land potentials of residual land were estimated by assuming optimum use of residual land in individual grid-cells. This was achieved by choosing for each grid-cell the best producing biofuel feedstock in terms of energy. Grid-cell values were aggregated by micro-regions, states and regions.

4 Results

4.1 Suitability and productivity of biofuel feedstocks on residual land

Brazil comprises of 26 states grouped in five main regions (Figure III-3) and has a total land area of 852 Mha, of which 528 Mha is forest. Agricultural area includes 61 Mha cropland and 157 Mha pasture. Residual land outside the Amazon, not protected and not biodiverse, amounts to 37 Mha (4.4% of Brazil) and is considered to be potentially available for biofuel production. From a total of 37 Mha residual land (4.4% of Brazil's total land area), almost three-quarters are suitable for biofuel feedstock production with a varying degree of productivity depending on biofuel feedstock. Figure III-4 presents a summary of extents of residual land and its suitability distribution for the production of biofuel feedstocks aggregated by regions.

The 37 Mha residual lands includes 2% prime (VS) quality land, 24% of good (S and MS) land, 46% of poor (mS and VmS) land and 28% not suitable (NS) land for any of the assessed biofuel feedstocks.

About half of residual land occurs in the South-East region where almost 20% of all land is of the residual land category. Significant amounts of residual land also occur in the North-East (about 8 Mha or 22% of total land) and the Central-East (about 7 Mha or 19%). At state level, Minas Gerais contains by far the largest extents (12.5 Mha). Other states with substantial extents of residual land include Bahia (4.2 Mha), Goiás (3.4 Mha), São Paulo (3.3 Mha) and Tocantis (2.5 Mha).

Suitability profiles differ significantly across biofuel feedstocks. While almost 5 Mha of residual land are of prime and good quality for rain-fed sugarcane and rain-fed miscanthus production, this extent increases to 8.6, 9.6 and

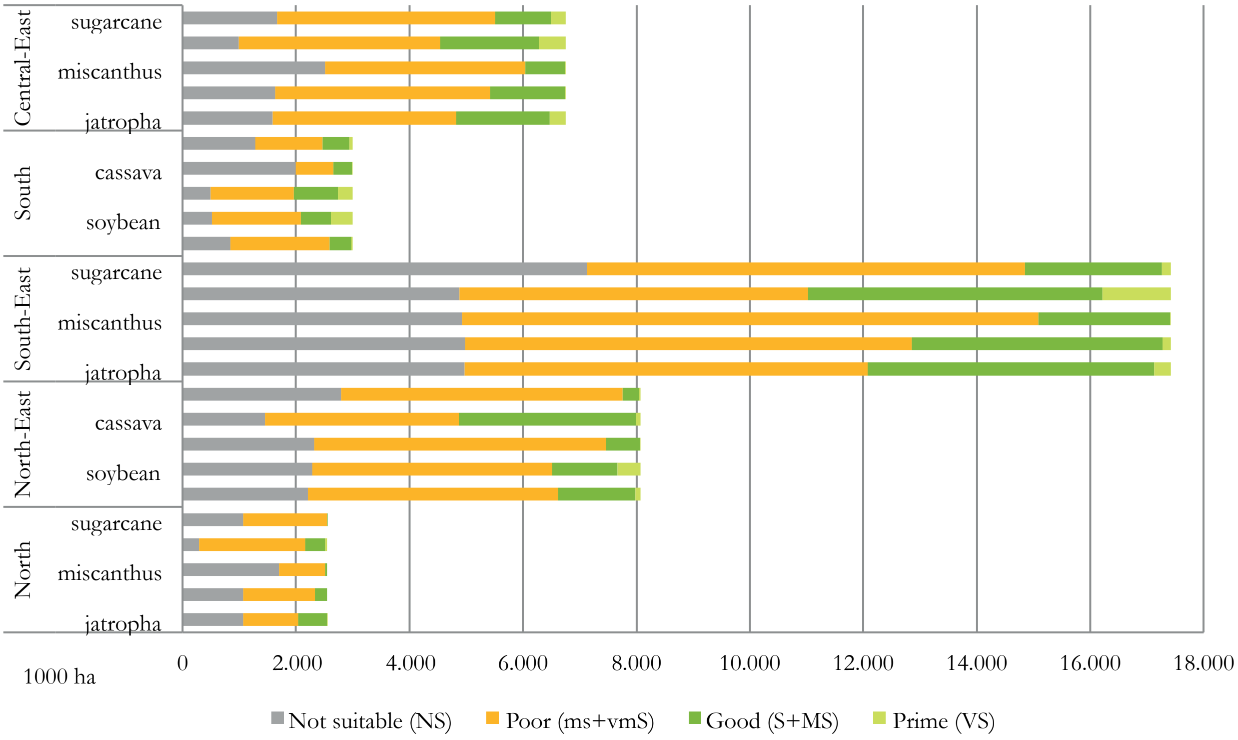

Figure III - 4 Biofuel feedstock suitability of residual land by regions

12.5 Mha when residual land is used for the rain-fed production of soybean, jatropha and cassava respectively. Depending on feedstock, between 40 and 50% of the residual land is marginally suitable for biofuel feedstock production. In these poor areas economic feedstock production may only be feasible with substantial investments in land improvement and irrigation. Almost 10 Mha or 28% of the residual land is not suitable for any of the biofuel feedstocks of this study. The highest production potential occurs in Minas Gerais, the state with largest extents of residual land, however the per average hectare production is low. Figures III-5 – III-9 present maps depicting the suitability of residual land for the five biofuel feedstocks; sugarcane, cassava, miscanthus, soybean and jatropha. Table III-4 compares suitable residual land and potential rain-fed production from residual land in Brazil for the biofuel feedstocks assuming mixed level of input (Table III-3).

Sugarcane

Sugarcane cultivation on residual land could produce potentially up to 50 Mt sugar. Half of this potential is located in the South-East (in particular in the state of Minas Gerais and São Paulo) and one-quarter in the Central-East (primarily in Mato Grosso do Sul and Goiás). About 54% of total potential sugar production from residual land or 27 Mt would come from prime and good quality land with average yields around 5 to 10 t/ha sugar. In comparison in 2010 Brazil's sugar production was over 70 Mt from 9 Mha implying an average yield of 7.9 t/ha sugar (FAO 2011).

Cassava

80 Mt of cassava roots (DW) could be produced from Brazil's residual land, half of which is located in the South-East. About 83% of total potential cassava production from residual land or 66 Mt (DW) would come from prime and good land with average yields of between 5 to 9 t/ha. Brazil is the second largest cassava producer in the world. In 2010 production was 24 Mt fresh weight roots (or 8.4 Mt (DW)) from 1.7 Mha, corresponding to an average yield of 4.6 t/ha (DW) (FAO 2011).

Miscanthus

Some 25 Mha of residual land is suitable for miscanthus production. Total production potential over all suitability classes amounts to 208 Mt above ground biomass (DW). About half of the production potential would occur in the residual land in the South-East region with a potential production of 100 Mt (DW). Maximum attainable yield could be achieved in Rio Grande do Sul, where maximum rain-fed yield potentials are over of 33 t/ha (DW). Average yields that could be attained in prime and good land would be in the order of 19 t/ha.

Soybean

Total potential soybean production from residual land is 33 Mt grain (DW). Three-quarters of this potential (25 Mt) would come from prime and good quality residual land with average yields of around 3.0 t/ha (DW). Almost half of total production potential is found in the South-East (16.6 Mt (DW)). Highest yields are around 5 t/ha (DW) and are found in Rio Grande do Sul. For comparison, in 2010 Brazil's soybean production was over 68 Mt or 61 Mt (DW), harvested from 23 Mha with an average yield of 2.9 t/ha (or 2.6 t/ha DW) soybean grain (FAO 2011).

Jatropha

Some 27 Mha of residual land is suitable for jatropha cultivation, of which 9 Mha are of prime and good quality. Total jatropha oil production potential in all residual land is 17 Mt. Average potential yields on prime and good land are in the order of 1.3 t/ha vegetable oil. Note that potential jatropha yields can only be achieved after 3-4 years (Atabani et al. 2013)

States	**Sugarcane**		**Cassava**		**Miscanthus**		**Soybean**		**Jatropha**	
	Suitable land[a,b]	**Potential Yield[d]**	**Suitable land[a,b]**	**Potential Yield[d]**	**Suitable land[a,b]**	**Potential Yield[d]**	**Suitable land[a,b]**	**Potential Yield[d]**	**Suitable land[a,b]**	**Potential Yield[d]**
	1000 ha	1000 ton sugar	1000 ha	1000 ton roots DW	1000 ha	1000 ton AGB DW	1000 ha	1000 ton seeds DW	1000 ha	1000 ton oil
North[c]	**1,480**	**996**	**2,252**	**3,201**	**851**	**5,730**	**1,480**	**729**	**1,486**	**977**
Rondônia	-	-	-	-	-	-	-	-	-	-
Acre	-	-	-	-	-	-	-	-	-	-
Amazonas	-	-	-	-	-	-	-	-	-	-
Roraima	-	-	-	-	-	-	-	-	-	-
Pará	-	-	-	-	-	-	-	-	-	-
Amapá	-	-	-	-	-	-	-	-	-	-
Tocantins	1,480	996	2,252	3,201	851	5,730	1,480	729	1,486	977
North-East	**5,273**	**5,988**	**6,619**	**17,174**	**5,748**	**39,470**	**5,788**	**6,994**	**5,868**	**3,271**
Maranhão	942	918	1,387	2,868	927	6,330	937	762	937	486
Piauí	461	113	693	1,256	544	2,790	579	421	571	251
Ceará	122	65	140	100	146	720	147	187	147	72
Rio Grande do Norte	64	75	83	138	91	470	110	102	101	39
Paraíba	112	379	141	552	130	670	133	129	145	136
Pernambuco	112	109	191	278	164	580	189	109	175	63
Alagoas	18	31	23	55	23	90	23	12	23	10
Sergipe	36	64	43	85	43	90	43	4	43	6
Bahia	3,406	4,234	3,918	11,842	3,680	27,730	3,627	5,268	3,726	2,207
South-East	**10,304**	**24,793**	**12,542**	**41,249**	**12,496**	**100,170**	**12,440**	**16,612**	**12,452**	**8,622**
Minas Gerais	6,982	12,935	8,807	25,004	8,481	56,810	8,500	10,291	8,511	5,028
Espírito Santo	276	1,032	456	1,662	494	3,830	457	434	456	242
Rio de Janeiro	232	733	376	985	413	2,560	384	280	384	195
São Paulo	2,814	10,093	2,903	13,598	3,108	36,970	3,099	5,607	3,101	3,157
South	**1,706**	**5,036**	**1,001**	**2,509**	**2,502**	**28,200**	**2,480**	**3,560**	**2,151**	**1,016**
Paraná	765	1,673	445	806	1,143	10,550	1,130	1,274	1,064	347
Santa Catarina	191	451	127	339	469	3,540	463	223	255	92
Rio Grande do Sul	750	2,912	429	1,364	890	14,110	887	2,063	832	577
Central-East	**5,087**	**13,371**	**5,762**	**16,007**	**4,240**	**34,280**	**5,127**	**5,586**	**5,167**	**3,166**
Mato Grosso do Sul	1,401	5,948	1,409	4,559	1,409	15,610	1,411	2,079	1,421	1,100
Mato Grosso	1,016	1,808	1,646	5,525	982	5,640	1,024	684	1,044	826
Goiás	2,658	5,581	2,695	5,871	1,844	12,890	2,681	2,802	2,690	1,226
Distrito Federal	12	34	12	52	5	140	11	21	12	14
Total Brazil	**23,850**	**50,184**	**28,176**	**80,140**	**25,837**	**207,850**	**27,315**	**33,481**	**27,124**	**17,051**

a Residual land is defined as remaining fraction currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome. Source: Brazilian 1 km land use database (Lossau et.al. 2015)

b Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. Not suitable land is not considered

c Rondônia, Acre, Amazonas, Roraima, Pará and Amapá are states located in legal Amazonas biome. Residual land in this states is excluded due definition

AGB Above Ground Biomass

DW Dry Weights

Table III - 4 Biofuel feedstock production potential from residual land by states

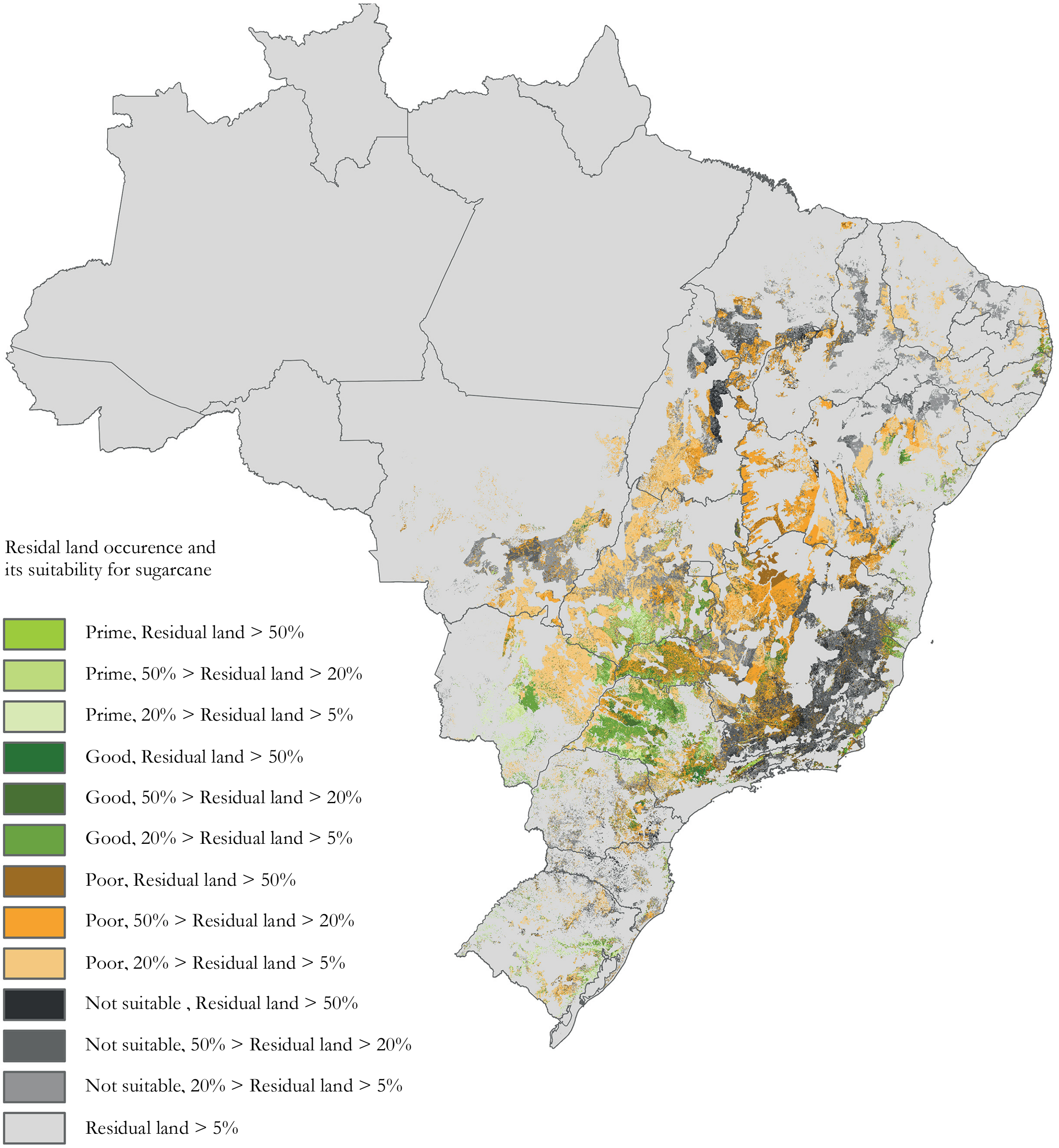

Figure III - 5 Rain-fed sugarcane suitability for residual land under mixed input level (30 arc second grid-cell resolution)

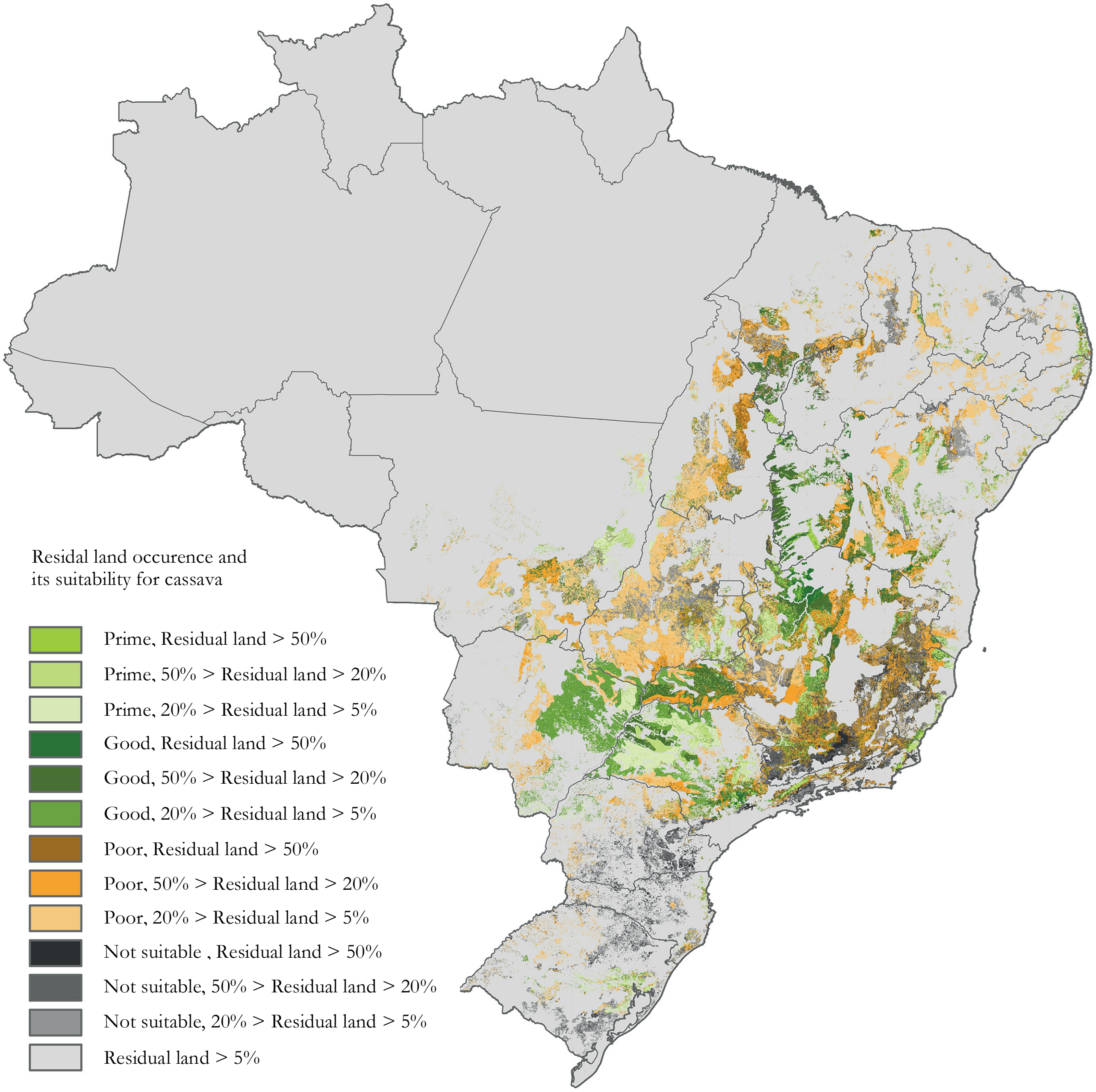

Figure III - 6 Rain-fed cassava suitability for residual land under mixed input level (30 arc second grid-cell resolution)

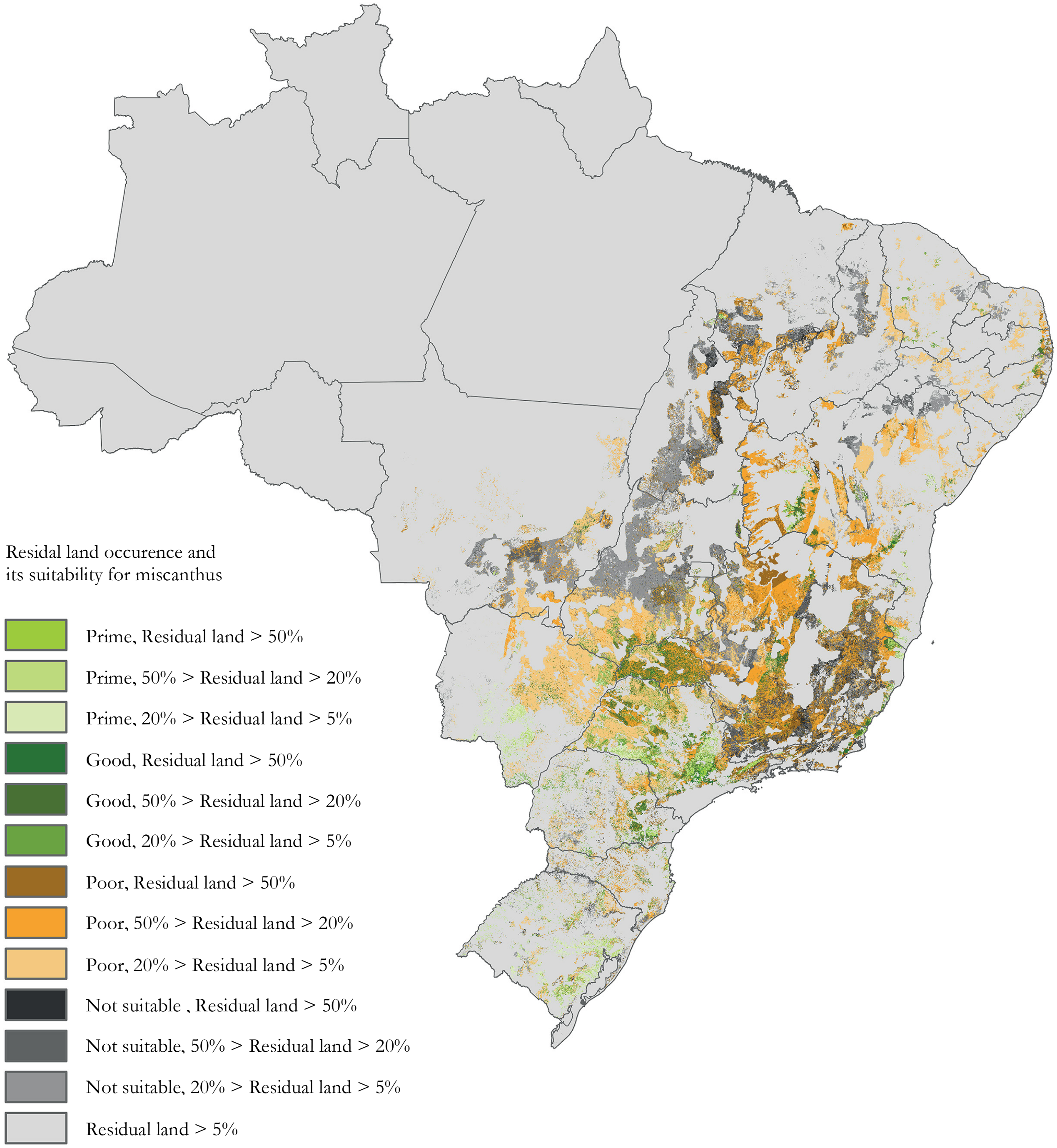

Figure III - 7 Rain-fed miscanthus suitability for residual land under mixed input level (30 arc second grid-cell resolution)

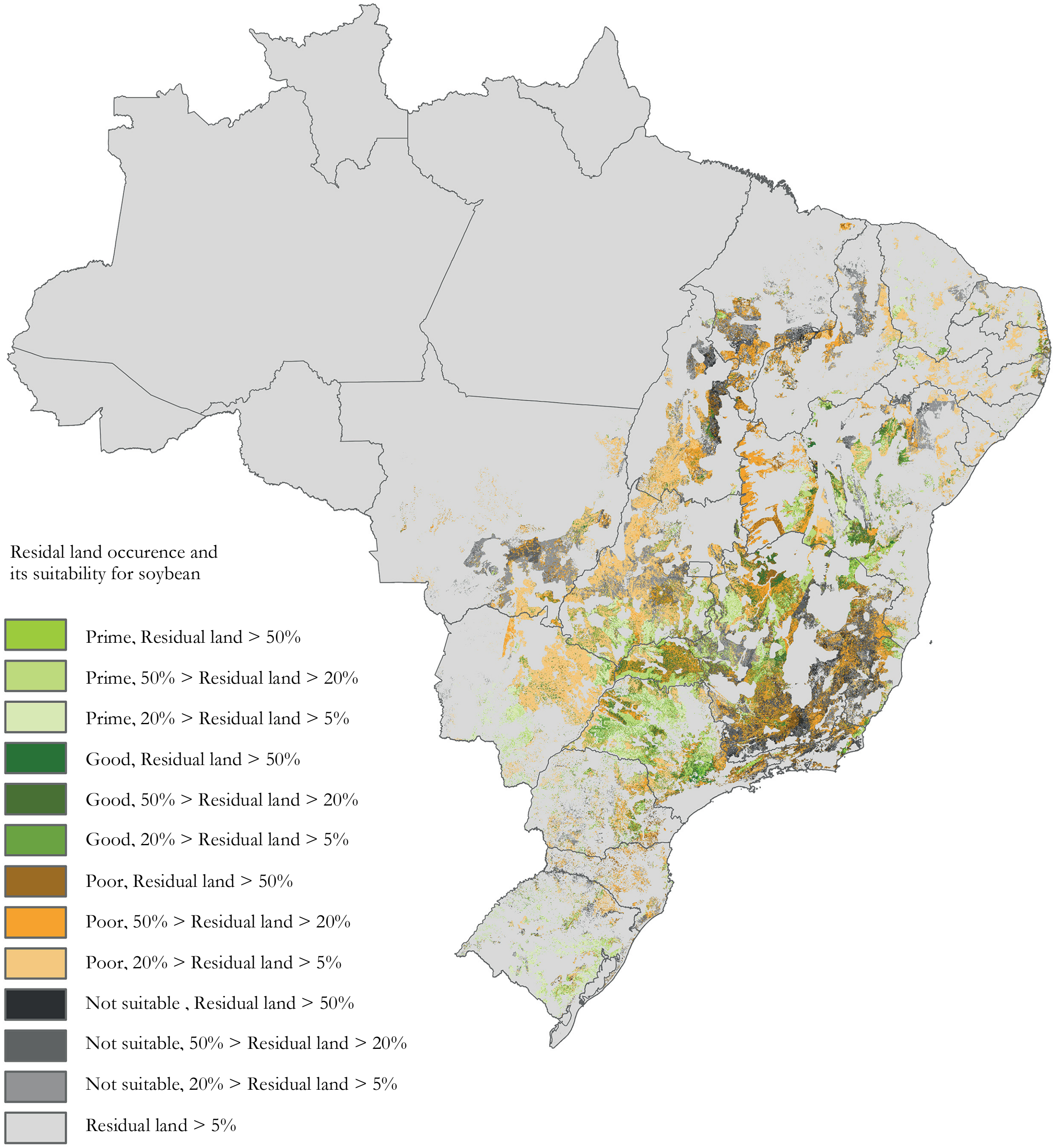

Figure III - 8 Rain-fed soybean suitability for residual land under mixed input level (30 arc second grid-cell resolution)

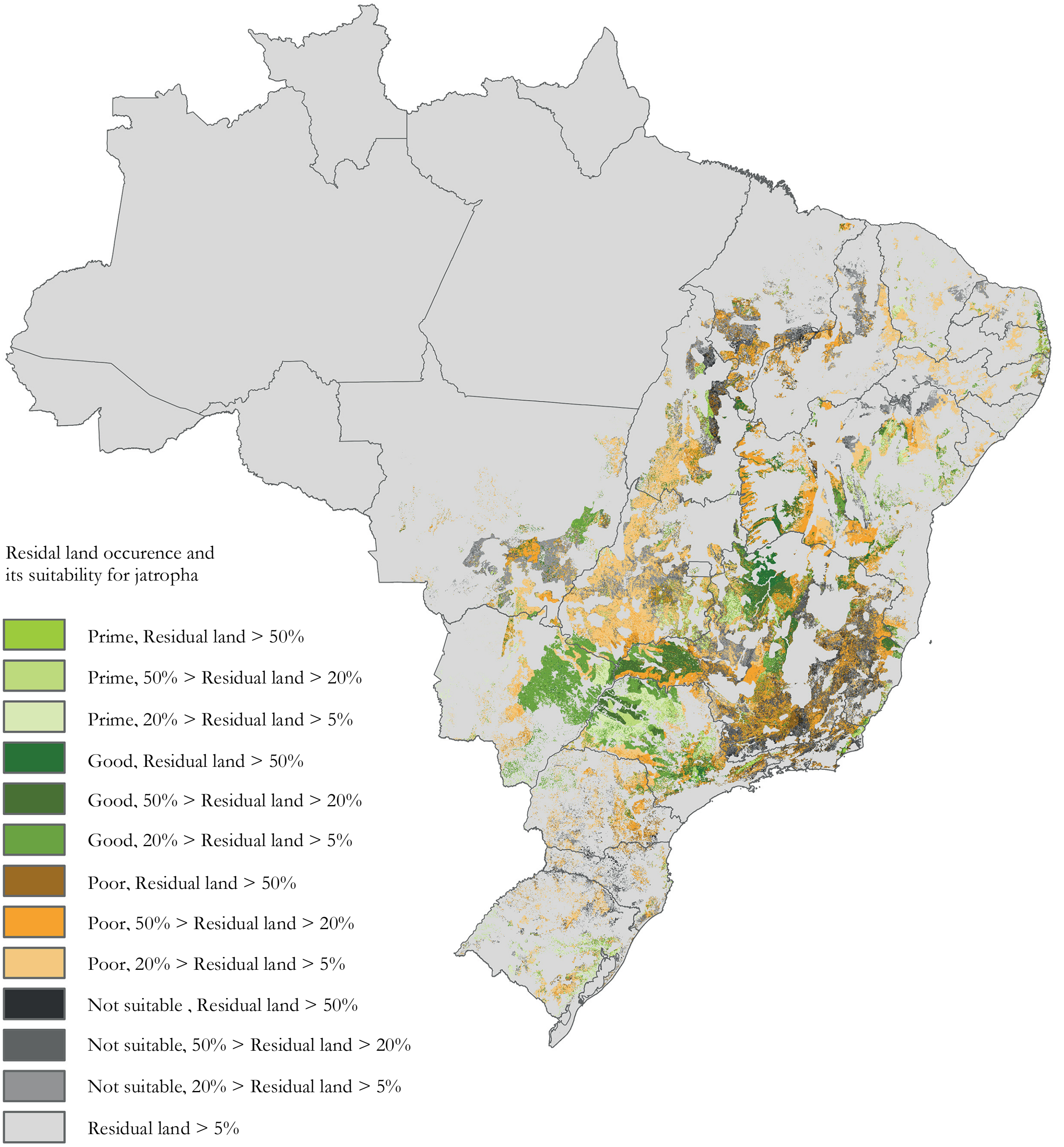

Figure III - 9 Rain-fed jatropha suitability for residual land under mixed input level (30 arc second grid-cell resolution)

4.2 Biofuel potentials of residual land

Figure III-10 illustrates biofuel potentials from residual land by region. In Brazil about 50 Mt sugar, or 80 Mt cassava roots (DW), or 208 Mt miscanthus (DW AGB) could be produced from residual land (Table III-4). This implies that 34 billion litres of bioethanol could be produced when solely sugarcane was produced on residual land, or 31 billion litres from cassava or about 62 billion litres from miscanthus (second-generation technology). In the case of biodiesel, 33 Mt soybean grain (DW) equivalent to 7 billion litres biodiesel or 17 Mt jatropha oil equivalent to 18 billion litres biodiesel could potentially be produced from residual land. Energy yields across the different feedstocks, show the highest potential for miscanthus bioethanol (1.320 PJ), followed by sugar bioethanol (720 PJ), cassava bioethanol (664 PJ) and jatropha biodiesel (588 PJ). Potential production of soybean Figure III-12 presents a suitability map showing residual land shares and its suitability by selecting in each individual grid-cell the "best performing biofuel feedstock" in terms of energy output. In almost 57% of grid-cells with suitable residual land shares, miscanthus was chosen as best producing biofuel feedstock (Figure III-11) with a biomass potential of 139 Mt above ground biomass (DW) equivalent to 42 billion litres bioethanol. biodiesel is least promising (242 PJ). In 2% of the grid-cells with residual land jatropha produced best with potential production of 0.5 billion litres biodiesel. For the regions North-East (58% of grid-cells), South-East (65% of grid-cells) and South (95% of grid-cells) miscanthus is the best performing crop. In Cetral-East cassava (39% of grid-cells) is best performing followed by miscanthus (33% of grid-cells) and sugarcane (27% of grid-cells). The best results for jatropha are found in the North (17% of grid-cells) after cassava (61% of grid-cells) and miscanthus (20% of grid-cells).

In comparison to other biofuel feedstocks, the results for soybeans are negligible, only 2% of grid-cells in the North-East are chosen. Table III-5 and III-6 shows the biofuel feedstock composition in each state, which provides maximum biofuel energy output.

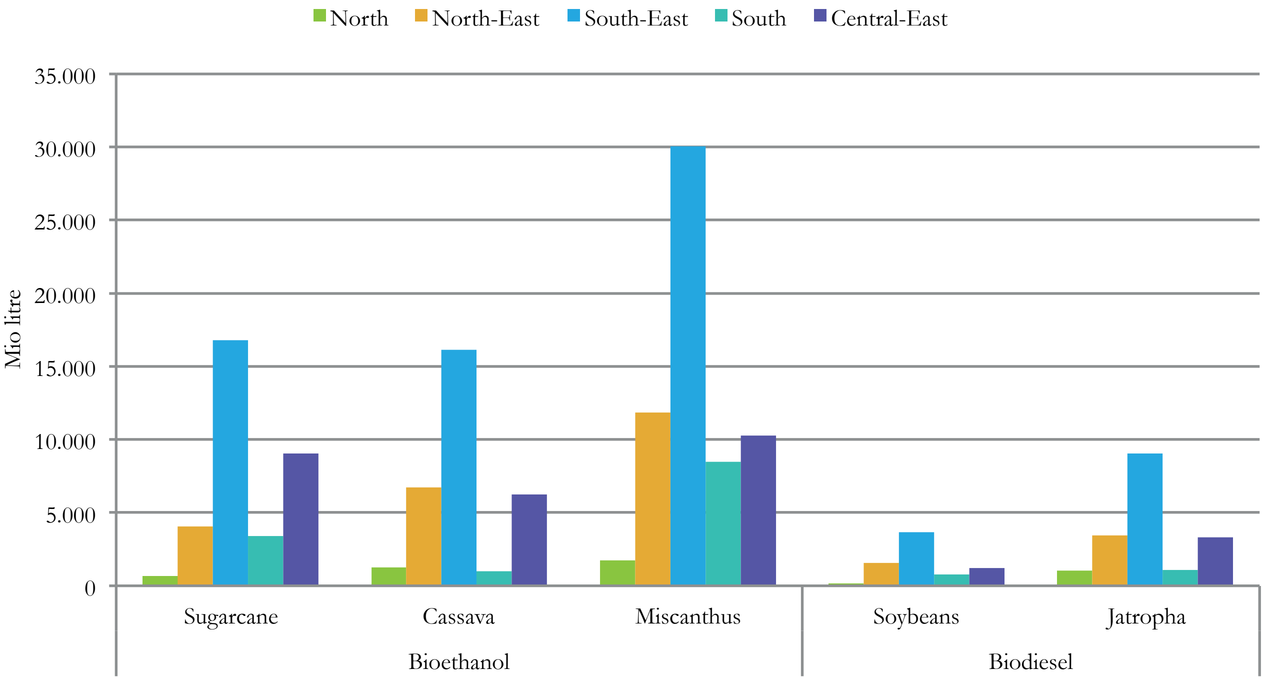

Figure III - 10 Biofuel potential from residual land by feedstock and regions

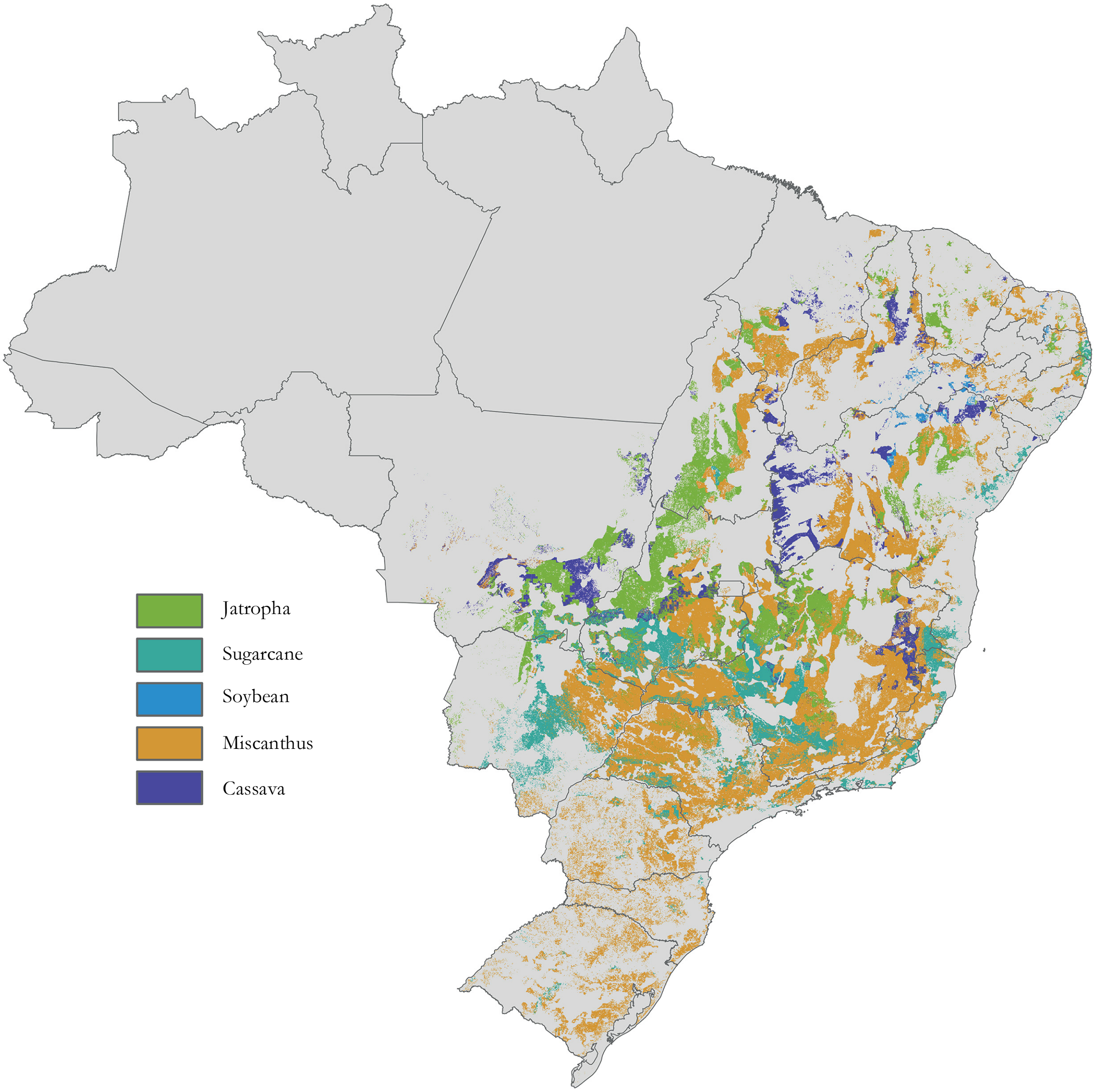

Figure III - 11 Best biofuel feedstock solution for residual land by feedstock (30 arc second grid-cell resolution)

States	Residual Land[a]	Residual Land suitable for biofuel feedstocks[b]	Sugarcane			Cassava		
			Potential Yield	Biofuel potential[d]	Energy yield[e]	Potential Yield	Biofuel potential[d]	Energy yield[e]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	PJ	1000 ton roots DW	Mio litre	PJ
North[c]	**2,550**	**1,523**	**14**	**10**	**0**	**1,986**	**777**	**16**
Rondônia	-	-	-	-	-	-	-	-
Acre	-	-	-	-	-	-	-	-
Amazonas	-	-	-	-	-	-	-	-
Roraima	-	-	-	-	-	-	-	-
Pará	-	-	-	-	-	-	-	-
Amapá	-	-	-	-	-	-	-	-
Tocantins	2,550	1,523	14	10	0	1,986	777	16
North-East	**8,074**	**6,202**	**1,058**	**717**	**15**	**7,450**	**2,913**	**62**
Maranhão	1,879	1,085	-	-	-	1,153	451	10
Piauí	1,138	562	-	-	-	147	57	1
Ceará	176	147	-	-	-	14	5	0
Rio Grande do Norte	128	92	-	-	-	4	2	0
Paraíba	173	149	304	206	4	31	12	0
Pernambuco	236	188	55	37	1	14	6	0
Alagoas	27	20	27	18	0	15	6	0
Sergipe	46	40	58	39	1	15	6	0
Bahia	4,271	3,919	614	416	9	6,058	2,369	50
South-East	**17,425**	**12,378**	**7,220**	**4,888**	**104**	**9,746**	**3,811**	**81**
Minas Gerais	12,547	8,460	3,337	2,259	48	9,715	3,798	81
Espírito Santo	794	436	707	479	10	31	12	0
Rio de Janeiro	779	387	592	400	8	-	-	-
São Paulo	3,305	3,095	2,584	1,749	37	-	-	-
South	**2,994**	**2,482**	**491**	**332**	**7**	**-**	**-**	**-**
Paraná	1,306	1,124	250	169	4	-	-	-
Santa Catarina	576	468	48	33	1	-	-	-
Rio Grande do Sul	1,112	890	193	131	3	-	-	-
Central-East	**6,756**	**5,408**	**6,974**	**4,722**	**100**	**6,082**	**2,378**	**50**
Mato Grosso do Sul	1,427	1,408	3,533	2,392	51	37	15	0
Mato Grosso	1,835	1,614	257	174	4	4,817	1,883	40
Goiás	3,482	2,380	3,184	2,156	46	1,228	480	10
Distrito Federal	12	6	-	-	-	0	0	0
Total Brazil	**37,799**	**27,993**	**15,758**	**10,668**	**226**	**25,264**	**9,878**	**209**

a Residual land is defined as remaining fraction currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome. Source: Brazilian 1 km land use database (Lossau et.al. 2015)

b Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. Not suitable land is not considered

c Rondônia, Acre, Amazonas, Raraima, Pará and Amapá are states located in legal Amazonas biome. Residual land in this states is excluded due definition d sugarcane (677 litre bioethanol / ton sugar), cassava (391 litre bioethanol / ton cassava roots (DW)), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), soybean (221 litre bioethanol / ton soybean grain (DW))jatropha (1049 litre biodiesel / ton jatropha oil)

e sugarcane (14.34 GJ / ton sugar), cassava (8.29 GJ / ton cassava roots (DW), miscanthus (6.35 GJ / ton miscanthus ABG (DW)), soybean (7.24 GJ / ton soybean grain (DW)), jatropha (34.51 GJ / ton jatropha oil)

AGB Above Ground Biomass

DW Dry Weights

Table III - 5 Best biofuel feedstock solutions for residual land (Part 1)

States	**Miscanthus**			**Soybean**			**Jatropha**		
	Potential Yield	**Biofuel potential[d]**	**Energy yield[e]**	**Potential Yield**	**Biofuel potential[d]**	**Energy yield[e]**	**Potential Yield**	**Biofuel potential[d]**	**Energy yield[e]**
	1000 ton AGB DW	Mio litre	PJ	1000 ton grain DW	Mio litre	PJ	1000 ton oil	Mio litre	PJ
North[c]	**1,501**	**450**	**10**	**-**	**-**	**-**	**426**	**447**	**15**
Rondônia	-	-	-	-	-	-	-	-	-
Acre	-	-	-	-	-	-	-	-	-
Amazonas	-	-	-	-	-	-	-	-	-
Roraima	-	-	-	-	-	-	-	-	-
Pará	-	-	-	-	-	-	-	-	-
Amapá	-	-	-	-	-	-	-	-	-
Tocantins	1,501	450	10	-	-	-	426	447	15
North-East	**25,988**	**7,796**	**165**	**33**	**7**	**0**	**23**	**24**	**1**
Maranhão	4,803	1,441	31	-	-	-	-	-	-
Piauí	2,591	777	16	6	1	0	0	0	0
Ceará	651	195	4	-	-	-	3	3	0
Rio Grande do Norte	443	133	3	1	0	0	2	3	0
Paraíba	287	86	2	0	0	0	1	1	0
Pernambuco	435	131	3	6	1	0	-	-	-
Alagoas	15	5	0	-	-	-	-	-	-
Sergipe	13	4	0	-	-	-	-	-	-
Bahia	16,748	5,025	106	19	4	0	17	18	1
South-East	**67,961**	**20,388**	**432**	**-**	**-**	**-**	**12**	**13**	**0**
Minas Gerais	34,249	10,275	217	-	-	-	12	13	0
Espírito Santo	1,945	584	12	-	-	-	-	-	-
Rio de Janeiro	1,169	351	7	-	-	-	-	-	-
São Paulo	30,598	9,180	194	-	-	-	-	-	-
South	**27,320**	**8,196**	**173**	**-**	**-**	**-**	**-**	**-**	**-**
Paraná	9,953	2,986	63	-	-	-	-	-	-
Santa Catarina	3,409	1,023	22	-	-	-	-	-	-
Rio Grande do Sul	13,958	4,187	89	-	-	-	-	-	-
Central-East	**16,249**	**4,875**	**103**	**-**	**-**	**-**	**37**	**39**	**1**
Mato Grosso do Sul	7,610	2,283	48	-	-	-	3	3	0
Mato Grosso	983	295	6	-	-	-	10	11	0
Goiás	7,517	2,255	48	-	-	-	25	26	1
Distrito Federal	139	42	1	-	-	-	-	-	-
Total Brazil	**139,019**	**41,706**	**883**	**33**	**7**	**0**	**498**	**523**	**17**

a Residual land is defined as remaining fraction currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome. Source: Brazilian 1 km land use database (Lossau et.al. 2015)

b Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. Not suitable land is not considered

c Rondônia, Acre, Amazonas, Raraima, Pará and Amapá are states located in legal Amazonas biome. Residual land in this states is excluded due

d sugarcane (677 litre bioethanol / ton sugar), cassava (391 litre erthanol / ton cassava roots (DW)), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), soybean (221 litre bioethanol / ton soybean grain (DW))jatropha (1049 litre biodiesel / ton jatropha oil)

e sugarcane (14.34 GJ / ton sugar), cassava (8.29 GJ / ton cassava roots (DW), miscanthus (6.35 GJ / ton miscanthus ABG (DW)), soybean (7.24 GJ / ton soybean grain (DW)), jatropha (34.51 GJ / ton jatropha oil)

AGB Above Ground Biomass

DW Dry Weights

Table III – 6 Best biofuel feedstock solutions for residual land (Part 2)

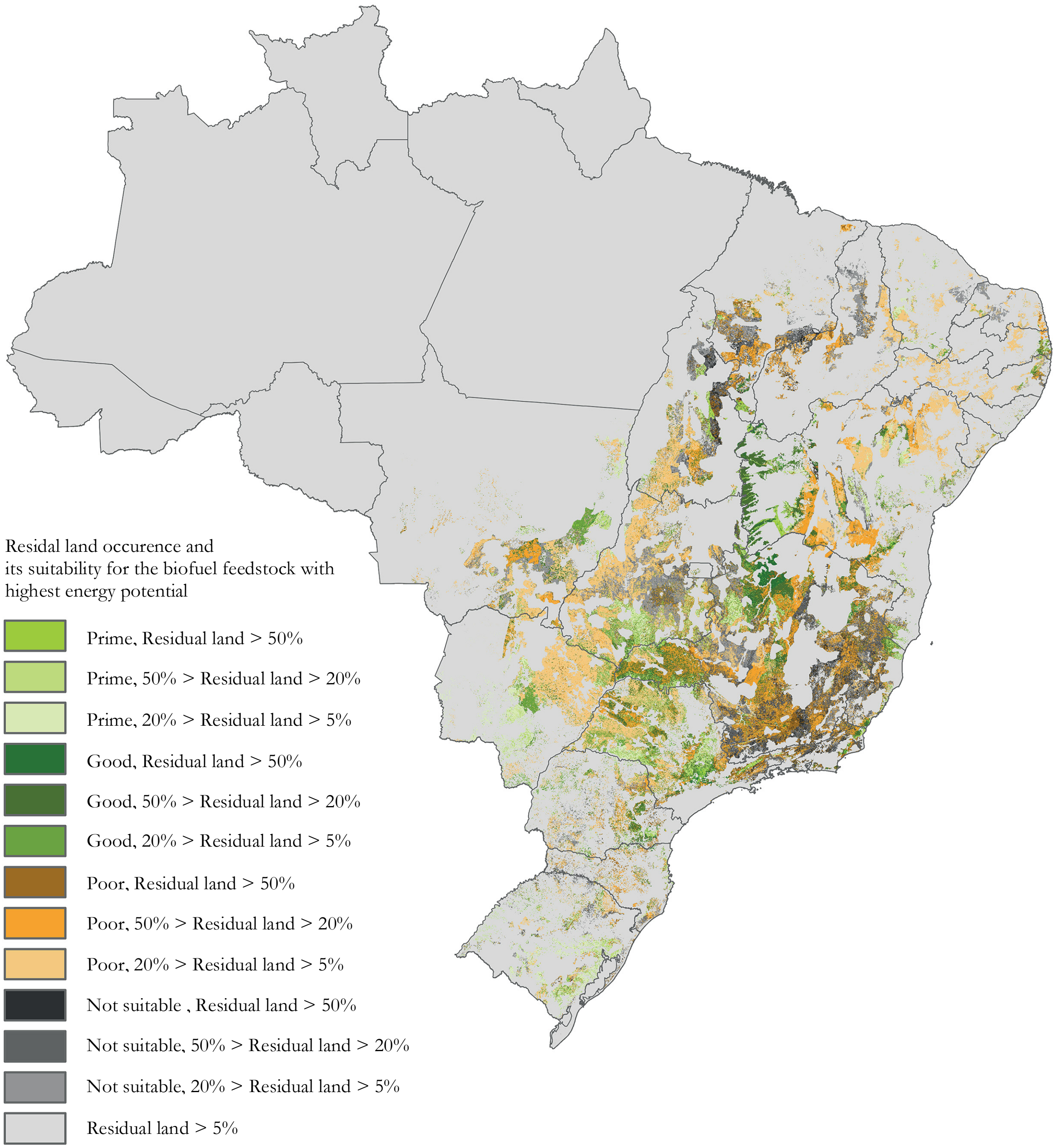

Figure III - 12 Suitability of residual land for the biofuel feedstock with highest biofuel energy potential (30 arc second grid-cell resolution)

5 Discussion

Results illustrate the ample agronomic potential for specific biofuel feedstock in residual land. Almost three-quarters of the residual land area is suitable for biofuel feedstock production with a varying degree of productivity depending on biofuel feedstock. The 37 Mha residual land comprises 2% prime land, 24% of good land, 46% of poor land and 28% not suitable land for any of the assessed biofuel feedstock. The following discusses the potential importance of biofuels for Brazil's transport sector, GHG mitigation potentials when replacing fossil fuels by biofuels produced from Brazil's residual land, followed by a discussion on potential replacement of fossil transport fuels.

5.1 Potential contribution of biofuels to Brazil's transport energy demand

Residual land when used for sugarcane potentially produces about 50 Mt sugar (equivalent to 34 billion litres bioethanol or 720 PJ). This is more than Brazil's current domestic ethanol demand for fuel of 23 billion litres (490 PJ) (see Table III-7) (USDA 2014a). Alternatively a similar amount of bioethanol, about 31 billion litres (664 PJ), could be produced from cassava or about 62 billion litres (1,320 PJ) from miscanthus. Using residual land for the production of biodiesel could either produce between 7 billion litres biodiesel (242 PJ) from soybean or 18 billion litres biodiesel (588 PJ) from jatropha cultivation. This is more than Brazil's current domestic biodiesel demand for fuel of 3 billion litres (115 PJ) (USDA 2014a). However experiences with miscanthus as biofuel feedstock are still researched with commercial scale application being still under development and achievable oil yields from jatropha cultivation are still uncertain from an agronomic viewpoint.

	Mio litres	**PJ**	**% of demand**
Ethanol Demand (2014)	23,200	491	
Bioethanol potential from residual land			
sugarcane [a]	33,975	720	146%
cassava [a]	31,335	664	135%
miscanthus [a]	62,355	1,320	269%
best biofuel feedstock [b]	62,252	1,318	268%
Biodiesel Demand (2014)	3,500	115	
Biodiesel potential from residual land			
soybean [a]	7,399	242	211%
jatropha [a]	17,887	588	511%
best biofuel feedstock [b]	530	17	15%

a Production potential when solely this biofuel feedstock is planted on residual land
b The best biofuel feedstock was achieved by choosing for each grid-cell the best producing biofuel feedstock in terms of energy
Source: (USDA 2014a) and self-calculations

Table III - 7 Potential contribution of biofuels to Brazil's transport energy demand

A comparison of the different biofuel feedstocks potentially grown on residual land suggests that from the 27.9 Mha residual land suitable for biofuel feedstock production, miscanthus cultivation would provide the highest output in energy terms (883 PJ) on 16.1 Mha, sugarcane (226 PJ) on 3.9 Mha , cassava (209 PJ) on 7.5 Mha, jatropha (17 PJ) on 0.4 Mha and soybeans (0.2 PJ) on 0.1 Mha. Assuming that the best biofuel feedstock in energy terms is grown at each location suggests a theoretical maximum biofuel potential of 1,336 PJ available from Brazil's residual land. This equates to more than twice of Brazil's current bioethanol demand and underlines that Brazil will also be a key player in bioethanol trade in future. Current bioethanol exports are around 1 billion litres but could potentially raise up to 40 billion litres. In the case of biodiesel only 15% of current energy demand could be met assuming that the best biofuel feedstock in terms of energy is used.

However, not all land with identified technical potential of residual land qualifies equally for the practical implementation of biofuel feedstock plantations. Hence, in addition to the quality and suitability of residual land also location-specific investment requirement and transport cost as well as future demand for food, livestock feed and pasture land will play an important role in the discussion of residual land potentials for biofuel feedstocks.

Farm economics and logistics will favour production of biofuel feedstocks in areas of high residual land concentration with prime and good quality. Most such areas are concentrated in the West of Bahia, all over São Paulo, in the East of Mato Grosso and in the West of Paraná. In these areas the residual land shares per pixel are higher than 33% and in addition more than half of the land is from prime or good quality for biofuel feedstocks.

By 2030 availability of the 37 Mha residual land for biofuel feedstock production is possible when pastures are carefully used for livestock and cropland expansion (see Lossau et al. 2015). However, it is important to emphasize that food and livestock feed demand higher than those projected would exceed Brazil's pasture production capacities, then at least part of the residual land will be required for the food and livestock feed sector assuming that safeguarding forest ecosystems is a prime objective.

5.2 GHG reduction potential

Over the past few years there has been a debate on the extent to which biofuels reduce GHG in view of emissions associated with direct and indirect land-use changes (LUC) triggered by biofuel production (Edwards et al. 2010, Tyner et al. 2010, Bauen et al. 2010, Rettenmaier et al. 2009, Lange 2010). GHG emission factors vary depending on the specific biofuel production process, feedstock production practices, and amount and type of agro-chemicals used. The Renewable Energy Directive 2009 (RED) (EC 2009) by the European Commission (EC) has put forward regulations discouraging LUC for expansion of the bioenergy feedstock production area. The Renewable Energy Directive provides values for carbon intensities for different biofuel chains in CO_2 equivalent (CO_2eq) per MJ of biofuel for sugarcane bioethanol and soybean biodiesel. For jatropha biodiesel, cassava and miscanthus bioethanol GHG emission values are taken from the Renewable Transport Fuel Obligation (RTFO) (RFA-RTFO 2012). GHG values for different biofuel systems, summarized by Renewable Fuels Agency (RFA), specify values for each step of the fuel chain, from crop production to filling station. The GHG emission factors are presented in Table III-1.

Biofuel GHG emissions are compared with the energy systems replaced. The fossil reference system indicates 83,8 g CO_2eq emissions per MJ of consumed gasoline or diesel (EC 2009). Figure III-13 presents potential GHG emissions saving assuming that the feedstock with the highest energy potential in residual land is used for replacing fossil transport fuels.

Results suggest that sugarcane bioethanol has a significant potential for GHG mitigation. About 43 Mt CO_2eq could be saved annually by using sugarcane bioethanol from Brazil's residual land. The GHG mitigation savings associated with biodiesel from soybeans are more modest; only 8 Mt CO_2eq could be saved. More promising is cassava bioethanol with a GHG saving potential about 27 Mt CO_2eq. The best biofuel option for reducing GHG emissions of the transport sector is miscanthus bioethanol (98 Mt CO_2eq) followed by jatropha biodiesel (34 Mt CO_2eq).

Reference values of GHG within the framework of the sustainability directive of the Renewable Energy Directive, are conservative (Rettenmaier et al. 2014). The levels of CO_2 mitigation associated with biofuels could be substantially reduced when accounting the use of co-products and to use of process energy from renewable sources rather than from fossil fuels (OECD-IEA 2011). The Renewable Energy Directive attributes a bonus of

29 g CO_2eq/MJ in the computation of the carbon balance, in case land is degraded has low organic matter content or is heavily contaminated and therefore unsuitable for food and livestock feed production (EC 2009). This degraded land (in terms of land suitability) is part of residual land and the biofuel produced will likely be eligible for additional emission bonuses.

5.3 Replacement potential of fossil transport fuels

Average fuel consumption of one passenger car amounts to 7.4 litres of gasoline per 100 km and 5.1 litres for diesel respectively (BMELV-FNR 2012). Taking into account the different energy content of gasoline and fuel ethanol (0.65 gasoline equivalent) (BMELV-FNR 2009) fuel consumption increases to 11.4 litres of pure ethanol (E100) per 100 km. For biodiesel, fuel consumption to 5.7 litres per 100 km for soybean biodiesel (0.90 diesel equivalent) (BMELV-FNR 2009) and 5.5 litres for jatropha biodiesel (0.92 diesel equivalent) (BMELV-FNR 2009). Figure III-14 shows the achievable distance a passenger car could travel when it is fuelled by biofuels cultivated on residual land. Comparing travel distances, miscanthus and jatropha appears as the best biofuel feedstock options for residual land. One passenger car could drive 547 billion km using miscanthus bioethanol and 325 billion km using jatropha biodiesel produced from residual land, followed by sugarcane bioethanol (300 billion km), cassava bioethanol (275 billion km) and soybean biodiesel (130 billion km).

In summary, depending on type of feedstock, land quality and conversion technology, substantial quantities of biofuel feedstock could be produced on Brazil's residual land. However, not all land with identified potential of residual land qualifies equally for the practical implementation of best biofuel feedstock option in terms of biofuel output. Brazil is the world's second largest producer of sugarcane based bioethanol and the world's largest exporter.

Brazil's biodiesel production has started in 2006 and now has ample experience with biofuel production from both sugarcane and soybean. Cassava cultivation and management itself is well established; cassava roots have

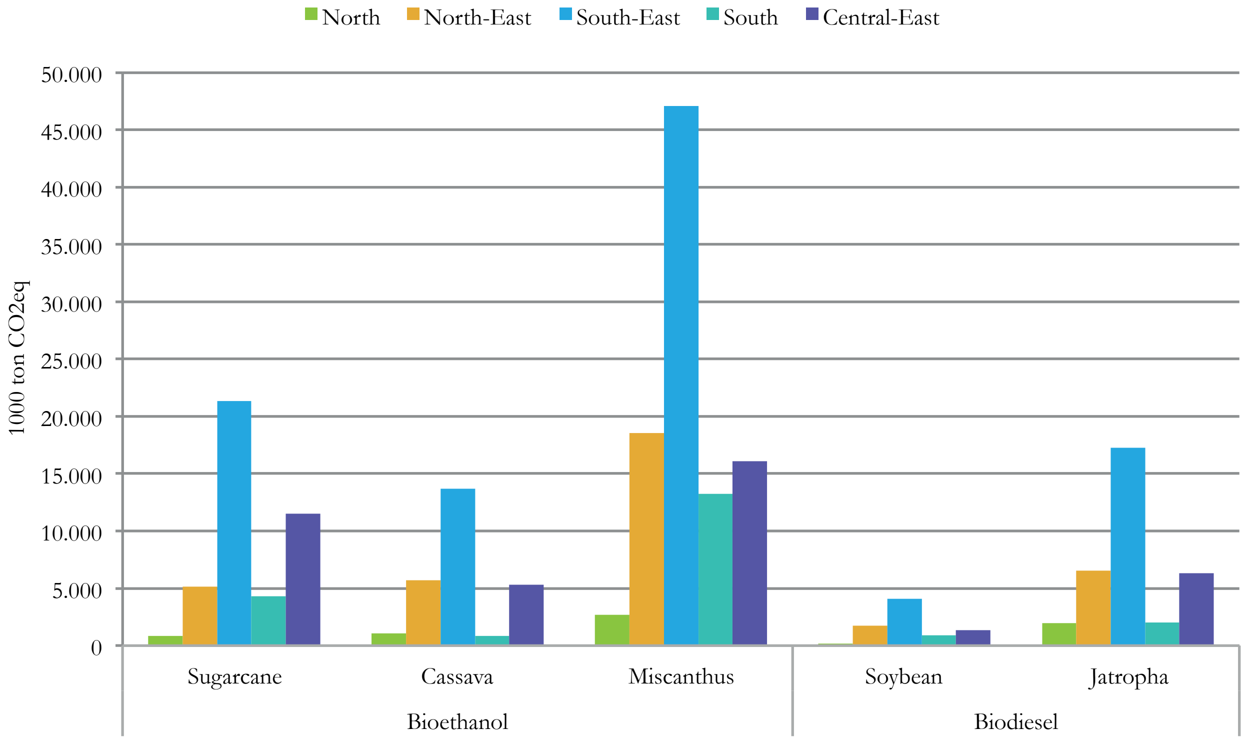

Figure III - 13 Biofuel GHG saving potential from residual land long been produced as food crop. In the case of jatropha and miscanthus, relevant experience is currently not available both at the feedstock production level and for the industrial biofuel production. Varying of degrees of spatial concentration and quality and suitability of residual land, location-specific investment requirements, feedstock transportation costs, and future demand for food and livestock feed will motivate future exploitation of residual land potentials for biofuel feedstock production.

6 Conclusions

A detailed land balance analysis of Brazil (Lossau et al. 2015) suggests availability of 37 Mha residual land, an area equivalent to about 50% of current cropland. Residual land excludes cropland, pastures, forests, urban areas, the Amazon biome, and all areas designated as protected or of high biodiversity value. Residual land is mainly concentrated in the South-East (17 Mha), other important regions include the North-East (8 Mha) and Central-East (7 Mha).

Land suitability assessment of residual land reveals that almost three-quarters of the residual land area is to some degree suitable for biofuel feedstock production. Of the 37 Mha residual land 2% is prime of quality land, 24% of good land, of 46% poor land and 28% of not suitable land for the assessed biofuel feedstocks.

Residual land when used for sugarcane potentially produces about 50 Mt sugar (equivalent to 34 billion litres bioethanol or 720 PJ). This is more than Brazil's current domestic ethanol demand of 23 billion litres (491 PJ) (USDA 2014a). Alternatively a similar amount of bioethanol, about 31 billion litres (664 PJ), could be produced from cassava or about 62 billion litres (1,320 PJ) from miscanthus. However miscanthus conversion to biofuel requires second-generation technologies, for which commercial-scale application is still under development.

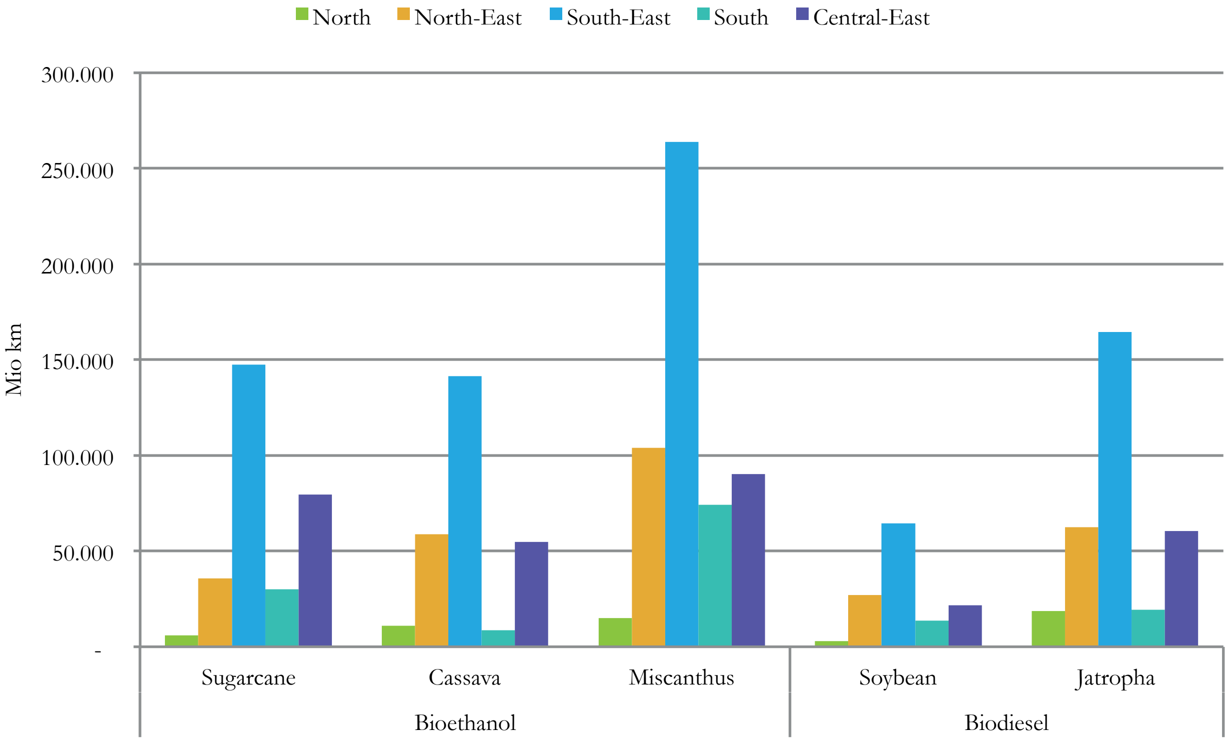

Figure III - 14 Cruising range of one passenger car using biofuels from residual land

Using residual land for the production of biodiesel could either produce between 7 billion litres biodiesel (242 PJ) from soybeans or 18 billion litres biodiesel (588 PJ) from jatropha cultivation. However, achievable oil yields from jatropha cultivation are still uncertain from an agronomic point of view.

Assuming that the best biofuel feedstock in energy terms is grown in each location, suggests a theoretical maximum biofuel potential of 1,378 PJ available from Brazil's residual land. Of this potential the majority is from miscanthus grown on 16 Mha, followed by cassava on 7.5 Mha and sugarcane grown on 4 Mha. Jatropha derived biodiesel is the best option in energy terms only on 0.4 Mha followed by soybean on 0.1 Mha residual land.

Not all land with identified technical potential of residual land qualifies equally for the practical implementation of biofuel feedstock plantations. Varying of degrees of spatial concentration and quality and suitability of residual land, location-specific investment requirements, feedstock transportation costs, and future demand for food and livestock feed will motivate future exploitation of residual land potentials for biofuel feedstock production.

Only when the livestock sector continues to increase its non-pasture based feed share, the 37 Mha (27.5 Mha) residual land can be available for the use of biofuel feedstock production beyond 2010 (Lossau et al. 2015). Potential future biofuel feedstock production from residual land may need adjustment due to climate change impacts, to be explored in follow-up research.

Acknowledgement

The authors thank Professor Sobral from University of Pernambuco for kindly providing information on available land use data for Brazil. Additionally thanks goes to Mr George Francis for providing support on available data for jatropha and miscanthus. We would like to acknowledge the importance of the funding provided by the Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU), within the scope of the Young Scientist Summer Program (YSSP), organized by the International Institute for Systems analysis (IIASA).

Chapter IV
Biofuels from Wasteland in India: Agro-ecological assessment for Jatropha, Miscanthus and Sugarcane[4]

Abstract

There is a large interest in biofuels in India as a substitute to fossil fuels, with a purpose of enhancing energy security and promoting rural development. India has set an ambitious target of substituting 20% of fossil fuel consumption of biodiesel and bioethanol by 2017. India has announced a national biofuel policy and launched a large program to promote biofuel production, particularly for wastelands. The implications need to be studied intensively considering the fact that India is a large transitional economy with high population density and large rural population depending upon agricultural activities for their livelihood. Another factor is that Indian economy is experiencing high growth rate, which increases demands for food and livestock products. This paper presents an assessment of biofuel production potentials on Indian wasteland, which combines available statistical information from the agricultural survey and specific statistical data of wastelands from the Wasteland Atlas with geospatial information for wasteland suitability for biofuel feedstocks obtained from the Global Agro-ecological Zones (GAEZ) assessment, which was carried out for the purpose of this study. Downscaling procedures have been implemented to estimate the suitability of biofuel feedstocks on culturable wasteland. Results indicate that of the total continental area of India (327 Mha), 14% of which is considered wasteland contains less than one-third (13 Mha) that is somehow suitable for growing biofuels feedstocks. The potential productivity estimates of wasteland, expressed in biomass (t/ha) and biofuel equivalents (l/t), for established biofuel feedstock sugarcane has been compared with alternative biofuel feedstocks, miscanthus and jatropha. The production potential of wastelands we estimate to be 3.9 billion litres bioethanol for sugarcane and 11.7 billion litres for miscanthus. Potential biodiesel production of jatropha was estimated to be about 6.6 billion litres biodiesel. Biofuel feedstocks production potentials have been converted to energy output (GJ) and equated with GHG saving potential (ton CO2eq). Further, for the culturable wasteland share in a district the maximum amount of biofuel energy, was determined by selecting for each district the best yielding biofuel feedstocks in terms of biofuel energy output

Keywords: Wasteland, GAEZ methodology, Biofuel, India, GHG savings

1 Introduction

India is the world's fourth largest primary energy consumer and fourth largest petroleum consumer (EIA 2014). Rapid economic expansion of around 9% (OECD-IEA 2012b) in recent years has increased primary energy demand from 13 EJ in 1990 to 29 EJ in 2010, which is expected to more than double by 2035 (OECD-IEA 2012a). The highest growth rate occurs in the transport sector (WEO 2007), which is driven by road traffic with annual growth rates during recent years of 7 to 10% (USDA 2012). The current 2 EJ energy demand of the transport sector is expected to more than quadruple by 2035 (OECD-IEA 2012a). Diesel and gasoline cover

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[4] Lossau S, Fischer G, Tramberend S, van Velthuizen H, Kleinschmit B, Schomäcker R. Biofuels from Wasteland in India: Agro-ecological assessment for Jatropha, Miscanthus and Sugarcane. Forthcoming at Biomass and Bioenergy, Elsevier B.V, Amsterdam, Netherlands

more than 95% of the national transportation fuel needs. This sector consumes 50% of India's oil, which is for 75% imported (OECD-IEA 2012b). Volatile oil prices and the uncertainty about sustained oil supplies have led the Indian Government to search for alternatives to fossil fuels to improve energy security. Biofuels are considered as a promising option as it can be produced locally and can substitute fossil diesel and gasoline in the transportation sector. The National Biofuel Steering Committee (NBSC) under the Prime Minister announced a target of substituting 20% of fossil fuel consumption by biodiesel and bioethanol from 2017 (USDA 2014b). The key feedstocks for sustainable production systems and to develop economically viable biofuel supply chains for biofuel provision. The use of biofuels should stimulate rural development through increased employment opportunities, should provide environmental benefits and support the automobile industry with CO_2 credits (Riegel 2009).

The critical question is whether there is adequate spare land available in India that is suited for biofuel feedstock production. Unlike other emerging economics such as Brazil, where significant extents of residual land exist (Lossau et al. 2015), spare land for biofuel production in India is very scarce.

India comprising 2.4% of the world's land area, is supporting over 1.24 billion world's second largest population (WDI 2014). India comprises of 30 states grouped in six main regions (Figure IV-1) and has a total land area of 327 Mha, of which 67 Mha is forest. Agricultural area includes 179 Mha made up for 95% crop and fallow land and for 5% of pasture land (DACNET 2007). Other land for waterbodies, build-up, barren and wasteland areas amounts to 80 Mha, almost 24% of the country. High population density close to 380 persons per km² and annual population growth rates of 1.3% (WDI 2014) highlight scarce land availability for food, livestock feed and biofuel production. Limited availability of agriculture land, slow agricultural productivity growth, increasing land demand by competing sectors, risks of acute food shortages and consequential price hikes have prompted India policymakers to launch a large program promoting the use of wasteland for biofuel feedstock. The use of those wastelands that are otherwise unsuited to food or livestock feed production, avoids possible conflicts of fuel- versus food security and deforestation (USDA 2012). Although wasteland areas are readily available and relatively cheap, the extent to which wasteland areas may considered for economically viable biofuel feedstock production requires a critical and a priori assessment of its production potential.

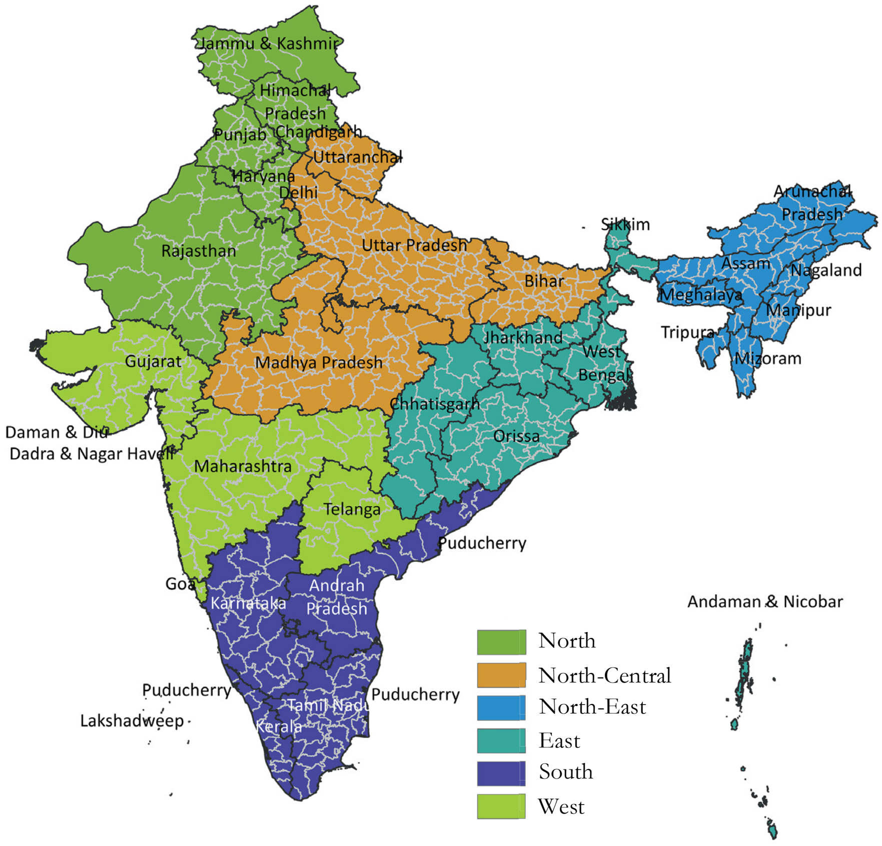


Figure IV - 1 Administrative regions of India

For these reasons, Daimler AG in co-operation with the International Institute for Applied System Analysis (IIASA) and the Technical University of Berlin launched a project to locate and subsequently assess suitability and yield potentials of wasteland for promising biofuel feedstocks.

The research combines available statistical information from India's agricultural survey (DACNET 2007) and statistical data contained in the Wasteland Atlas of India (NRSC 2010). Derived locations and extents of wasteland have been assessed for feedstock production potentials (FAO-IIASA 2012). Suitability and productivity of jatropha, sugarcane and miscanthus is estimated as follows:

(i) Assessment of biophysical production potentials of wastelands for sugarcane (currently cultivated for biofuel production); jatropha (currently tested) and miscanthus (option for additional feedstock currently under consideration);

(ii) Aggregation of attainable yield and production of wasteland by district and by state, calculated in terms of biomass (t/ha), biofuel equivalent (l/ha) and energy (GJ/ha);

(iii) Quantification of greenhouse gas (GHG) saved (in tonnes CO_2 equivalent (CO_2eq)) through replacement of fossil fuels with biofuels from wasteland;

(iv) Maximizing biofuels produced from wasteland at district level by selection of biofuel feedstocks in terms of biofuel energy output (GJ/ton biomass);

(v) Assessing the degree of concentration of suitable wasteland based on best performing feedstock;

(vi) Determining potential future use of wasteland for biofuel feedstocks and its impact on biofuel production and CO_2 emission reductions

After introducing the current Indian status of biofuel production in section 2, section 3 presents data and methodology applied for the location of wasteland and the assessment of biomass yield potentials. Section 4 presents results for biofuel potentials in terms of biomass and energy. In section 5 potentials for reducing GHGs and substitution fossil fuels for biofuels are discussed. The final section presents conclusions.

2 Current biofuel production in India

2.1 Bioethanol production

In India sugar molasses, a by-product of the sugar industry, is the main feedstock for bioethanol production. India has an important sugar cane industry based on 5 Mha of cultivated land with a production of 342 Mt in the year 2011 (FAO 2011). Most of the sugarcane production is located in Maharashtra, where more than one-thirds of sugarcane is being produced (DACNET 2007). Further. sugarcane is grown in Uttar Pradesh (30%), Tamil Nadu (10%) and Karnataka (7%) states. Only a small part of this production is used for bioethanol (1.2–1.8 Mt per year (OFID-IIASA 2009)) which can be produced from 330 distilleries (USDA 2014b). Support for fuel bioethanol production started in 2003, when India's government mandated that nine States and four Union territories were required to sell E-5, a 5% blend of ethanol in gasoline through its ambitious Ethanol Blending Program (EBP) (USDA 2014b). However, in view of supply constraints from the sugar industry, the original proposal was first reduced to only 4 states and later fully suspended (OFID-IIASA 2009). The recovery of sugar and molasses output during 2005– 06 generated renewed interest in the ethanol program. In October 2008 the government introduced an E-10 mandate (F.O. Lichts 2008).

Sugarcane (Saccharum officinarum) production in India is cyclical; the ethanol production varies with sugar and sugarcane production and does not warrant optimum supply levels needed to meet the demand at any given time. Reduced sugar molasses availability and consequent higher molasses prices affect the cost of production of ethanol and disrupts the supply of ethanol for the blending program at pre-negotiated fixed ethanol prices (USDA 2014). Bioethanol utilization is restricted to the transportation sector only (Pisces 2011). In India conventional bioethanol is solely produced from sugar molasses; production of bioethanol from miscanthus (second-generation cellulosic ethanol production) is in a nascent phase only (research and development) (USDA 2012).

Miscanthus (miscanthus x giganteus), is a perennial feedstock with a high cellulose yield potential and moderate input requirements, which makes the plant a leading candidate for second-generation cellulosic ethanol production (DOE 2006). Miscanthus originates from East Asia (Heaton E et al. 2004) where it is used for forage, clothing, shelter, etc. (Chou 2009). From its second season onwards miscanthus grows to a height of 2.5–3.5 m. It remains productive for over 15 years (up to 25 years) (McKervey et al. 2008) and has relative low fertilizer requirements compared to most agricultural crops. Miscanthus is adapted a wide range of soil conditions, including marginal low nutrient soils, but is most productive on good agricultural soils (ISU 2010). The Ministry of New and Renewable Energy, especially through the Department of Biotechnology, and the Ministry of Science and Technology have promoted research and development in second- generation biofuels (ADB 2011).

2.2 Biodiesel production

Commercial production of biodiesel, is almost non-existent in India. Due to high vegetable oil prices in the domestic market, biodiesel production is currently un-economic. The Government of India launched the National Biodiesel Mission (NBM), which identified jatropha as promising oilseed for biodiesel production.

Jathropha (Jatropha curcas), is a perennial large shrub native from Central America. It has a rotation length of 30 to 50 years and can bear fruits after 12 months and reaches its maximum productivity 5 years after planting (Atabani et al. 2013). There are various promising features of growing jatropha as biofuel feedstock. It grows relatively well under marginal conditions, i.e. it tolerates marginal soils with low nutrient content, can grow in a broad range of rainfall regimes, from 500 up to 3000 mm per annum, is reported fairly resistant to pests and diseases and proved to be useful for soil conservation (Achten et al. 2008). Jatropha is well adapted to moist semi-arid conditions, however it performs best in humid environments. Yet, jatropha's productivity is reported to be highly variable and its yield performance is uncertain when specific varieties are transferred to different ecological circumstances and management (OFID-IIASA 2009). Jatropha's seeds contain around 25 to 40% oil (Moncaleano-Escandon et al. 2013). Seed yield of jatropha varies widely, reported yields range between 439 to 2,217 litre oil per ha (Jongschaap et al. 2007).

India's Planning Commission had set an ambitious target of planting between 11.2 to 13.4 Mha of land to jatropha by the end of 2012 (USDA 2014b). Today, even though the central government and several state governments provide fiscal incentives in support of planting jatropha and several public institutions are supporting the biofuel mission (USDA 2014b), only small quantities of jatropha and other non-edible oilseeds are crushed for oil, mainly used for lighting. By 2008 more than 700,000 ha of land was planted with jatropha. This mostly concerns new plantations that are as to date not yet fully productive (Biswas et al. 2013). The ambitious blending target of 20% for biodiesel had to be postponed from 2011/2012 to 2016/2017 (OFID-IIASA 2009).

However, currently India is one of the largest producers of jatropha globally (Upham et al. 2012). Commercial production and marketing of jatropha-based biodiesel in India is still small, estimates varying from 140 to 300 million litres per year (USDA 2012). There are about 6 biodiesel plants with a capacity of 480 million litres in India that produce biodiesel (USDA 2014b).

3 Methodology and Data

The assessment follows a five-step approach:

(i) Allocation of wasteland

(ii) Land suitability for biofuel feedstock

(iii) Suitability of wasteland for biofuel feedstock

(iv) Characterization of culturable wasteland using Wasteland Atlas statistics.

(v) Biofuel production potential of allocated wasteland

3.1 Allocation of wasteland

For the estimation of suitability of India's wasteland areas for biofuel feedstock, relative location and extents of culturable wasteland is required. Available statistical information from agricultural survey of the year 2007 (DACNET 2007) and statistical data from the Wasteland Atlas of the year 2010 (NRSC 2010) are combined and scaled against spatial information on administrative units for India provided by Global Administrative Unit Layers (GAUL) (FAO 2014). Statistical information of land use/land cover survey by the Department of Agriculture and Cooperation (DACNET) was obtained for India's 420 districts (DACNET 2007). These land use/land cover statistics include extents of the following major land categories: (i) cropland, (ii) fallow land, (iii) miscellaneous trees/groves, (iv) pastures, (v) forest, (vi) built-up land, (vii) barren/unculturable land and (viii) extents of culturable wasteland. The culturable wasteland category is considered for the assessment of potential biofuel feedstock production. Other wasteland is found in the category barren/unculturable land. The definition of culturable wasteland and barren/unculturable land are shown in Table IV-1.

Types	**Description**
Culturable Wasteland	Culturable wasteland is defined as land available for cultivation, whether taken up or not taken up for cultivation once, but not cultivated during the last five years or more in succession including the current year for some reason or the other. Such land may be either fallow or covered with shrubs and jungles, which are not put to any use. They may be accessible or un-accessible and may lie in isolated blocks or within cultivated holdings
Barren/unculturable land	Barren/unculturable land is defined as land covered by mountains, deserts, etc. Such land cannot be brought under cultivation except at an exorbitant cost is classified as unculturable whether such land is in isolated blocks or within cultivated
Source: Department of Agriculture and Cooperation (DACNET 2007)	

Table IV - 1 Definition of culturable wasteland and barren/unculturable land

In total 13 Mha (4% of total geographical area) are surveyed as culturable wasteland and 17 Mha (5% of total geographical area) as barren/unculturable land (DACNET 2007). Table IV-2 summarizes major land categories including culturable wasteland and barren/unculturable land aggregated at state level.

According to estimates presented in the Wastelands Atlas of India - a satellite-based land survey by the Indian Ministry of Rural Development - the total area under wastelands is 47 Mha (14% of the total geographical area). The wasteland is consisting of 23 different wasteland categories (Table IV-3) (NRSC 2010). The difference between the 47 Mha of wasteland estimates in the Wasteland Atlas 2010 and the 30 Mha (culturable wasteland and barren/unculturable land) surveyed by DACNET can be explained through different wasteland definitions and the fact, that Wasteland Atlas categories like shifting cultivation areas, degraded forest, pasture or land under plantation crops, urban land and used for infrastructure and industrial purposes might already included in the DACNET categories cropland, fallow land, miscellaneous trees/groves, pasture, forest and built-up land.

States **in 1000 ha**	**Total Land Area**	**Crop Land**	**Fallow Land**	**Miscellaneous Trees & Groves**	**Pastures**	**Forests**	**Built-up Land**	**Barren / Unculturable Land**	**Cultur-able Waste Land**
North	**71,484**	**25,787**	**4,557**	**174**	**3,353**	**4,794**	**3,504**	**3,505**	**4,963**
Haryana	4,421	3,556	149	12	27	39	421	103	65
Himachal Pradesh	5,567	541	78	66	1,491	1,101	473	658	137
Jammu and Kashmir	22,224	742	89	72	128	658	293	289	146
Punjab	5,036	4,184	36	4	2	298	477	27	4
Rajasthan	34,224	16,764	4,204	20	1,706	2,698	1,835	2,427	4,611
Chandigarh	11	1	0	0	-	0	5	-	-
North-Central	**69,830**	**37,762**	**4,022**	**902**	**1,650**	**14,444**	**6,604**	**2,677**	**2,039**
Bihar	9,416	5,665	686	241	17	622	1,647	436	46
Madhya Pradesh	30,825	14,735	1,381	19	1,348	8,699	1,992	1,406	1,177
Uttar Pradesh	24,093	16,573	1,827	373	64	1,657	2,729	507	440
Uttarakhand	5,348	765	108	269	220	3,465	161	312	367
Delhi	148	23	19	1	0	1	76	16	10
North-East	**25,508**	**4,087**	**928**	**615**	**184**	**12,854**	**1,535**	**1,642**	**665**
Arunachal Pradesh	8,374	209	109	37	18	5,154	23	42	67
Assam	7,844	2,753	186	209	160	1,954	1,065	1,447	77
Manipur	2,233	225	-	6	1	1,742	26	1	1
Meghalaya	2,243	213	237	158	-	942	91	137	450
Mizoram	2,108	91	208	69	5	1,594	125	9	5
Nagaland	1,658	316	186	111	-	863	74	4	64
Tripura	1,049	280	2	27	-	606	131	3	1
East	**47,471**	**17,265**	**4,009**	**520**	**1,472**	**16,883**	**4,504**	**1,741**	**1,108**
Chhattisgarh	13,519	4,722	509	1	857	6,355	683	313	350
Jharkhand	7,971	1,504	2,368	93	110	2,239	758	564	334
Orissa	15,571	5,654	755	342	494	5,813	1,298	840	375
Sikkim	710	77	9	8	-	584	11	-	3
West Bengal	8,875	5,296	363	58	5	1,174	1,733	21	34
Andaman and Nicobar	825	13	4	18	6	717	22	3	12
South	**63,629**	**27,502**	**9,362**	**891**	**1,647**	**12,470**	**6,672**	**3,414**	**1,561**
Andhra Pradesh	16,021	6,143	2,035	206	275	3,467	1,888	1,494	512
Karnataka	19,179	10,105	2,080	292	934	3,072	1,363	788	416
Kerala	3,886	2,101	129	9	0	1,082	449	26	90
Tamil Nadu	13,006	5,126	2,400	268	110	2,106	2,160	502	354
Telangana	11,486	4,003	2,714	114	327	2,743	795	603	184
Lakshadweep	3	3	-	-	-	-	-	-	-
Puducherry	48	20	5	1	-	-	18	0	4
West	**50,804**	**27,435**	**3,183**	**253**	**2,107**	**7,191**	**2,611**	**4,315**	**2,943**
Goa	370	137	7	1	1	125	37	-	53
Gujarat	19,602	9,801	642	4	853	1,833	1,163	2,595	1,976
Maharashtra	30,771	17,473	2,531	249	1,252	5,212	1,407	1,720	914
Dadra and Nagar Haveli	49	21	3	-	1	20	4	0	0
Daman and Diu	11	2	0	0	-	-	0	-	0
TOTAL	**328,726**	**139,839**	**26,060**	**3,355**	**10,414**	**68,636**	**25,431**	**17,294**	**13,278**

Source: Department of Agriculture and Cooperation National Information Center (DACNET 2007). District Wise Land Use Statistics from the year 2006/2007. Due to lack of data, statistic of the year 2005/2006 were used for Chatisgarh and Maharastrah, statistics of the year 1999/2000 for Lakshadweep and statistics of the year 2007/2008 for Nagaland

Table IV - 2 Major land categories aggregated by state

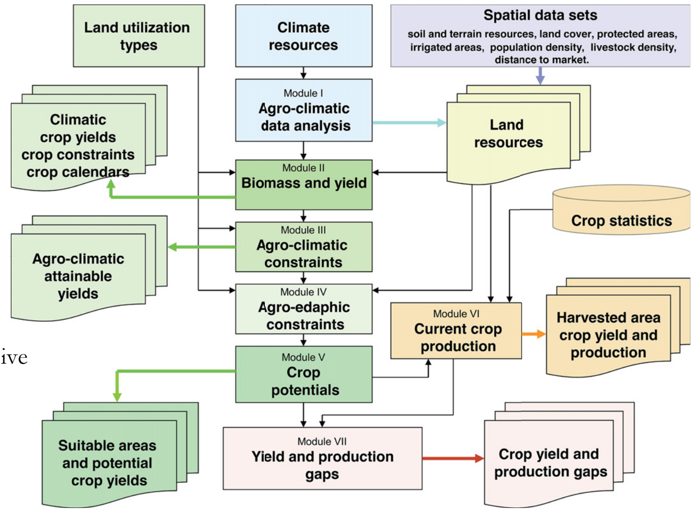
3.2 Land suitability for biofuel feedstock

The assessment of the quality of wasteland for biofuel feedstock production was preceded by India-wide assessments of suitability, potentially attainable yields and potential productivity of biofuel feedstocks: sugarcane, miscanthus and jatropha. The biofuel feedstock suitability and productivity assessments were carried out with the Global Agro-ecological Zoning modelling framework (GAEZ) (FAO-IIASA 2012) (Box IV-1).

GAEZ- Global agro-ecological zones Modell

The International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) jointly developed the global Agro-Ecological Zones (AEZ) methodology for assessing agricultural resources and their sustainable production potential. The AEZ methodology uses a land resources inventory to assess, for specified management conditions and levels of inputs, a comprehensive range of agricultural land-use options and to quantify anticipated production of cropping activities relevant in the specific agro-ecological context.

Geo-referenced global climate, soil and terrain data are combined into a land resources database, commonly assembled on the basis of global grids, typically at 5 arc-minute and 30 arc-second resolutions. Climatic data comprises monthly values of precipitation, temperatures, 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. Application of matching procedures to identify crop-specific limitations of prevailing climate, soil and terrain resources and comprehensive simulations with AEZ crop models, under assumed levels of inputs and management conditions, provides maximum potential and agronomically attainable crop yields for basic land resources units under different agricultural production systems.



Calculation procedures for establishing crop suitability estimates in AEZ include five main steps of data processing, namely:

(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.

For attributing statistical data to spatial land units, i.e., obtaining grid-cell level area, yield and production of prevailing main crops, two main activities are involved, namely:

(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.

Source: Food and Agriculture Organisation and Institute for Applied System Analysis (FAO-IIASA 2012)

Box IV - 1 GAEZ Methodology

The GAEZ procedures enable assessment of grid-cell productivity and suitability for sugarcane, miscanthus and jatropha individually. It quantifies suitability and agro-ecologically attainable yields in this case for rain-fed crop production set to high level inputs/ advanced management. High level inputs/ advanced management includes the following main socio-economic and agronomic/farm-management characteristics: The farming system is market oriented; commercial production is the main management objective; production is based on currently available.

Mapping and aggregation of grid-cell results providing average yields per administrative unit as well as distributions of land and production potential by suitability in terms of six suitability classes:

VS or very suitable (80–100% of maximum achievable yield in India);

S or suitable (60–80%);

MS or moderately suitable (40–60%);

mS or marginally suitable (20–40%);

VmS or very marginally suitable (5-20%), and

NS or not suitable (less than 5%)

3.3 Suitability of wasteland for biofuel feedstocks

For estimating the agricultural potentials of wasteland, a computational sequence was applied to match a grid-cell's suitability class distribution to its land use shares.

First the Global Administrative Unit Layer (GAUL) (FAO 2014) was used to delineate inland water bodies. Next, land was further categorized according to its legal protection status. A legally protected areas layer at 30 arc second grid-cell resolution was derived from the protected areas layer from United Nations Environment Program (UNEP) and World Conservation Monitoring (WCMC), which is based on the World Database of Protected Areas (WDPA) from the year 2010 (UNEP 2010). After excluding water grid-cells, land use/land cover categories were allocated in accordance with statistical data from DACNET and geographic suitability distributions in a grid-cell in two ways.

1. For protected land, it is assumed that the most suitable part of grid-cells will be assigned in the following sequence of the shares of statistical land use occurrence present in a district: 1) forest 2) pasture and barren/unculturable land 3) culturable wasteland and miscellaneous trees/groves 4) crop, fallow and built-up land.

2. For unprotected land, it is assumed that the most suitable part of grid-cells will be assigned in the following sequence of the shares of statistical land use occurrence present in a district: 1) crop, fallow and built-up land; 2) forest, miscellaneous trees/groves, pasture and culturable wasteland 3) barren/unculturable land.

In practice it means, that in the protected land the better land will be first allocated to forest, when any of this better land is left then this is allocated in sequence first to pasture and barren/unculturable land than to culturable wasteland and miscellaneous trees/groves etc. After protected land has been allocated the unprotected land will be allocated, respectively. For example see Box IV-2. The sum of the eight DACNET land use/land cover shares in each district is 1, i.e. consistency without double-counting or leakage. Potential suitability and productivity of culturable wasteland has in this way been estimated for biofuel feedstocks individually by district.

Allocation example for district Nellore (Andrah Pradesh)

Statistical landuse data from DACNET

State in 1000 ha	District	Total Land Area	Crop Land	Fallow Lands	Misc. Trees/ Groves	Pastures	Forest	Built-up Land	Barren/Un-culturable Land	Culturable Waste-Land
Andrah Pradesh	Nellore	1,307	330	115	18	73	263	253	138	117

GAEZ suitability distribustions for rainfed Jatropha under high input management

State in 1000 ha	District	Biofuel Feedstock	Protection Status	Total	VS	S	MS	mS	vMS	NS
Andrah Pradesh	Nellore	Jatropha	protected	40	0	4	1	14	7	14
Andrah Pradesh	Nellore	Jatropha	unprotected	1267	0	186	810	271	0	0
Andrah Pradesh	Nellore	Jatropha	total	1307	0	190	811	285	7	14

1. Allocation for protected land

Protected Areas	DACNET categories	Extents	Left over	Total	VS	S	MS	mS	vMS	NS
step 1	forests	263	223	40	0	4	1	14	7	14

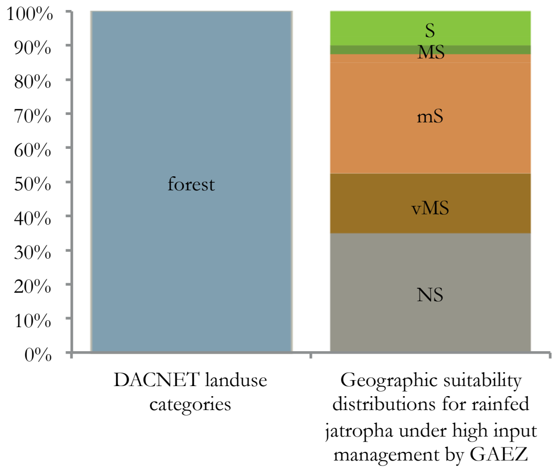
2. Allocation for unprotected land

Unprotected Areas	DACNET categories	Extents	Left over	Total	VS	S	MS	mS	vMS	NS
step 1	crop, fallow and built-up land	698	0	698	0	186	512	0	0	0
step 2	forest, misc.tress/grooves, pasture, cult. wasteland	431	0	431	0	0	298	133	0	0
step 3	barren/unculturable land	138	0	138	0	0	0	138	0	0

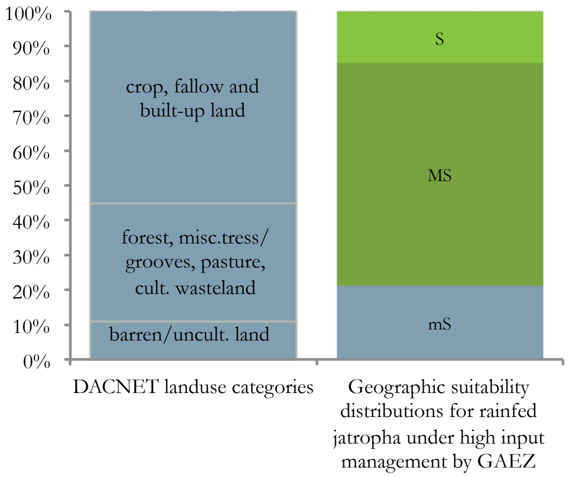
3. Suitability distribution for culturable wasteland

State in 1000 ha	District	Biofuel Feedstock	Protection Status	Total	VS	S	MS	mS	vMS	NS
Andrah Pradesh	Nellore	Jatropha	unprotected	117	0	0	81	36	0	0

Allocation for protected land



Allocation for unprotected land



Box IV - 2 Allocation of suitability distribution for culturable wasteland

3.4 Characterization of culturable wasteland and barren land using Wasteland Atlas statistics

The information in the Wasteland Atlas (NRSC 2010) provides additional suitability constraints for biofuel feedstock productivity. The allocation procedure applies weights for each of the 23 Wasteland Atlas classes (NRSC 2010) for individual biofuel feedstocks. The weights have been based on information contained in Wasteland Atlas class descriptions (NRSC 2010) and data on feedstock sensitivities to different soil and terrain conditions. Table IV-3 gives an overview of 23 wasteland classes and suitability constraints for sugarcane, miscanthus and jatropha.

Wasteland Atlas Classes			**Ranking Parameter**	**Inherent Suitability Constraints**		
Category	**Description**	**Extents 1000 ha**		**Sugarcane %**	**Miscanthus %**	**Jatropha %**
WAC 1	Gullied and /or ravinous land (medium)	700		0	0	0
WAC 2	Gullied and /or ravinous land (deep)	171		0	0	0
WAC 3	Land with dense scrub	9,339	1	75	90	90
WAC 4	Land with open scrub	9,163	2	50	75	75
WAC 5	Waterlogged and marshy land (permanent)	253		0	0	0
WAC 6	Waterlogged and marshy land (seasonal)	299	3	25	0	0
WAC 7	Land affected by salinity/alkalinity (moderate)	543	3	0	0	25
WAC 8	Land affected by salinity/alkalinity (strong)	174		0	0	0
WAC 9	Shifting cultivation area (current Jhum)	563	5	75	90	90
WAC 10	Shifting cultivation area (abandoned Jhum)	461	6	50	75	75
WAC 11	Under utilised/degraded notified forest land	8,577	7	50	75	75
WAC 12	Under utilised/degraded notified forest land (agriculture)	1,639	6	75	90	90
WAC 13	Degraded pastures/grazing land	720	7	50	75	75
WAC 14	Degraded land under plantation crop	32	7	50	75	75
WAC 15	Sands-riverine	243	4	0	0	0
WAC 16	Sands-coastal sand	72		0	0	0
WAC 17	Sands-desertic	528		0	0	0
WAC 18	Sands-(semi stab.-stab>40m)	1,119		0	0	0
WAC 19	Sands-(semi stab.-stab moderately. high 15-40m)	1,563		0	0	0
WAC 20	Mining wastelands	51		0	0	0
WAC 21	Industrial wastelands	6	8	0	0	0
WAC 22	Barren rocky/stone waste/sheet rock area	6,937		0	0	0
WAC 23	Snow covered and/or glacial area	4,069		0	0	0
	Total Wasteland	47,221				

a ranking parameters for wasteland Atlas classes according to most likely occurrence in the culturable wasteland DACNET category. Wasteland classes without ranking parameters are most likely occuring in the barren/unculturable land DACNET category

WAC: Wasteland Atlas Category

Source: Department of Land Resources Ministry of Rural Development (DACNET 2007), Govt. of India, Wasteland Atlas of India 2010 (NRSC 2010)

Table IV - 3 Ranking and additional suitability constraints of Wasteland Atlas classes for individual biofuel feedstock

Allocation example of adjusted production potential for jatropha from culturable wasteland for the district Bastar (Chhattisgarh)

Wasteland Atlas Categories (Wasteland Atlas)

WAC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Suitability Constraint Jatropha	0.00	0.00	0.90	0.75	0.00	0.00	0.25	0.00	0.90	0.75	0.75	0.90	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wasteland in 1000 ha	0.00	0.00	8.54	3.23	0.00	0.00	0.00	0.00	0.00	0.00	14.7	24.9	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00

Production potential of culturable wasteland by GAEZ

State	District	Biofuel crop	barren/unculturable land	culturable wasteland	Production Potential of culturable wasteland in 1000 ton of oil					
			1000 ha	1000 ha	Total	VS	S	MS	mS	vMS
Chhattisgarh	Bastar	Jatropha	39.60	58.89	154.94	5.15	113.02	33.00	3.56	0.22

Allocation of Wasteland Atlas categories to culturable wasteland

Step	Description	Culturable Wasteland		
		Left over 1000 ha	Extents 1000 ha	Suitability Constraints
step 1	WAC 3	50.35	8.54	0.90
step 2	WAC 4	47.12	3.23	0.75
step 3	WAC 6 ,WAC 7	47.12	-	0.25
step 4	WAC 15	47.07	0.05	0.00
step 5	WAC 9	47.07	-	0.90
step 6	WAC 10, WAC 12	22.14	24.93	0.90
step 7	WAC 11, WAC 13 , WAC 14	7.44	14.70	0.75
step 8	WAC 21	7.44	-	0.00
step 9	Culturable wasteland left and barren/uncult. land < WAC Rest	7.44		0.00
step 10	Culturable wasteland left and barren/ uncult. land (39.60) > WAC Rest (1.64)	-	7.44	1.00
step 11	Suitability constraints for district		58.89	0.87

Adjusted Production potential of culturable wasteland

State	District	Biofuel crop	Suitability Constraints	culturable wasteland	Production Potential of culturable wasteland in 1000 ton of oil					
				1000 ha	Total	VS	S	MS	mS	vMS
Chhattisgarh	Bastar	Jatropha	0.87	58.89	134.21	4.48	98.33	28.71	3.10	0.19

Box IV – 3 Allocation of adjusted production potential of culturable wasteland using Wasteland Atlas statistics

The adjustment of wasteland categories from Wasteland Atlas to culturable wasteland shares (DACNET 2007) in a district, is achieved by applying iterative procedures controlled by ranking parameters. These parameters rank Wasteland Atlas categories according to most likely occurrence in the culturable wasteland category (DACNET 2007) as follows: 1) land with dense shrub, 2) land with open shrub, 3) waterlogged and marshy land and land affected moderately by salinity /alkalinity, 4) sands riverine etc. The Wasteland Atlas categories without ranking are defined as most likely occurring in the barren/unculturable land category (DACNET 2007). The ranking is presented in Table IV-3. In cases where culturable wasteland is remaining the Wasteland Atlas categories without ranking are compared to DACNET barren/unculturable land shares. If these are higher, culturable wasteland is allocated than next to the remaining part. If not, it is suggested that remaining culturable wasteland does not occur in any of the Wasteland Atlas categories and no suitability constraints are set. For example see Box IV-3.

3.5 Biofuel production potential of allocated wasteland

The assessments for wasteland suitability and adjusted production potential of biofuel feedstocks were carried out as described before. Values were aggregated by districts, states and regions. Published conversion factors (Table IV-4) were applied for calculating potentials of biofuel production and energy output across different biofuel feedstock. Biofuel potentials of wasteland were estimated by assuming optimum use of wasteland in individual districts. The feedstock with the highest energy output was chosen to represent district energy output potentials from biofuel feedstock of wasteland.

	Bioethanol		**Biodiesel**
	Sugarcane [a]	**Miscanthus** [b]	**Jatropha** [c]
Feedstock (dry weight)	sugar	ligno cellulose	vegetable oil
Biofuel (l/ton feedstock)	677.27	300.00	1048.91
Energy yield (GJ/ton feedstock)	14.34	6.35	34.51
Heating Value (MJ/l biofuel)	21.17	21.17	32.90
GHG savings (kg CO_2eq/GJ)	60.00	74.00	58.00
Fossil fuel equivalent (1l fuel/1l biofuel)	0.65	0.65	0.92

a sugarcane: 74.5 litre ethanol /ton sugarcane (FAO 2008) / 0,11 ton sugar/ton sugarcane (FAO 1972) = 677,27 litre ethanol /ton sugar * 21.17 MJ/litre ethanol (BMELV-FNR 2009) = 14,34 GJ/ton sugar | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012)-24gCO_2eq/MJ sugarcane bioethanol (RFA-RTFO 2012) = 60g CO_2eq/MJ GHG savings | 1 litre sugarcane bioethanol = 0,65 litre gasoline (BMELV-FNR 2009)

b miscanthus: Hydrolysis ethanol 300 litres ethanol/dry ton (Carriquiry et al. 2010) * 21.17 MJ/litre ethanol (BMELV-FNR 2009)=6,35 GJ/dry ton miscanthus| 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012)-10 g CO_2eq/MJ ligno-cellulosic ethanol (RFA-RTFO 2012) = 74 g CO_2eq/MJ GHG savings | 1 litre miscanthus bioethanol = 0,65 litre gasoline (BMELV-FNR 2009)

c jatropha: 0,92 kg oil / litre oil (BMELV-FNR 2009) →1086,95 litre oil/ton jatropha oil* 0,965 (Biodiesel content) (EC 2008) = 1048,91 litre biodiesel/ ton jatropha oil * 32.9 MJ/litre jatropha biodiesel (BMELV-FNR 2009) = 34,51 | 84 g CO_2eq/MJ fossil fuel (BMELV-FNR 2012) -26 g CO_2eq/MJ jatropha biodiesel (RFA-RTFO 2012) = 58g CO_2eq/MJ GHG savings | 1 litre jatropha biodiesel = 0,92 litre diesel (BMELV-FNR 2009)

Table IV - 4 Biophysical and energy characteristics of biofuel feedstocks

4 Results

4.1 Extent and quality of culturable wasteland

India comprises of 29 states and 7 union territories grouped in six main regions (Figure IV-1) with a total land area of 329 Mha. About 14% is wasteland (NRSC 2010) of which, approximately 13 Mha (DACNET 2007) is designated as culturable. This culturable wasteland equates to 8% of India's current land used for crop cultivation. About 40% or 5.2 Mha culturable wasteland is found in the North, occupying there about 7% of total land extent. Culturable wasteland extents in the regions West, North-Central and South are respectively 3 Mha, 2 Mha and 1.5 Mha. At state level, Rajasthan contains by far the largest extents of culturable wasteland, 4.6 Mha of culturable wasteland. Other states with substantial extents of culturable wasteland include Gujarat (1.9 Mha), Madhya Pradesh (1.2 Mha), Maharashtra (0.9 Mha) and Andhra Pradesh (0.5 Mha). The quality of culturable wasteland for biofuel feedstock production has been estimated with the GAEZ (FAO-IIASA 2012) modelling framework. Land suitability and attainable yields for respectively sugarcane, miscanthus and jatropha were assessed at 30 arc second grid-cell resolution. Figure IV-2 presents a summary of extents of culturable wasteland and its suitability for biofuel feedstocks aggregated for the six main regions.

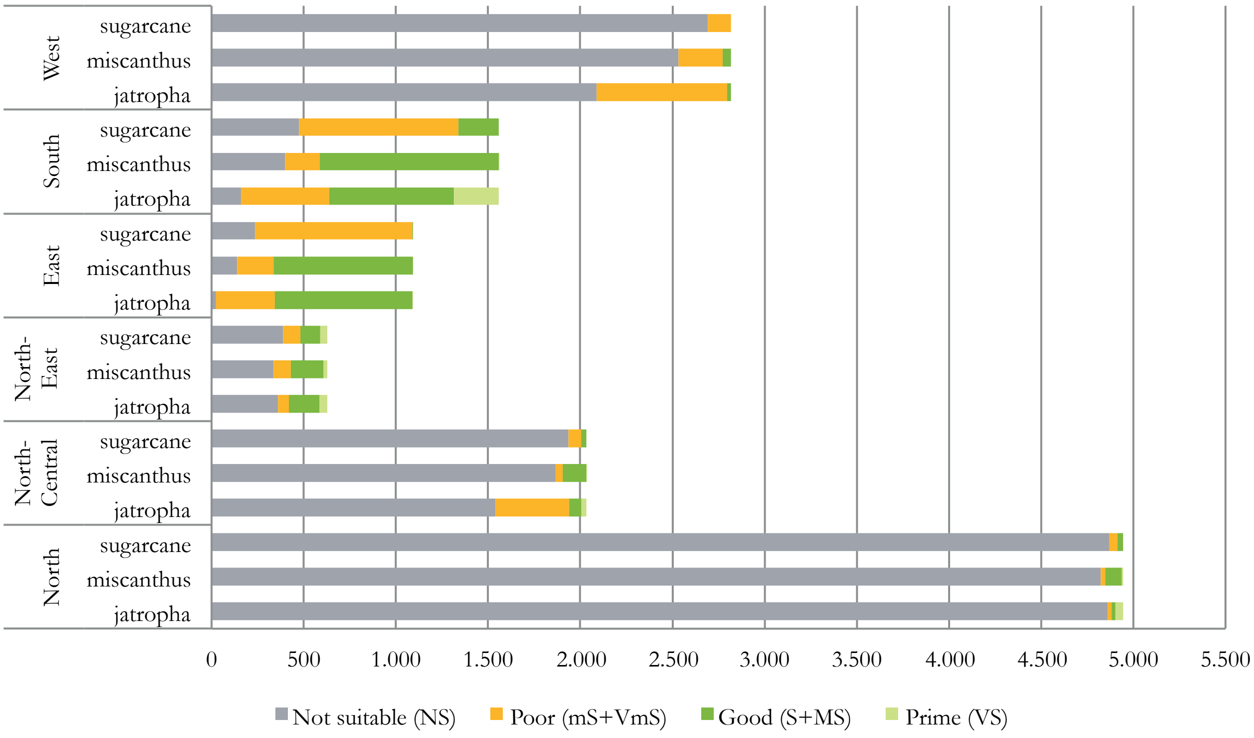


Figure IV - 2 Biofuel feedstock suitability of culturable wasteland by regions

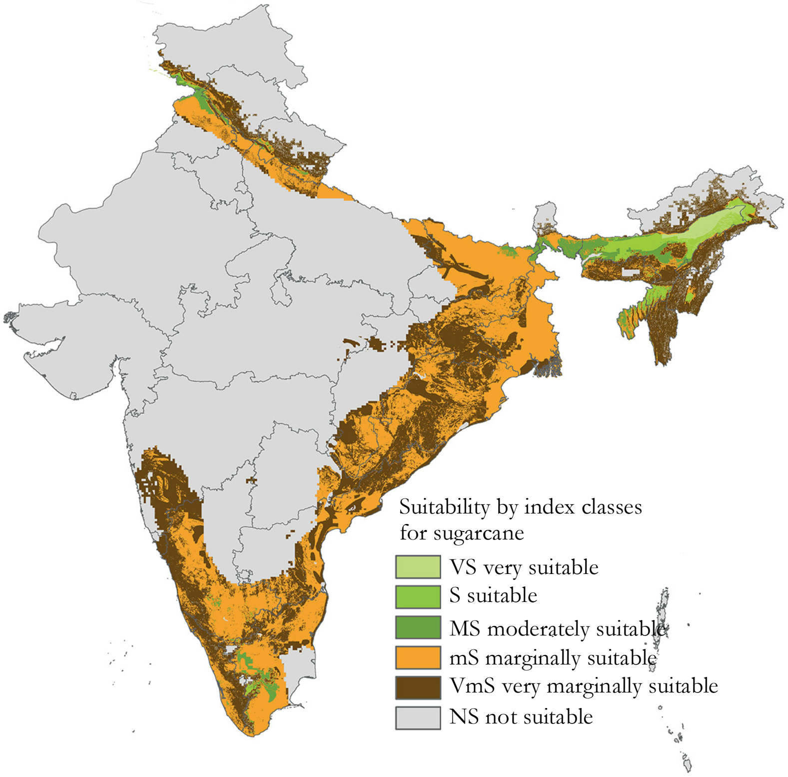


Figure IV - 3 Suitability for rain-fed sugarcane under high input management (30 arc second grid-cell resolution)

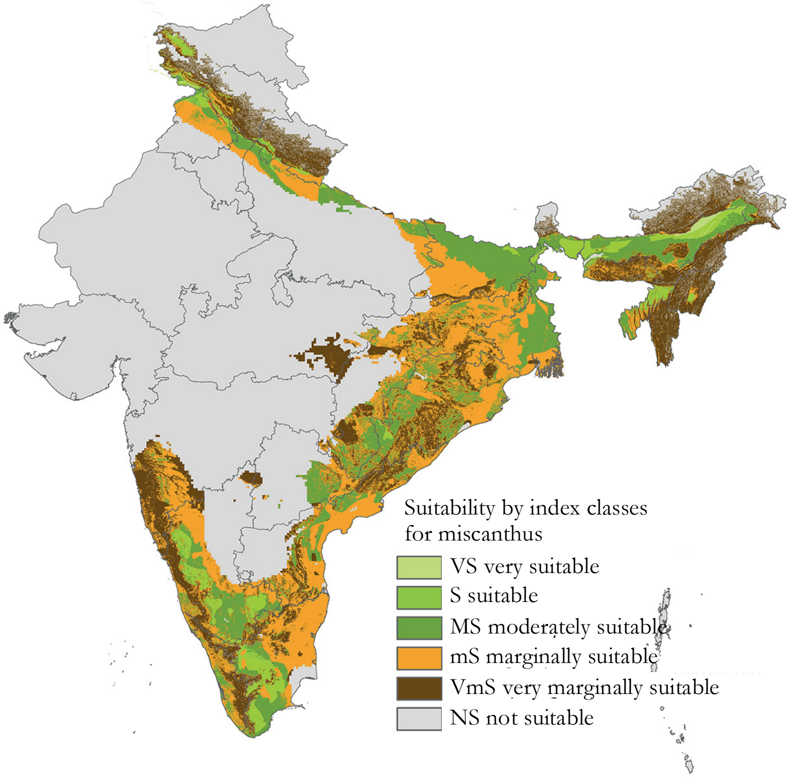


Figure IV - 4 Suitability for rain-fed miscanthus under high input management (30 arc second grid-cell resolution)

In India as a whole about 2.4 Mha of culturable wasteland was found suitable for rain-fed sugarcane while some 3.0 or 4.0 were found suitable for respectively rain-fed miscanthus and jatropha. Suitability profiles differ significantly between regions and across biofuel feedstocks. Almost 0.4 Mha of culturable wasteland are of prime and good quality for rain-fed sugarcane that is about 3%. When culturable wasteland would be used for rain-fed jatropha and miscanthus production then more good and prime areas are found; respectively 2.1 Mha (16%) and 2.2 Mha (17%). Depending on feedstock, between 6% and 15% of culturable wasteland is of only poor quality and marginally suitable for biofuel feedstock production. That means that almost 9 Mha (70%) of the culturable wasteland is not suitable at all for any of the assessed feedstock. In part of marginal and not suitable culturable wasteland areas, depending on nature of production constraints, economic feedstock production may become feasible with substantial investments in irrigation infrastructure and/or crop management. Such land reclamation potentials have not been taken into account.

Figures IV-3 - IV-5 present maps depicting the suitability of culturable wasteland for the biofuel feedstocks; sugarcane, miscanthus and jatropha.

The best production potential occurs in the South although the culturable wasteland acreage is relatively small, the quality for biofuel feedstock is high.

Rain-fed sugarcane could produce potentially up to 6 Mt sugar. Half of this potential is found in Tamil Nadu, Kerala and Orissa. About 68% of total potential sugar production from residual land or 2 Mt comes from poor quality land with average yields of about 2 t/ha sugar only. Average yields in good and prime land are in the order of 3 to 7 t/ha.

In the case of miscanthus, total production potential over all suitability classes amounts to 40 Mt above ground biomass (DW). About three-quarters of the production potential occurs in the culturable wasteland in the South and East. Average yields in prime and good land are in the order of 20 t/ha. Some 6 Mt vegetable oil from jatropha could be produced from culturable wasteland, of which 5 Mt are from prime and good land. Potential yields as high as of 33 t/ha could potentially be achieved in locations in Jammu and Kashmir.

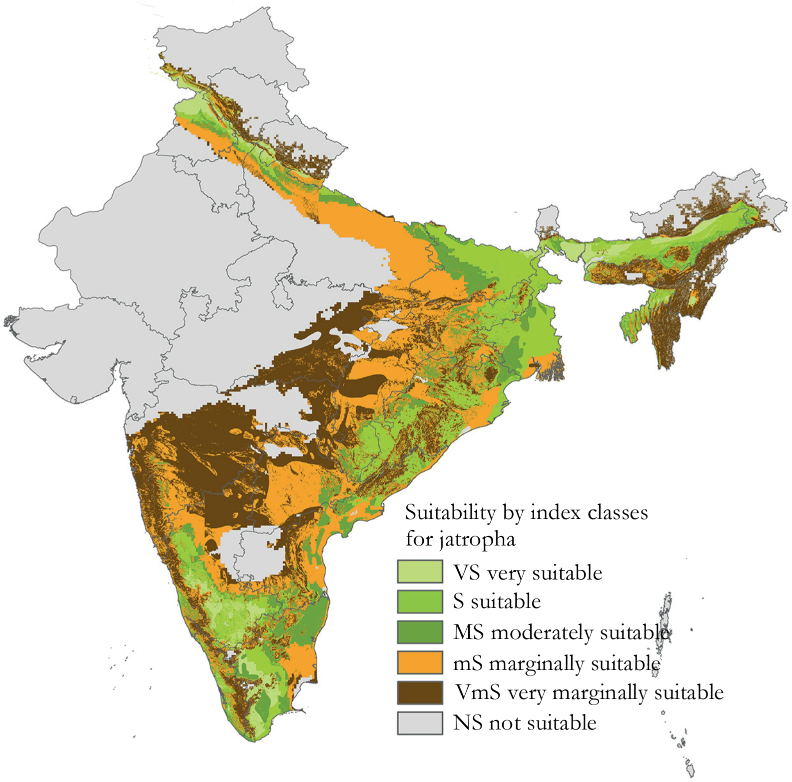


Figure IV - 5 Suitability for rain-fed jatropha under high input management (30 arc second grid-cell resolution)

4.2 Biofuel potentials on residual land

Table IV-5 presents rain-fed production potentials of culturable wasteland for biofuel feedstocks and resulting biofuel and energy output potential by biofuel feedstock. Biofuel feedstock production potential converted to bioethanol implies that 4 billion litres of bioethanol could be produced from sugarcane, or 12 billion litres bioethanol from miscanthus. Alternatively 6 billion litres biodiesel can potentially be produced from jatropha vegetable oil. The highest energy potential comes from miscanthus bioethanol (247 PJ) followed by jatropha biodiesel (216 PJ). Potential production of sugar ethanol is least promising; the energy production potential is in the order of only 85 PJ. Figure IV-6 shows the biofuel feedstock composition in each state based on selection of best performing feedstock in individual districts, providing the maximum biofuel energy output on culturable wasteland by state. In other words in each district the feedstock giving the highest energy output potential on culturable wasteland share within the district, was selected. Considering all feedstocks the 13 Mha culturable wasteland include 0.4% of prime land, 16.3% of good land, 14.5% of marginal land and 68.8% not suitable land for any of the assessed biofuel feedstock. In almost 87% of districts with culturable wasteland, miscanthus was chosen as best producing biofuel solution with a biomass potential of 37.19 Mt above ground biomass (DW) equivalent to 237 PJ. About 2% of districts with culturable wasteland were chosen for sugarcane with a potential of 0.13 Mt sugar and 2 PJ. In 12% of districts with culturable wasteland, jatropha produced best with a biomass output of 0.97 Mt of vegetable oil and potential energy output of 33 PJ. Assuming that the best biofuel feedstock in energy terms is grown at each location suggests a theoretical maximum biofuel potential of 11 billion litres bioethanol and 1 billion litres biodiesel.

States	Sugarcane			Miscanthus			Jatropha		
	Product. Potential[a]	**Biofuel potential**[b]	**Energy yield**[c]	**Product. Potential**[a]	**Biofuel potential**[b]	**Energy yield**[c]	**Product. Potential**[a]	**Biofuel potential**[b]	**Energy yield**[c]
	1000 ton sugar	Mio litre	PJ	1000 ton AGB DW	Mio litre	PJ	1000 ton oil	Mio litre	PJ
North	**198**	**134**	**3**	**1,664**	**499**	**11**	**176**	**185**	**6**
Haryana	-	-	-	-	-	-	-	-	-
Himachal Pradesh	5	3	0	38	12	0	7	7	0
Jammu and Kashmir	83	56	1	564	169	4	82	86	3
Punjab	103	70	1	1,026	308	7	82	86	3
Rajasthan	7	5	0	35	10	0	5	6	0
Chandigarh	-	-	-	-	-	-	-	-	-
North-Central	**270**	**183**	**4**	**2,160**	**648**	**14**	**501**	**526**	**17**
Bihar	66	45	1	514	154	3	78	82	3
Madhya Pradesh	-	-	-	-	-	-	-	-	-
Uttar Pradesh	-	-	-	432	130	3	182	191	6
Uttarakhand	49	33	1	458	137	3	126	132	4
Delhi	155	105	2	757	227	5	116	122	4
North-East	**796**	**539**	**11**	**2,960**	**888**	**19**	**407**	**427**	**14**
Arunachal Pradesh	112	76	2	356	107	2	47	49	2
Assam	314	213	5	678	203	4	94	98	3
Manipur	0	0	0	0	0	0	0	0	0
Meghalaya	365	247	5	1,908	572	12	264	277	9
Mizoram	-	-	-	-	-	-	-	-	-
Nagaland	2	1	0	9	3	0	1	1	0
Tripura	3	2	0	9	3	0	1	1	0
East	**1,765**	**1,195**	**25**	**12,857**	**3,857**	**82**	**1,980**	**2,077**	**68**
Chhattisgarh	15	10	0	85	25	1	11	11	0
Jharkhand	399	270	6	3,375	1,012	21	542	568	19
Orissa	416	281	6	3,559	1,068	23	535	561	18
Sikkim	852	577	12	5,373	1,612	34	818	858	28
West Bengal	-	-	-	-	-	-	-	-	-
Andaman and Nicobar	84	57	1	465	140	3	75	78	3
South	**2,706**	**1,832**	**39**	**16,929**	**5,079**	**107**	**2,656**	**2,786**	**92**
Andhra Pradesh	552	373	8	4,650	1,395	30	581	609	20
Karnataka	886	600	13	5,346	1,604	34	894	938	31
Kerala	246	167	4	1,239	372	8	194	204	7
Tamil Nadu	-	-	-	-	-	-	-	-	-
Telangana	2	1	0	50	15	0	5	5	0
Lakshadweep	984	666	14	5,255	1,576	33	797	836	27
Puducherry	35	24	1	388	116	2	186	195	6
West	**167**	**113**	**2**	**2,289**	**687**	**15**	**552**	**579**	**19**
Goa	-	-	-	-	-	-	-	-	-
Gujarat	-	-	-	-	-	-	-	-	-
Maharashtra	-	-	-	31	9	0	3	3	0
Dadra and Nagar Haveli	-	-	-	-	-	-	-	-	-
Daman and Diu	167	113	2	2,258	677	14	548	575	19
Total	**5,903**	**3,996**	**85**	**38,860**	**11,658**	**247**	**6,273**	**6,580**	**216**

a The farming system is market oriented; commercial production is the main management objective; production is based on currently available best-yielding cultivars, is fully mechanized with low labor intensity, and provides adequate applications of nutrients and chemical pest, disease and weed control

b sugarcane (677 litre bioethanol / ton sugar), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), jatropha (1049 litre biodiesel / ton jatropha oil)

c sugarcane (14.34 GJ / ton sugar), miscanthus (6.35 GJ / ton miscanthus ABG (DW)), jatropha (34.51 GJ / ton jatropha oil)

AGB Above Ground Biomass

DW dry weights

Table IV - 5 Rain-fed production potentials of culturable wasteland, biofuel production potential and energy output for biofuel feedstocks

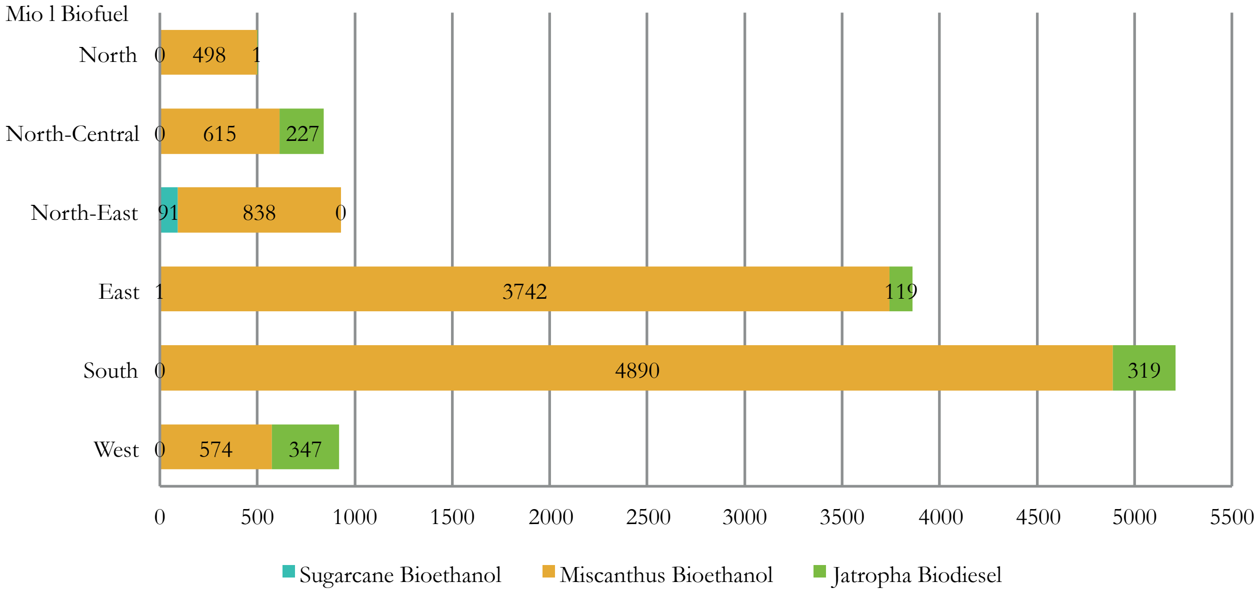


Figure IV - 6 Best biofuel feedstock solution for culturable wasteland

5. Discussion

	2012	2020	2020
in Mt	**PPAC**	**PPAC**	**TERI**
Gasoline	15.74	24.52	74.00
E20	5.17	8.06	24.31
Bioethanol potential from culturable wasteland			
Sugarcane (3.16 Mt)	61%	39%	13%
Miscanthus (9.18 Mt)	178%	114%	38%
Best biofuel feedstock (8.92 Mt)	172%	111%	37%
Diesel	69.08	118.69	144.00
B20	15.92	27.36	33.19
Biodiesel potential from culturable wasteland			
Jatropha (5.78 Mt)	36%	21%	17%
Best biofuel feedstock (0.89 Mt)	6%	3%	3%

Gasoline density 0.74 kg/l, bioethanol density 0.79 kg/l, 1 Mt bioethanol = 0.61 Mt gasoline
Diesel density 0.83 kg/l, jatropha biodiesel density 0.88 kg/l, 1 bioethanol = 0.61 Mt gasoline, 1 Mt jatropha biodiesel = 0.87 Mt diesel
Source: (PPAC 2013), (TERI 2008) and self-calculations

Table IV - 6 Projected demand for biofuel in India for the year 2020

5.1 Replacement potential of fossil transport fuels in terms of the aims of policy

With more than 95% of India's surface transport dependent on imported fossil fuel, India has made a concerted effort to promote biofuels (PPAC 2013). The Government of India approved the National Policy on Biofuels in 2009. The policy encourages use of renewable energy resources as alternative fuel to supplement transport fuels and had proposed an indicative target to replace 20 % of petroleum fuel consumption with biofuels (bioethanol and biodiesel) by end of 12th Five-Year Plan (2017) (USDA 2013). The Indian biofuel policy has launched a large program to promote biofuel production, particularly on wastelands (Ravindranath et al. 2011).

The land requirement of culturable wasteland for biofuels for blending purposes would obviously depends on the consumption of fossil fuels and their growths. Table IV-6 estimates of current and future demand of diesel and gasoline in the country and calculates the amount of biofuels at 20% blend in comparison of assed biofuel potential from cultivated wasteland.

The Petroleum Planning and Analysis Cell (PPAC) of the Indian Ministry of Petroleum and Natural Gas reports a consumption of 15.74 Mt gasoline and 69.08 Mt diesel in the years 2012-2013 (PPAC 2013). Considering a biofuel blend of 20%, 5.17 Mt of bioethanol and 15.92 Mt of biodiesel would be required to fulfil the 20% substitution target of the Indian government. Results illustrate relatively low agronomic potential for specific biofuel feedstock of culturable wasteland across India. Miscanthus seems to be the best option to fulfil the bioethanol demand. However 9.18 Mt bioethanol could be potentially produced if miscanthus is planted on total culturable wasteland. In the case of sugarcane only 61% (3.16 Mt bioethanol) of required bioethanol demand could be meet. Presently, ethanol supply (2013) is sufficient to meet 2.9 % blending target, mostly derived from sugar molasses/juice of surplus sugar production from sugar mills.

According to the Planning Commission Jatropha is a main biodiesel crop for India and it is proposed to use only marginal or wastelands for biodiesel plantation. Thus, only 36% (5.78 Mt biodiesel) of biodiesel demand could be meet when jatropha is planted on total culturable wasteland.

For the future two scenarios for 2020 are considered, the first one assumes that the current trends in gasoline (6%) (PPAC 2013) and diesel consumption (7%) (PPAC 2013) for transport continues in the future, and second scenario uses the projected transport demand for gasoline and diesel given by the "National Energy Road Map for 2030" of the Energy and Resource Institute (TERI) (TERI 2008). If we go by the trend rate of growth India would consume about 24.52 Mt of gasoline and 118.69 Mt of diesel by 2020. The projections by TERI are much higher; they project a gasoline demand of 74.00 Mt and diesel demand of 144 Mt by the end of 2020. According to the 20% target, the annual ethanol demand is expected to rise to 8.06 Mt in the case of trend-rate scenario and to 24.31 Mt in the case of 2020 scenario by TERI. Biodiesel demand is likely increase to 27.36 and 33.19 Mt, respectively in the cases of trend-rate and TERI scenarios (Table IV-6) to meet the 20% target. In the case of bioethanol miscanthus is the best option, thus more than 100% (38% for TERI scenario) of required bioethanol demand could be meet by 2020. Jatropha biodiesel from culturable wasteland meets only 17% (3% for TERI scenario) of required biodiesel demand in 2020. Assuming that the best biofuel feedstock in terms of energy output is grown at each location suggests a theoretical maximum bioethanol potential of 8.92 Mt and biodiesel potential of 0.89 Mt available from India's culturable wasteland. Of this potential the majority is from miscanthus grown on 3 Mha, followed by jatropha grown on 10 Mha. Sugarcane derived bioethanol is negligible. At 20% blending requirement, more than 100% (37% for TERI) of bioethanol and 3% (2.7% for TERI) of biodiesel demand could be meet by 2020.

However estimations shows, that only miscanthus could meet the ambitious target of substituting 20% of fossil fuel consumption bioethanol by 2020 in the case of trend rate scenario. It should be noted that the potentially achieved yields from miscanthus are based on experimental sites only. Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of miscanthus are not available. Experience with miscanthus plantations show high uncertainty about the yield (the average being less than half of what was expected) and some ended in failure (Euler et al. 2004). Assuming that the biofuel feedstock composition with the highest energy potential is cultivated on culturable wasteland in each state and replaces fossil transport fuels a substitution of 36% (12% for TERI) of gasoline and less than 1% (0.6% for TERI) of diesel could be achieved. As comparison The Renewable Energy Outlook 2013 by OECD and IEA

(OECD-IEA 2013) assumes that even under advanced policy scenario biofuels will constitute only 8% of the demand by 2035.

However, not all land with identified technical potential of culturable wasteland qualifies equally for the practical implementation of biofuel feedstock plantations. Hence, in addition to the quality and suitability of culturable wasteland also location specific investment requirement and transport cost as well as infrastructure such as roads and electricity as well as ownership of the land will play an important role in the discussion of culturable wasteland potentials for biofuel feedstocks. Another factor is that Indian economy is experiencing high growth rate, which may lead to enhanced demand for food, livestock products, timber, paper, etc., with implications for land use.

5.2 GHG reduction potential of biofuels grown on culturable wasteland

Results illustrate agronomic potential for specific biofuel feedstock of culturable wasteland across India. Given that India is the third largest global contributor to carbon emissions (EIA 2014), in addition to reducing dependency on fossil fuels, the growth of biofuels is importantly also driven by the potential of GHG emissions savings compared to fossil transport fuels. The following discusses the GHG mitigation potential when fossil fuels would be replaced by biofuels produced on India's culturable wasteland. GHG emission factors vary, depending on the specific biofuel production process and the feedstock management practices, including the amount of fertilizers used. GHG default values for different biofuel systems are summarized by Renewable Fuels Agency (RFA), giving specific values for each step of the fuel chain, from crop production to filling station, for more details see (RFA-RTFO 2012). The GHG emission factors for biofuels produced from sugarcane, jatropha and miscanthus are summarized in Table IV-4.

The role of biofuels in reducing GHG emissions needs to be evaluated by comparison with the energy systems they replace. As fossil reference system an 83.8 g CO_2eq emissions per MJ of consumed gasoline or diesel are adopted from the Renewable Energy Directive 2009/28/EC (EC 2009). Figure IV-7 highlights the potential

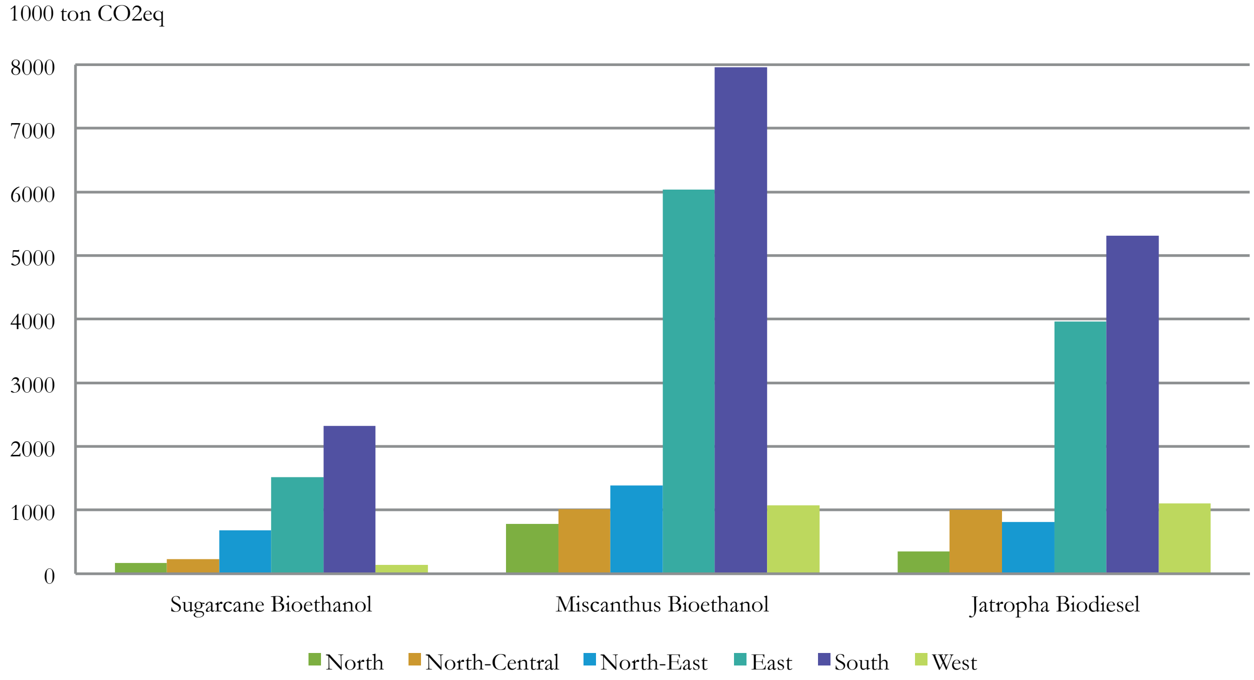


Figure IV - 7 Biofuel GHG saving potential from culturable wasteland

GHG emissions saving potential from culturable wasteland for different biofuel feedstocks by regions. Results demonstrate, that biodiesel from jatropha shows potential for GHG mitigation. 13 Mt CO_2eq could be saved annually by using sugarcane bioethanol from India's culturable wasteland instead of gasoline. The GHG mitigation saving associated with bioethanol from sugarcane are more modest, replacing gasoline could only save 5 Mt CO_2eq. The best biofuel option for reducing GHG emissions of the transport sector is miscanthus bioethanol (18 Mt CO_2eq). However, estimates for miscanthus and jatropha processes are theoretical or based on pilot plants implying higher uncertainties for commercial scale production (OECD-IEA 2011). In its Renewable Energy Directive 2009 (EC 2009), the European Commission (EC) has put forward sustainability regulations and attributes a bonus of 29 g CO_2eq/MJ in the computation of the carbon balance, if evidence is provided that the land is degraded with a low organic matter content or heavily contaminated and thus unsuitable for the cultivation of food and livestock feed production. Since we allocated the unfavourable land (in terms of land suitability) to culturable wasteland, biofuel produced from this land will likely be eligible for this additional emission bonus.

5.3 Barriers to biofuel development on wasteland

Total ethanol supply for ethanol blending program during 2013 is anticipated to be just sufficient to meet the 3% blending target (USDA 2013) while production of biodiesel in India is commercially insignificant at present. This stands in contrast to the National Biofuel Policy,which aims to replace 20% of petroleum fuel consumption with biofuels by end of 12th Five-Year Plan (2016/2017) (USDA, 2012b).

One reason for the stagnating biofuel development could be that India's biofuel program relied more heavily on promoting jatropha than on other biodiesel feedstocks or feedstocks for bioethanol production. The development of jatropha cultivation including technology, plant varieties and practices, is in a nascent stage. As a result, the yield is very low. It should be noted that achieving yields from jatropha is based on experimental sites only. Despite considerable investment and projects being undertaken in many regions, reliable scientific data on the agronomy of jatropha are not available. Experience with jatropha plantations show high uncertainty about the yield (the average being less than half of what was expected) and some ended in failure (Euler et al. 2004). The development of jatropha sector hinges on how effectively farmers performs these tasks and thus helps overcome main constraints, namely mobilisation of land, development of suitable plant varieties and suitable cultivation/harvesting techniques and creation of incentives for the stakeholders.

The failure to develop appropriate institutions responsible for the development of plant verities, dissemination of true information to farmers and feedback from the farmers, have largely resulted in little progress in respect of biofuel mission (Biswas et al. 2013). On the part of a farmer, adoption of an entirely new crop variety as jatropha requires that he should be provided with adequate information about the crop, its risk and return, and more importantly its cultivation practices. Based on this information, the farmer takes the decision whether to cultivate or not. The farmer would then look for finance, seeds and other inputs for cultivation. Traditionally, farmers were very much involved in the innovation process through cross breeding, selection of higher yielding plants, etc. and thus they used to have clear knowledge of the cultivation practices of a new crop, its risk and return. Under the modern system of crop innovation and diffusion, agricultural extension centres including demonstration farms pass on the relevant information about method of farming, risk and return of a new crop innovated in a national research centre. Over a couple of decades during green revolution in India, several new varieties of rice, wheat, pulses, oilseeds, potatoes and other crops were innovated in the national and regional research laboratories. Subsequently, the innovated crops were diffused to the farmers with the help of extension/demonstration centres. In the process, two-way communication networks between farmers and inventors were established. Over the years, this system has been institutionalized. These institutions have been supplemented by private operators, such as local retailers selling seeds, fertilisers, pesticides and other farm inputs that provide information to the farmers. The minimum support price policy of the government provided added incentives to the farmers to grow new crops by reducing price risk.

An other reason could be the wasteland availability for biofuel feedstocks. With regard to availability of land for growing biofuel feedstocks, there is no consensus among policy-makers. According to Wasteland Atlas of India (NRSC 2010), about 55 Mha of lands is considered to be wastelands. Out of these, 13 Mha is considered to be suitable for growing biofuel according to the criteria of Ministry of Rural Development (DACNET 2007). The availability refers only to the physical availability. By contrast, the access of land for biofuel feedstock plantations depends on a number of factors including access to infrastructure such as roads and electricity as well as ownership of the land.

One of the major problems with these lands is that although they are rightly declared as wasteland, they are not necessarily left unused and readily available for planting jatropha or other biofuel feedstocks. In general, a sizeable section of the wasteland is used by poor people for fuel, grazing animals and collection of some other products, which are vital for their livelihood (Findlater et al. 2011). Barring a few cases, they were not given proper land rights and their occupations are usually treated as encroachment (Friends of the Earth Europe 2009). According to TERI (TERI 2008) about 5.6 million ha of wastelands has been allotted to many poor families under various programs over the last 20 years. With the insistence of NGOs and government officials, particularly forest officials, these poor people diverted the marginal/wasteland for planting jatropha. Their traditional source of livelihood is dislocated and at the same time jatropha has brought little hope for them due to yield. However, it is possible to grow biofuel feedstocks on wastelands for the betterment of the livelihood of the users, who may be convinced to grow these plants by providing adequate incentive and information and demonstrating the yield and other benefits. Even for the unoccupied wastelands if farmers have to be involved for plantation, it requires the same process of providing incentives, information and demonstration.

6 Conclusion

Of the total land area of India (327 Mha), about 14% (NRSC 2010) is wasteland of this total, approximately 13 Mha (DACNET 2007) would be suitable for growing biofuel feedstocks. An iterative sequential downscaling procedure has been implemented to estimate culturable wasteland shares and suitability for biofuel feedstocks. Land suitability assessment results illustrate the prevalence and overall quality of culturable wasteland for different biofuel feedstocks across India. Only 30% of 13 Mha culturable wasteland area is suitable for biofuel feedstock production with a varying degree of productivity depending on biofuel feedstock.

Culturable wasteland when used for sugarcane produces about 6 Mt sugar (equivalent to 4 billion litres bioethanol or 85 PJ), Half of India's current domestic ethanol demand of 6 billion litres considering a biofuel blend of 20% (PPAC 2013). Alternatively about 12 billion litres (247 PJ) could be produced from miscanthus. Using culturable wasteland land for the production of biodiesel could produce 7 billion litres biodiesel (216 PJ) from jatropha cultivation. A comparison of the different biofuel feedstocks potentially grown on culturable wasteland suggests that from the 4 Mha culturable wasteland suitable for biofuel feedstock production, miscanthus cultivation would provide the highest output in energy terms (237 PJ) on 2.7 Mha, sugarcane (2 PJ) on 0.1 Mha and jatropha (33 PJ) on 1.2 Mha. Assuming that the best biofuel feedstock in energy terms is grown at each location suggests a theoretical maximum biofuel potential of 272 PJ available from Indias culturable wasteland. However experiences with miscanthus as biofuel feedstock are still researched with commercial scale application being still under development and achievable oil yields from jatropha cultivation are still uncertain from an agronomic point of view. Not all land with identified technical potential of culturable wasteland qualifies equally for the practical implementation of biofuel feedstock plantations. One of the major problems with these lands is that although they are rightly declared as wasteland, they are not necessarily left unused. It is quite likely that given the population pressure of India in the rural areas, a large part of the wasteland is occupied by marginal farmers and landless people. Future demand for food, livestock feed and pasture land will play an important role in the discussion of culturable wasteland potentials for biofuel feedstocks. According to the results of this study the biofuel program of the National Biofuel Policy, which aims to replace 20 percent of petroleum and diesel fuel consumption with biofuels by end of 12th Five-Year Plan (2016/2017), seems very ambitiousness and difficult to reach.

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Chapter V Synthesis

1 Brazil: Concluding remarks and future research

A detailed land balance analysis suggests 37 Mha residual land in Brazil, an area equivalent to about 50% of current croplands. Residual land excludes cropland and pastures reported in Brazil Census 2006, forests, urban areas, the Amazon biome, and all areas designated as protected or of high biodiversity value. Residual land is mainly concentrated in the South-East (17 Mha), other important regions include the North-East (8 Mha) and Central-East (7 Mha).

Land suitability assessment results illustrate the prevalence and overall quality of residual land for different biofuel feedstocks across Brazil. Almost three-quarters of the residual land area is suitable for biofuel feedstock production with a varying degree of productivity depending on biofuel feedstock. The 37 Mha residual land comprises 2% prime land, 24% of good land, 46% of poor land and 28% not suitable land for any of the assessed biofuel feedstock.

Residual land when used for sugarcane produces about 50 Mt sugar (equivalent to 34 billion litres bioethanol or 720 PJ), more than Brazil's current domestic ethanol demand of 23 billion litres (490 PJ) (USDA 2014a). Alternatively a similar amount of bioethanol, about 31 billion litres (664 PJ) could be produced from cassava or about 62 billion litres (1,320 PJ) from miscanthus.

Using residual land for the production of biodiesel could either produce between 7 billion litres biodiesel (242 PJ) from soybeans or 18 billion litres biodiesel (588 PJ) from jatropha cultivation. This is much higher than Brazil's current domestic biodiesel demand for fuel of 3 billion litres (115 PJ) (USDA 2014a).

A comparison of the different biofuel feedstocks potentially grown on residual land suggests that from the 27.9 Mha residual land suitable for biofuel feedstock production, miscanthus cultivation would provide the highest output in energy terms (883 PJ) on 16.1 Mha, sugarcane (226 PJ) on 3.9 Mha , cassava (209 PJ) on 7.5 Mha, jatropha (17 PJ) on 0.4 Mha and soybeans (0.2 PJ) on 0.1 Mha. Assuming that the best biofuel feedstock in energy terms is grown at each location suggests a theoretical maximum biofuel potential of 1,336 PJ available from Brazil's residual land. However experiences with miscanthus as biofuel feedstock are still researched with commercial scale application being still under development and achievable oil yields from jatropha cultivation are still uncertain from an agronomic point of view.

However, not all land with identified technical potential of residual land qualifies equally for the practical implementation of biofuel feedstock plantations. Hence, in addition to the quality and suitability of residual land also location-specific investment requirement and transport cost as well as future demand for food, livestock feed and pasture land will play an important role in the discussion of residual land potentials for biofuel feedstocks.

Farm economics and logistics will favour production of biofuel feedstocks in areas of high residual land concentration with prime and good quality. Most such areas are concentrated in the West of Bahia, all over São Paulo, in the East of Mato Grosso and in the West of Paraná. In these areas the residual land shares per pixel are higher than 33% and in addition more than half the land is of prime or good quality for biofuel feedstocks.

Future residual land availability does not necessarily have to decrease due to projected demand increases in crop and livestock products until 2030, assuming pastures for livestock grazing are well utilized and managed and cropland expansion is respecting livestock carrying capacities and existing designation for nature protection and biodiversity.

Only when the livestock sector continuous to increase its non-pasture based feed the 37 Mha (27.5 Mha) residual land may be used for biofuel feedstock production beyond 2010. Potential future biofuel feedstock production from residual land may need adjustment due to climate change impacts, to be explored in follow-up research.

2 India: Concluding remarks and future research

Of the total land area of India (327 Mha), about 14% (NRSC 2010) is wasteland of this total, approximately 13 Mha (DACNET 2007) would be culturable for biofuel feedstocks. An iterative sequential downscaling procedure has been implemented to estimate culturable wasteland shares and suitability for biofuel feedstocks. Land suitability assessment results illustrate the prevalence and overall quality of culturable wasteland for different biofuel feedstocks across India. Only 30% of culturable wasteland area is suitable for biofuel feedstock production with a varying degree of productivity depending on biofuel feedstock.

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Using culturable wasteland land for the production of biodiesel could produce 7 billion litres biodiesel (216 PJ) from jatropha cultivation. A comparison of the different biofuel feedstocks potentially grown on culturable wasteland suggests that from the 4 Mha culturable wasteland suitable for biofuel feedstock production, miscanthus cultivation would provide the highest output in energy terms (237 PJ) on 2.7 Mha, sugarcane (2 PJ) on 0.1 Mha and jatropha (33 PJ) on 1.2 Mha. Assuming that the best biofuel feedstock in energy terms is grown at each location suggests a theoretical maximum biofuel potential of 272 PJ available from Indias culturable wasteland. However experiences with miscanthus as biofuel feedstock are still researched with commercial scale application being still under development and achievable oil yields from jatropha cultivation are still uncertain from an agronomic viewpoint. However, not all land with identified technical potential of culturable wasteland qualifies equally for the practical implementation of biofuel feedstock plantations. One of the major problems with these lands is that although they are rightly declared as wasteland, they are not necessarily left unused. It is quite likely that given the population pressure of India in the rural areas, a large part of the wasteland is occupied by marginal farmers and landless people. Future demand for food, livestock feed and pasture land will play an important role in the discussion of culturable wasteland potentials for biofuel feedstocks. According to the results of this study the biofuel program of the National Biofuel Policy, which aims to replace 20% of petroleum and diesel fuel consumption with biofuels by end of 12th Five-Year Plan (2016/2017), seems very ambitiousness and difficult to reach.

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Appendix A

Brazilian residual land suitability for bioethanol feedstocks by micro-regions

Micro-region[a]	**Residual land[b]**	**Sugarcane**			**Cassava**			**Miscanthus**		
		Suitable land[c]	**Product. potential**	**Biofuel potential[d]**	**Suitable land[c]**	**Product. potential**	**Biofuel potential[d]**	**Suitable land[c]**	**Product. potential**	**Biofuel potential[d]**
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Acre	**No residual land assessed**									
Alagoas	**27**	**18**	**31**	**21**	**23**	**55**	**22**	**23**	**90**	**27**
Alagoana do Sertão do São Francisco	5	1	1	1	1	0	0	5	20	6
Arapiraca	0	0	0	0	0	0	0	0	0	0
Batalha	0	0	0	0	0	0	0	0	0	0
Litoral Norte Alagoano	0	0	0	0	0	0	0	0	0	0
Maceió	6	4	24	16	5	29	11	5	50	15
Mata Alagoana	3	0	2	1	1	5	2	1	0	0
Palmeira dos Índios	0	0	0	0	0	0	0	0	0	0
Penedo	2	1	2	1	1	9	4	1	10	3
Santana do Ipanema	2	2	0	0	2	0	0	2	0	0
São Miguel dos Campos	2	0	2	1	0	5	2	0	0	0
Serrana do Sertão Alagoano	7	6	0	0	7	0	0	7	10	3
Serrana dos Quilombos	3	0	0	0	1	5	2	1	0	0
Traipu	1	1	0	0	1	0	0	1	0	0
Amapá	**No residual land assessed**									
Amazonas	**No residual land assessed**									
Bahia	**4,271**	**3,406**	**4,234**	**2,866**	**3,918**	**11,842**	**4,630**	**3,680**	**27,730**	**8,319**
Alagoinhas	32	25	83	56	32	120	47	32	230	69
Barra	214	115	68	46	185	494	193	122	1,010	303
Barreiras	624	607	469	318	617	2,426	949	615	4,030	1,209
Bom Jesus da Lapa	304	287	103	70	300	711	278	297	1,770	531
Boquira	177	130	129	87	164	314	123	132	900	270
Brumado	224	167	86	58	208	521	204	200	1,460	438
Catu	9	5	21	14	9	32	13	8	50	15
Cotegipe	150	131	92	62	144	420	164	135	1,160	348
Entre Rios	6	4	13	9	6	19	7	6	40	12
Euclides da Cunha	96	74	42	28	42	60	23	88	250	75
Feira de Santana	33	25	150	102	28	140	55	30	460	138
Guanambi	290	260	99	67	277	601	235	271	1,680	504
Ilhéus-Itabuna	0	0	0	0	0	0	0	0	0	0
Irecê	75	53	46	31	72	135	53	58	240	72
Itaberaba	22	12	24	16	13	32	13	16	110	33
Itapetinga	36	25	159	108	32	126	49	32	510	153
Jacobina	69	62	126	85	65	179	70	62	430	129
Jequié	59	26	58	39	40	116	45	44	330	99

Micro-region[a]	**Residual land**[b]	**Sugarcane**			**Cassava**			**Miscanthus**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Jeremoabo	11	7	1	1	11	7	3	11	20	6
Juazeiro	206	62	47	32	161	220	86	68	450	135
Livramento do Brumado	60	38	22	15	53	100	39	42	340	102
Paulo Afonso	75	4	0	0	72	23	9	10	20	6
Porto Seguro	132	83	371	251	120	339	133	122	1,030	309
Ribeira do Pombal	16	13	18	12	15	23	9	16	90	27
Salvador	10	8	42	28	10	51	20	9	60	18
Santa Maria da Vitória	776	754	1,184	802	772	3,232	1,264	773	7,240	2,172
Santo Antônio de Jesus	3	0	6	4	3	6	2	2	0	0
Seabra	104	54	126	85	81	222	87	54	520	156
Senhor do Bonfim	176	145	120	81	134	261	102	155	780	234
Serrinha	24	22	47	32	10	44	17	23	150	45
Valença	0	0	0	0	0	0	0	0	0	0
Vitória da Conquista	262	206	480	325	245	863	337	248	2,330	699
Ceará	**176**	**122**	**65**	**44**	**140**	**100**	**39**	**146**	**720**	**216**
Baixo Curu	0	0	0	0	0	0	0	0	0	0
Baixo Jaguaribe	21	3	0	0	4	1	0	4	10	3
Barro	3	2	2	1	2	6	2	2	20	6
Baturité	0	0	0	0	0	0	0	0	0	0
Brejo Santo	4	3	1	1	3	6	2	3	20	6
Canindé	9	7	11	7	8	5	2	8	60	18
Cariri	4	3	4	3	3	7	3	4	30	9
Caririaçu	1	0	0	0	0	0	0	0	0	0
Cascavel	1	1	0	0	1	0	0	1	0	0
Chapada do Araripe	7	4	4	3	6	8	3	7	40	12
Chorozinho	1	1	0	0	1	0	0	1	0	0
Coreaú	3	2	0	0	2	0	0	3	10	3
Fortaleza	0	0	0	0	0	1	0	0	0	0
Ibiapaba	2	1	0	0	0	1	0	0	0	0
Iguatu	5	3	1	1	3	1	0	5	10	3
Ipu	4	1	0	0	3	4	2	2	20	6
Itapipoca	4	3	0	0	4	1	0	4	10	3
Lavras da Mangabeira	1	0	0	0	0	0	0	1	0	0
Litoral de Aracati	2	0	0	0	1	0	0	1	0	0
Litoral de Camocim e Acaraú	1	0	0	0	1	0	0	1	0	0
Médio Curu	2	1	3	2	1	3	1	2	20	6
Médio Jaguaribe	9	6	0	0	5	1	0	7	0	0
Meruoca	0	0	0	0	0	0	0	0	0	0
Pacajus	1	1	0	0	1	0	0	1	0	0
Santa Quitéria	14	11	3	2	13	15	6	13	100	30
Serra do Pereiro	2	1	0	0	0	0	0	1	0	0
Sertão de Cratéus	7	4	4	3	6	9	4	6	50	15

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Sertão de Inhamuns	26	22	18	12	24	6	2	24	70	21
Sertão de Quixeramobim	19	17	6	4	18	5	2	18	70	21
Sertão de Senador Pompeu	10	9	2	1	10	2	1	10	10	3
Sobral	14	11	3	2	13	13	5	13	100	30
Uruburetama	0	0	0	0	0	0	0	0	0	0
Várzea Alegre	3	2	1	1	2	2	1	2	10	3
Distrito Federal	**12**	**12**	**34**	**23**	**12**	**52**	**20**	**5**	**140**	**42**
BrasÌlia	12	12	34	23	12	52	20	5	140	42
Espírito Santo	**794**	**276**	**1,032**	**699**	**456**	**1,662**	**650**	**494**	**3,830**	**1,149**
Afonso Cláudio	49	3	4	3	11	19	7	16	60	18
Alegre	56	2	2	1	13	19	7	17	60	18
Barra de São Francisco	131	20	23	16	60	101	39	68	220	66
Cachoeiro de Itapemirim	48	3	6	4	14	27	11	16	80	24
Colatina	125	19	23	16	56	63	25	64	180	54
Guarapari	21	6	24	16	10	59	23	11	110	33
Itapemirim	50	36	155	105	49	325	127	49	570	171
Linhares	49	18	67	45	30	134	52	32	260	78
Montanha	97	87	414	280	96	505	197	96	1,250	375
Nova Venécia	71	31	70	47	56	62	24	60	220	66
Santa Teresa	46	29	149	101	11	19	7	17	60	18
São Mateus	32	3	4	3	31	195	76	32	510	153
Vitória	19	15	89	60	17	131	51	17	260	78
Goiás	**3,482**	**2,658**	**5,581**	**3,778**	**2,695**	**5,871**	**2,296**	**1,844**	**12,890**	**3,867**
Anápolis	152	79	14	9	80	92	36	31	90	27
Anicuns	96	62	6	4	62	52	20	13	20	6
Aragarças	94	67	26	18	68	67	26	12	60	18
Catalão	183	140	352	238	145	889	348	143	1,170	351
Ceres	141	85	89	60	85	94	37	63	330	99
Chapada dos Veadeiros	3	2	5	3	2	7	3	1	30	9
Entorno de Brasília	405	256	265	179	257	452	177	117	910	273
Goiânia	162	106	89	60	106	290	113	42	650	195
Iporá	76	38	10	7	37	16	6	14	40	12
Meia Ponte	286	244	970	657	250	661	258	218	1,630	489
Pires do Rio	165	128	183	124	131	512	200	85	740	222
Porangatu	244	187	147	100	188	327	128	86	580	174
Quirinópolis	252	241	1,010	684	243	485	190	242	2,090	627
Rio Vermelho	121	86	9	6	91	65	25	7	20	6
São Miguel do Araguaia	161	141	44	30	149	211	83	27	160	48
Sudoeste de Goiás	692	603	1,680	1,137	609	1,289	504	597	3,350	1,005
Vale do Rio dos Bois	196	166	603	408	166	208	81	117	620	186
Vão do Paranã	54	27	78	53	27	150	59	27	360	108

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Maranhão	**1,879**	**942**	**918**	**621**	**1,387**	**2,868**	**1,121**	**927**	**6,330**	**1,899**
Aglomeração Urbana de São Luís	0	0	0	0	0	0	0	0	0	0
Alto Mearim e Grajaú	327	157	156	106	280	434	170	143	840	252
Baixada Maranhense	0	0	0	0	0	0	0	0	0	0
Baixo Parnaíba Maranhense	4	2	0	0	2	0	0	1	0	0
Caxias	17	8	0	0	13	5	2	1	10	3
Chapadas das Mangabeiras	351	128	79	53	212	345	135	132	910	273
Chapadas do Alto Itapecuru	111	32	4	3	86	76	30	35	170	51
Chapadinha	8	3	0	0	5	0	0	0	0	0
Codó	1	1	0	0	1	0	0	0	0	0
Coelho Neto	0	0	0	0	0	0	0	0	0	0
Gerais de Balsas	728	448	563	381	553	1,642	642	450	3,240	972
Gurupi	0	0	0	0	0	0	0	0	0	0
Imperatriz	12	8	11	7	10	31	12	7	50	15
Itapecuru Mirim	0	0	0	0	0	0	0	0	0	0
Lençois Maranhenses	36	35	4	3	36	51	20	35	150	45
Litoral Ocidental Maranhense	0	0	0	0	0	0	0	0	0	0
Médio Mearim	1	0	1	1	0	4	2	0	0	0
Pindaré	1	0	0	0	0	2	1	0	0	0
Porto Franco	282	122	99	67	188	278	109	122	950	285
Presidente Dutra	0	0	0	0	0	0	0	0	0	0
Rosário	0	0	0	0	0	0	0	0	0	0
Mato Grosso	**1,835**	**1,016**	**1,808**	**1,224**	**1,646**	**5,525**	**2,160**	**982**	**5,640**	**1,692**
Alta Floresta	0	0	0	0	0	0	0	0	0	0
Alto Araguaia	67	61	131	89	63	129	50	63	330	99
Alto Guaporé	0	0	0	0	0	0	0	0	0	0
Alto Pantanal	50	22	24	16	25	36	14	17	40	12
Alto Paraguai	0	0	0	0	0	1	0	0	0	0
Alto Teles Pires	32	30	56	38	31	95	37	30	200	60
Arinos	0	0	0	0	0	0	0	0	0	0
Aripuanã	1	1	1	1	0	2	1	1	0	0
Canarana	282	175	331	224	243	1,350	528	175	1,230	369
Colíder	0	0	0	0	0	0	0	0	0	0
Cuiabá	231	101	212	144	193	488	191	90	470	141
Jauru	6	6	3	2	5	11	4	6	10	3
Médio Araguaia	96	55	72	49	91	672	263	54	130	39
Norte Araguaia	78	64	22	15	77	371	145	63	160	48
Paranatinga	70	48	111	75	58	354	138	48	180	54
Parecis	94	90	203	137	92	252	99	90	650	195
Primavera do Leste	248	85	170	115	247	608	238	84	630	189

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Rondonópolis	180	138	245	166	174	327	128	121	630	189
Rosário Oeste	72	7	13	9	68	36	14	9	10	3
Sinop	0	0	0	0	0	0	0	0	0	0
Tangará da Serra	6	5	10	7	4	16	6	5	30	9
Tesouro	320	129	201	136	272	774	303	126	880	264
Mato Grosso do Sul	**1,427**	**1,401**	**5,948**	**4,027**	**1,409**	**4,559**	**1,783**	**1,409**	**15,610**	**4,683**
Alto Taquari	189	186	468	317	188	308	120	187	1,020	306
Aquidauana	7	5	33	22	6	9	4	5	90	27
Baixo Pantanal	14	4	5	3	4	2	1	4	30	9
Bodoquena	28	26	232	157	27	49	19	28	600	180
Campo Grande	174	171	1,086	735	174	425	166	172	2,230	669
Cassilândia	88	85	197	133	88	246	96	87	650	195
Dourados	193	192	1,568	1,062	192	382	149	193	3,670	1,101
Iguatemi	78	76	303	205	76	378	148	78	930	279
Nova Andradina	13	10	37	25	11	31	12	10	90	27
Paranaíba	230	227	766	519	230	1,187	464	229	2,410	723
Três Lagoas	417	416	1,252	848	417	1,540	602	417	3,910	1,173
Minas Gerais	**12,547**	**6,982**	**12,935**	**8,757**	**8,807**	**25,004**	**9,777**	**8,481**	**56,810**	**17,043**
Aimorés	209	20	16	11	71	91	36	81	240	72
Alfenas	141	71	126	85	84	279	109	83	610	183
Almenara	123	26	85	58	60	111	43	68	420	126
Andrelândia	131	40	45	30	16	34	13	73	360	108
Araçuaí	232	87	84	57	167	718	281	179	1,020	306
Araxá	306	166	326	221	173	300	117	173	1,050	315
Barbacena	196	87	75	51	42	42	16	115	510	153
Belo Horizonte	62	38	41	28	44	103	40	44	220	66
Bocaiúva	233	57	95	64	227	200	78	68	520	156
Bom Despacho	186	155	265	179	168	471	184	159	740	222
Campo Belo	83	50	43	29	58	54	21	59	170	51
Capelinha	79	38	56	38	69	232	91	63	420	126
Caratinga	210	36	27	18	100	138	54	101	370	111
Cataguases	65	6	4	3	32	27	11	33	90	27
Conceição do Mato Dentro	59	10	3	2	25	25	10	25	70	21
Conselheiro Lafaiete	97	44	36	24	58	130	51	57	310	93
Curvelo	361	332	655	443	341	1,303	509	341	3,140	942
Diamantina	43	4	5	3	39	20	8	7	40	12
Divinópolis	198	134	184	125	149	665	260	149	1,020	306
Formiga	133	84	129	87	97	338	132	96	630	189
Frutal	414	403	1,615	1,093	410	1,315	514	410	4,420	1,326
Governador Valadares	410	76	60	41	229	216	84	243	680	204
Grão Mogol	35	3	5	3	34	9	4	3	30	9
Guanhães	81	7	3	2	25	29	11	25	80	24
Ipatinga	105	15	13	9	39	54	21	39	140	42
Itabira	150	19	9	6	41	56	22	42	160	48
Itaguara	115	44	19	13	60	48	19	62	170	51

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Itajubá	43	1	1	1	0	2	1	3	20	6
Ituiutaba	118	112	385	261	113	339	133	114	1,080	324
Janaúba	147	95	72	49	136	256	100	103	750	225
Januária	500	494	791	536	498	2,072	810	498	3,880	1,164
Juiz de Fora	223	29	23	16	62	67	26	73	260	78
Lavras	142	97	132	89	106	229	90	111	520	156
Manhuaçu	89	5	2	1	27	24	9	28	80	24
Mantena	32	0	0	0	3	12	5	6	20	6
Montes Claros	628	500	728	493	610	1,467	574	546	3,680	1,104
Muriaé	62	5	3	2	24	20	8	24	60	18
Nanuque	199	57	127	86	139	182	71	148	520	156
Oliveira	138	55	41	28	72	129	50	72	300	90
Ouro Preto	12	2	0	0	6	10	4	6	30	9
Pará de Minas	64	36	35	24	44	78	30	44	200	60
Paracatu	659	486	1,021	691	544	2,299	899	474	3,590	1,077
Passos	101	58	67	45	65	64	25	66	210	63
Patos de Minas	159	38	47	32	71	65	25	44	130	39
Patrocínio	218	110	252	171	110	435	170	111	680	204
Peçanha	126	14	5	3	60	48	19	60	150	45
Pedra Azul	84	23	17	12	53	96	38	58	220	66
Pirapora	729	642	1,284	869	700	2,777	1,086	655	5,070	1,521
Piuí	37	10	9	6	18	17	7	13	50	15
Poços de Caldas	126	25	17	12	33	42	16	55	200	60
Ponte Nova	138	14	15	10	58	77	30	59	200	60
Pouso Alegre	103	13	19	13	14	32	13	36	160	48
Salinas	302	240	294	199	289	928	363	290	2,120	636
Santa Rita do Sapucaí	92	26	47	32	34	102	40	37	260	78
São João Del Rei	292	194	272	184	198	431	169	225	1,160	348
São Lourenço	104	23	33	22	30	71	28	36	190	57
São Sebastião do Paraíso	68	28	15	10	33	12	5	36	70	21
Sete Lagoas	60	48	79	53	52	197	77	51	470	141
Teófilo Otoni	292	27	26	18	107	277	108	132	470	141
Três Marias	240	167	301	204	217	501	196	168	1,050	315
Ubá	170	52	34	23	113	191	75	113	490	147
Uberaba	239	212	739	500	219	606	237	219	2,310	693
Uberlândia	434	386	1,074	727	396	1,560	610	396	4,280	1,284
Unaí	533	447	710	481	456	1,768	691	340	3,030	909
Varginha	210	110	183	124	130	410	160	131	880	264
Viçosa	175	34	13	9	98	98	38	97	310	93
Pará	**No residual land assessed**									
Paraíba	**173**	**112**	**379**	**257**	**141**	**552**	**216**	**130**	**670**	**201**
Brejo Paraibano	0	0	0	0	0	0	0	0	0	0
Cajazeiras	2	1	0	0	1	2	1	2	10	3
Campina Grande	3	2	0	0	2	0	0	2	0	0
Cariri Ocidental	6	4	1	1	5	1	0	5	10	3

Micro-region[a]	**Residual land[b]**	**Sugarcane**			**Cassava**			**Miscanthus**		
		Suitable land[c]	**Product. potential**	**Biofuel potential[d]**	**Suitable land[c]**	**Product. potential**	**Biofuel potential[d]**	**Suitable land[c]**	**Product. potential**	**Biofuel potential[d]**
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Cariri Oriental	4	3	0	0	4	1	0	4	10	3
Catolé do Rocha	3	0	0	0	1	1	0	2	10	3
Curimataú Ocidental	17	10	1	1	16	2	1	16	20	6
Curimataú Oriental	1	1	0	0	1	0	0	1	0	0
Esperança	0	0	0	0	0	0	0	0	0	0
Guarabira	0	0	0	0	0	1	0	0	0	0
Itabaiana	3	3	12	8	2	21	8	2	40	12
Itaporanga	4	2	0	0	3	0	0	3	0	0
João Pessoa	31	25	147	100	26	180	70	19	140	42
Litoral Norte	27	23	73	49	25	111	43	22	140	42
Litoral Sul	18	10	46	31	11	72	28	8	60	18
Patos	3	0	0	0	2	1	0	2	0	0
Piancó	7	3	0	0	6	0	0	7	0	0
Sapé	23	21	97	66	22	154	60	19	190	57
Seridó Ocidental Paraibano	0	0	0	0	0	0	0	0	0	0
Seridó Oriental Paraibano	8	0	0	0	8	1	0	2	0	0
Serra do Teixeira	2	0	0	0	1	0	0	1	0	0
Sousa	8	1	0	0	1	2	1	7	10	3
Umbuzeiro	3	1	0	0	2	1	0	2	0	0
Paraná	**1,306**	**765**	**1,673**	**1,133**	**445**	**806**	**315**	**1,143**	**10,550**	**3,165**
Apucarana	11	6	8	5	9	9	4	9	60	18
Assaí	32	21	45	30	26	29	11	30	250	75
Astorga	0	0	0	0	0	0	0	0	0	0
Campo Mourão	27	18	47	32	20	37	14	20	230	69
Capanema	7	5	9	6	6	3	1	7	60	18
Cascavel	47	21	37	25	29	15	6	38	270	81
Cerro Azul	13	5	5	3	2	6	2	5	40	12
Cianorte	14	14	35	24	13	62	24	12	150	45
Cornélio Procópio	15	13	51	35	13	18	7	13	210	63
Curitiba	114	32	53	36	3	3	1	105	1,220	366
Faxinal	4	2	3	2	4	3	1	4	30	9
Floraí	2	1	4	3	2	2	1	2	20	6
Foz do Iguaçu	3	3	9	6	2	6	2	3	30	9
Francisco Beltrão	36	13	21	14	10	3	1	25	150	45
Goioerê	11	8	18	12	8	19	7	8	110	33
Guarapuava	83	30	48	32	2	1	0	65	490	147
Ibaiti	48	27	54	37	43	46	18	45	180	54
Irati	37	28	42	28	0	0	0	36	330	99
Ivaiporã	24	14	28	19	18	22	9	19	160	48
Jacarezinho	4	2	20	14	3	7	3	3	50	15
Jaguariaíva	76	50	104	70	27	44	17	72	600	180
Lapa	58	44	76	51	0	0	0	51	750	225
Londrina	6	5	8	5	6	6	2	6	50	15
Maringá	26	21	66	45	23	30	12	23	210	63
Palmas	37	3	5	3	0	0	0	35	480	144

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Paranaguá	4	2	19	13	2	21	8	4	30	9
Paranavaí	54	49	134	91	49	153	60	51	460	138
Pato Branco	31	8	10	7	2	0	0	19	110	33
Pitanga	34	16	28	19	3	3	1	25	170	51
Ponta Grossa	122	96	213	144	0	0	0	114	1,170	351
Porecatu	10	9	31	21	9	14	5	10	120	36
Prudentópolis	63	48	95	64	1	0	0	58	380	114
Rio Negro	34	10	15	10	0	0	0	32	290	87
São Mateus do Sul	22	20	35	24	0	0	0	20	340	102
Telêmaco Borba	90	49	80	54	14	14	5	75	420	126
Toledo	12	9	32	22	11	20	8	12	170	51
Umuarama	22	21	57	39	22	106	41	22	220	66
União da Vitória	14	6	11	7	0	0	0	11	110	33
Wenceslau Braz	62	38	114	77	57	99	39	57	350	105
Pernambuco	**236**	**112**	**109**	**74**	**191**	**278**	**109**	**164**	**580**	**174**
Alto Capibaribe	0	0	0	0	0	0	0	0	0	0
Araripina	21	3	0	0	19	21	8	16	50	15
Brejo Pernambucano	15	6	8	5	12	29	11	11	50	15
Garanhuns	0	0	0	0	0	0	0	0	0	0
Itamaracá	1	0	0	0	0	1	0	0	0	0
Itaparica	22	10	1	1	22	14	5	16	50	15
Mata Meridional Pernambucana	0	0	0	0	0	0	0	0	0	0
Mata Setentrional Pernambucana	22	10	42	28	16	69	27	19	120	36
Médio Capibaribe	7	7	16	11	7	33	13	6	60	18
Pajeú	17	14	2	1	15	3	1	16	20	6
Petrolina	29	0	0	0	14	2	1	1	0	0
Recife	10	6	10	7	5	23	9	5	40	12
Salgueiro	28	15	1	1	27	4	2	24	20	6
Sertão do Moxotó	17	15	2	1	16	13	5	16	50	15
Suape	9	1	2	1	2	7	3	2	10	3
Vale do Ipanema	15	13	1	1	14	1	0	14	10	3
Vale do Ipojuca	2	2	0	0	2	0	0	2	0	0
Vitória de Santo Antão	21	10	24	16	16	54	21	16	100	30
Piauí	**1,138**	**461**	**113**	**77**	**693**	**1,256**	**491**	**544**	**2,790**	**837**
Alto Médio Canindé	33	1	0	0	27	9	4	8	10	3
Alto Médio Gurguéia	92	51	19	13	51	137	54	51	360	108
Alto Parnaíba Piauiense	246	158	61	41	161	408	160	159	980	294
Baixo Parnaíba Piauiense	10	0	0	0	9	0	0	0	0	0
Bertolínia	131	39	6	4	89	90	35	41	180	54
Campo Maior	118	31	4	3	58	94	37	45	180	54
Chapadas do	6	6	4	3	4	14	5	6	40	12

Micro-region[a]	**Residual land**[b]	**Sugarcane**			**Cassava**			**Miscanthus**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Extremo Sul Piauiense										
Floriano	244	123	14	9	183	361	141	159	800	240
Litoral Piauiense	3	0	0	0	2	1	0	0	0	0
Médio Parnaíba Piauiense	15	8	1	1	8	18	7	8	40	12
Picos	48	4	0	0	9	19	7	9	30	9
Pio IX	19	5	1	1	19	21	8	15	30	9
São Raimundo Nonato	16	3	0	0	11	10	4	8	20	6
Teresina	31	10	0	0	26	3	1	0	0	0
Valença do Piauí	126	22	3	2	37	73	29	35	120	36
Rio de Janeiro	**779**	**232**	**733**	**496**	**376**	**985**	**385**	**413**	**2,560**	**768**
Bacia de São João	1	0	1	1	0	0	0	0	0	0
Baía da Ilha Grande	0	0	0	0	0	0	0	0	0	0
Barra do Piraí	71	18	20	14	42	33	13	42	200	60
Campos dos Goytacazes	149	67	290	196	84	465	182	91	900	270
Cantagalo-Cordeiro	25	1	2	1	7	5	2	8	20	6
Itaguaí	16	3	12	8	5	5	2	4	20	6
Itaperuna	67	13	28	19	32	43	17	37	140	42
Lagos	23	13	59	40	12	17	7	14	70	21
Macacu-Caceribu	5	2	3	2	4	4	2	4	10	3
Macaé	54	40	155	105	43	218	85	45	430	129
Nova Friburgo	33	2	1	1	4	6	2	9	40	12
Rio de Janeiro	62	23	75	51	29	38	15	31	160	48
Santa Maria Madalena	31	1	1	1	3	3	1	4	20	6
Santo Antônio de Pádua	57	8	13	9	30	15	6	33	90	27
Serrana	33	2	0	0	2	1	0	6	20	6
Três Rios	51	4	5	3	16	8	3	16	50	15
Vale do Paraíba Fluminense	56	19	48	32	38	80	31	39	250	75
Vassouras	43	12	17	12	25	37	14	25	120	36
Rio Grande do Norte	**128**	**64**	**75**	**51**	**83**	**138**	**54**	**91**	**470**	**141**
Agreste Potiguar	4	4	4	3	4	4	2	4	30	9
Angicos	4	0	0	0	2	0	0	2	0	0
Baixa Verde	8	8	2	1	8	4	2	8	20	6
Borborema Potiguar	12	7	1	1	10	2	1	10	20	6
Chapada do Apodi	9	2	0	0	2	3	1	8	20	6
Litoral Nordeste	2	2	1	1	2	3	1	2	10	3
Litoral Sul	14	13	26	18	13	38	15	14	110	33
Macaíba	19	18	33	22	18	53	21	19	140	42
Macau	6	1	0	0	5	8	3	6	20	6
Médio Oeste	13	1	0	0	4	6	2	8	40	12

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Mossoró	12	0	0	0	0	0	0	1	0	0
Natal	3	3	6	4	3	9	4	3	20	6
Pau dos Ferros	4	2	0	0	2	3	1	4	20	6
Seridó Ocidental	0	0	0	0	0	0	0	0	0	0
Seridó Oriental	3	0	0	0	1	0	0	0	0	0
Serra de Santana	5	0	0	0	2	0	0	0	0	0
Serra de São Miguel	0	0	0	0	0	0	0	0	0	0
Umarizal	3	1	0	0	1	2	1	2	10	3
Vale do Açu	8	0	0	0	2	1	0	1	0	0
Rio Grande do Sul	**1,112**	**750**	**2,912**	**1,971**	**429**	**1,364**	**533**	**890**	**14,110**	**4,233**
Cachoeira do Sul	19	19	119	81	19	110	43	19	470	141
Camaquã	44	37	223	151	32	149	58	41	980	294
Campanha Central	40	35	243	165	26	56	22	35	500	150
Campanha Meridional	51	46	164	111	4	6	2	44	610	183
Campanha Ocidental	54	36	315	213	21	5	2	38	930	279
Carazinho	14	9	9	6	12	4	2	12	80	24
Caxias do Sul	14	3	1	1	0	0	0	10	70	21
Cerro Largo	10	6	32	22	7	10	4	7	140	42
Cruz Alta	19	16	44	30	15	12	5	17	260	78
Erechim	18	1	1	1	1	0	0	2	10	3
Frederico Westphalen	19	3	3	2	5	2	1	5	30	9
Gado-Canela	9	4	20	14	5	19	7	6	100	30
Guaporé	24	7	5	3	0	0	0	9	80	24
Ijuí	16	14	20	14	15	10	4	14	160	48
Jaguarão	19	14	55	37	0	0	0	15	330	99
Lajeado-Estrela	12	7	44	30	7	42	16	8	170	51
Litoral Lagunar	1	0	0	0	0	0	0	0	0	0
Montenegro	13	10	44	30	11	56	22	13	270	81
Não-Me-Toque	0	0	0	0	0	0	0	0	0	0
Osório	44	24	67	45	12	25	10	26	230	69
Passo Fundo	58	29	35	24	10	2	1	35	340	102
Pelotas	99	78	250	169	8	31	12	93	1,740	522
Porto Alegre	71	63	371	251	68	371	145	68	1,630	489
Restinga Seca	8	6	46	31	7	39	15	7	170	51
Sananduva	19	8	38	26	0	0	0	13	110	33
Santa Cruz do Sul	12	9	7	5	7	34	13	8	140	42
Santa Maria	29	17	101	68	19	68	27	19	370	111
Santa Rosa	14	9	26	18	10	9	4	9	150	45
Santiago	26	21	44	30	21	18	7	21	190	57
Santo Ângelo	32	26	129	87	25	31	12	26	540	162
São Jerônimo	45	41	230	156	42	235	92	43	940	282
Serras de Sudeste	72	58	102	69	6	4	2	65	910	273
Soledade	48	29	49	33	2	1	0	39	490	147
Três Passos	17	6	17	12	7	7	3	7	90	27
Vacaria	124	53	54	37	0	0	0	105	850	255

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Rondônia	**No residual land assessed**									
Roraima	**No residual land assessed**									
Santa Catarina	**576**	**191**	**451**	**305**	**127**	**339**	**133**	**469**	**3,540**	**1,062**
Araranguá	14	5	12	8	4	7	3	5	30	9
Blumenau	7	3	13	9	5	16	6	5	50	15
Campos de Lages	79	7	7	5	0	0	0	76	470	141
Canoinhas	69	53	86	58	0	0	0	65	530	159
Chapecó	42	11	9	6	22	5	2	23	60	18
Concórdia	6	0	0	0	0	0	0	1	0	0
Criciúma	30	21	51	35	20	41	16	23	230	69
Curitibanos	46	3	1	1	0	0	0	45	310	93
Florianópolis	12	8	42	28	10	48	19	10	140	42
Itajaí	19	15	77	52	18	95	37	18	250	75
Ituporanga	14	6	11	7	0	0	0	11	90	27
Joaçaba	80	6	3	2	0	0	0	70	400	120
Joinville	12	9	55	37	11	69	27	12	130	39
Rio do Sul	34	14	25	17	8	11	4	27	170	51
São Bento do Sul	18	4	5	3	0	0	0	18	150	45
São Miguel do Oeste	20	4	6	4	8	2	1	10	50	15
Tabuleiro	1	0	0	0	0	0	0	0	0	0
Tijucas	3	2	15	10	2	17	7	2	40	12
Tubarão	42	13	27	18	19	28	11	27	190	57
Xanxerê	27	5	3	2	2	0	0	23	190	57
São Paulo	**3,305**	**2,814**	**10,093**	**6,833**	**2,903**	**13,598**	**5,317**	**3,108**	**36,970**	**11,091**
Adamantina	31	31	105	71	31	248	97	31	320	96
Amparo	44	11	3	2	14	6	2	32	90	27
Andradina	108	107	333	225	108	525	205	107	1,140	342
Araçatuba	88	88	270	183	88	469	183	88	1,020	306
Araraquara	33	33	146	99	33	130	51	32	370	111
Assis	80	78	517	350	78	187	73	80	1,530	459
Auriflama	28	28	78	53	27	167	65	28	270	81
Avaré	57	54	150	102	57	191	75	57	660	198
Bananal	22	2	0	0	8	5	2	10	30	9
Barretos	36	35	104	70	36	152	59	35	320	96
Batatais	8	6	10	7	6	5	2	6	40	12
Bauru	105	103	356	241	105	549	215	105	1,250	375
Birigui	92	90	311	211	92	574	224	91	1,010	303
Botucatu	48	43	95	64	47	136	53	47	490	147
Bragança Paulista	62	35	48	32	55	96	38	56	350	105
Campinas	121	112	417	282	120	475	186	120	1,860	558
Campos do Jordão	8	0	0	0	0	0	0	1	0	0
Capão Bonito	73	41	84	57	20	49	19	60	520	156
Caraguatatuba	5	2	18	12	2	17	7	2	30	9
Catanduva	41	41	160	108	40	325	127	40	460	138
Dracena	27	26	100	68	27	159	62	27	300	90
Fernandópolis	45	45	127	86	44	217	85	44	510	153
Franca	28	19	26	18	20	16	6	20	90	27

Micro-region[a]	**Residual land**[b]	**Sugarcane**			**Cassava**			**Miscanthus**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Franco da Rocha	3	2	2	1	3	4	2	3	10	3
Guaratinguetá	86	38	154	104	52	208	81	65	610	183
Guarulhos	21	16	39	26	20	58	23	21	160	48
Itanhaém	2	1	2	1	1	0	0	1	0	0
Itapecerica da Serra	14	12	35	24	6	15	6	14	130	39
Itapetininga	82	73	197	133	82	239	93	82	960	288
Itapeva	77	58	137	93	69	153	60	75	710	213
Ituverava	44	36	158	107	38	53	21	38	350	105
Jaú	18	16	79	53	17	30	12	17	200	60
Jaboticabal	61	60	248	168	60	424	166	60	660	198
Jales	21	21	70	47	20	135	53	21	220	66
Jundiaí	32	25	75	51	31	126	49	32	350	105
Limeira	39	37	200	135	39	280	109	38	730	219
Lins	65	64	247	167	64	462	181	64	770	231
Marília	51	43	145	98	49	272	106	49	520	156
Mogi das Cruzes	34	25	69	47	22	44	17	32	230	69
Moji Mirim	14	12	41	28	13	65	25	13	190	57
Nhandeara	32	30	100	68	31	216	84	30	320	96
Novo Horizonte	25	25	120	81	25	206	81	25	340	102
Osasco	5	4	6	4	4	9	4	4	20	6
Ourinhos	95	91	395	267	94	192	75	95	1,620	486
Paraibuna/Paraitinga	106	18	14	9	3	2	1	52	170	51
Piedade	38	27	61	41	7	17	7	34	290	87
Piracicaba	123	114	402	272	122	526	206	122	1,750	525
Pirassununga	36	33	219	148	35	245	96	35	590	177
Presidente Prudente	192	190	656	444	191	1,044	408	191	2,070	621
Registro	0	0	0	0	0	0	0	0	0	0
Ribeirão Preto	0	0	3	2	0	1	0	0	0	0
Rio Claro	71	63	253	171	69	399	156	68	850	255
São Carlos	30	28	125	85	29	195	76	29	370	111
São João da Boa Vista	27	18	59	40	21	65	25	23	190	57
São Joaquim da Barra	6	6	31	21	5	10	4	6	30	9
São José do Rio Preto	175	173	632	428	174	1,112	435	174	2,090	627
São José dos Campos	140	85	348	236	110	428	167	119	1,210	363
São Paulo	12	10	39	26	11	33	13	10	100	30
Santos	3	1	6	4	1	3	1	1	0	0
Sorocaba	169	157	605	410	152	695	272	169	2,720	816
Tatuí	106	102	438	297	105	500	196	106	1,920	576
Tupã	17	17	56	38	16	134	52	17	170	51
Votuporanga	53	52	162	110	52	298	117	52	590	177
Sergipe	**46**	**36**	**64**	**43**	**43**	**85**	**33**	**43**	**90**	**27**
Agreste de Itabaiana	2	2	1	1	2	1	0	2	0	0
Agreste de Lagarto	1	0	0	0	1	1	0	1	0	0

Micro-region[a]	Residual land[b]	Sugarcane			Cassava			Miscanthus		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton root DW	Mio litre	1000 ha	1000 ton AGB DW	Mio litre
Aracaju	8	6	15	10	7	18	7	8	20	6
Baixo Cotinguiba	5	3	9	6	5	10	4	5	10	3
Boquim	2	2	0	0	2	1	0	2	0	0
Carira	0	0	0	0	0	0	0	0	0	0
Cotinguiba	1	0	0	0	0	1	0	1	0	0
Estância	14	11	32	22	14	37	14	14	30	9
Japaratuba	6	5	4	3	6	14	5	5	10	3
Nossa Senhora das Dores	0	0	0	0	0	0	0	0	0	0
Propriá	1	0	0	0	1	2	1	1	0	0
Sergipana do Sertão do São Francisco	4	3	2	2	2	0	0	2	20	6
Tobias Barreto	3	2	0	0	3	0	0	2	0	0
Tocantins	**2,550**	**1,480**	**996**	**674**	**2,252**	**3,201**	**1,252**	**851**	**5,730**	**1,719**
Araguaína	85	12	2	1	81	33	13	12	70	21
Bico do Papagaio	26	9	13	9	16	21	8	10	120	36
Dianópolis	402	304	148	100	315	508	199	154	740	222
Gurupi	317	293	98	66	294	353	138	77	490	147
Jalapão	1,166	444	518	351	1,079	1,292	505	444	3,210	963
Miracema do Tocantins	121	70	44	30	102	207	81	34	270	81
Porto Nacional	192	142	86	58	144	200	78	50	430	129
Rio Formoso	241	206	86	58	222	587	230	72	410	123
Total Brazil	**37,799**	**23,850**	**50,184**	**33,975**	**28,176**	**80,140**	**31,335**	**25,837**	**207,850**	**62,355**

a Rondônia, Acre, Amazonas, Roraima, Pará and Amapá are states located in legal Amazonas biome. Residual land in this states is excluded due definition (see b)

b Residual land is defined as remaining fraction currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome. Source: Brazilian 1 km land use database (Lossau et al. 2015)

c Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. Not suitable land is not considerd

d sugarcane (677 litre bioethanol / ton sugar), cassava (391 litre bioethanol / ton cassava roots (DW)), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), soybean (221 litre biodiesel / ton soybean seed (DW), jatropha (1049 litre biodiesel / ton jatropha oil)

AGB: Above Ground Biomas

DW: Dry Weight

Table A-1 Brazilian residual land suitability for bioethanol feedstocks by micro-region

Appendix B

Brazilian residual land suitability for biodiesel feedstocks by micro-regions

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Acre	**No residual land assessed**						
Alagoas	**27**	**23**	**12**	**3**	**23**	**10**	**10**
Alagoana do Sertão do São Francisco	5	5	1	0	4	2	2
Arapiraca	0	0	0	0	0	0	0
Batalha	0	0	0	0	0	0	0
Litoral Norte Alagoano	0	0	0	0	0	0	0
Maceió	6	5	8	2	5	6	6
Mata Alagoana	3	1	1	0	1	1	1
Palmeira dos Índios	0	0	0	0	0	0	0
Penedo	2	1	1	0	1	1	1
Santana do Ipanema	2	0	1	0	1	1	1
São Miguel dos Campos	2	2	0	0	2	0	0
Serrana do Sertão Alagoano	7	7	0	0	7	0	0
Serrana dos Quilombos	3	1	0	0	1	0	0
Traipu	1	1	0	0	1	0	0
Amapá	**No residual land assessed**						
Amazonas	**No residual land assessed**						
Bahia	**4,271**	**3,627**	**5,268**	**1,164**	**3,726**	**2,207**	**2,315**
Alagoinhas	32	31	18	4	32	23	25
Barra	214	123	180	40	127	60	63
Barreiras	624	615	496	110	613	349	366
Bom Jesus da Lapa	304	299	418	92	296	131	138
Boquira	177	133	267	59	132	88	93
Brumado	224	197	313	69	200	105	110
Catu	9	8	3	1	8	7	7
Cotegipe	150	135	193	43	135	77	81
Entre Rios	6	6	2	0	6	3	3
Euclides da Cunha	96	33	21	5	91	18	18
Feira de Santana	33	28	49	11	29	41	43
Guanambi	290	271	478	106	270	111	116
Ilhéus-Itabuna	0	0	0	0	0	0	0
Irecê	75	65	89	20	63	35	37
Itaberaba	22	12	11	2	17	12	12
Itapetinga	36	31	72	16	31	33	35
Jacobina	69	59	61	13	62	77	80
Jequié	59	37	43	10	43	24	25
Jeremoabo	11	8	1	0	10	1	1
Juazeiro	206	118	167	37	77	50	53
Livramento do Brumado	60	42	89	20	43	25	26
Paulo Afonso	75	32	3	1	42	3	3
Porto Seguro	132	120	126	28	121	53	55
Ribeira do Pombal	16	15	8	2	16	6	6

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Salvador	10	9	4	1	9	10	11
Santa Maria da Vitória	776	772	1,334	295	772	496	520
Santo Antônio de Jesus	3	2	0	0	2	1	1
Seabra	104	54	114	25	55	83	87
Senhor do Bonfim	176	122	91	20	153	86	91
Serrinha	24	9	20	4	24	14	15
Valença	0	0	0	0	0	0	0
Vitória da Conquista	262	241	594	131	247	186	195
Ceará	**176**	**147**	**187**	**41**	**147**	**72**	**76**
Baixo Curu	0	0	0	0	0	0	0
Baixo Jaguaribe	21	5	2	0	4	1	1
Barro	3	2	3	1	2	1	1
Baturité	0	0	0	0	0	0	0
Brejo Santo	4	3	2	0	3	1	1
Canindé	9	8	17	4	8	12	12
Cariri	4	3	7	2	4	2	2
Caririaçu	1	0	0	0	0	0	0
Cascavel	1	1	0	0	1	0	0
Chapada do Araripe	7	6	8	2	7	3	3
Chorozinho	1	0	0	0	1	0	0
Coreaú	3	2	2	0	2	0	0
Fortaleza	0	0	0	0	0	0	0
Ibiapaba	2	0	0	0	0	0	0
Iguatu	5	5	3	1	5	1	1
Ipu	4	3	6	1	3	1	1
Itapipoca	4	3	2	0	4	1	1
Lavras da Mangabeira	1	1	0	0	1	0	0
Litoral de Aracati	2	1	0	0	1	0	0
Litoral de Camocim e Acaraú	1	1	0	0	1	0	0
Médio Curu	2	1	4	1	1	3	3
Médio Jaguaribe	9	8	1	0	7	1	1
Meruoca	0	0	0	0	0	0	0
Pacajus	1	1	0	0	1	0	0
Santa Quitéria	14	13	33	7	13	5	5
Serra do Pereiro	2	1	0	0	1	0	0
Sertão de Cratéus	7	7	15	3	6	5	5
Sertão de Inhamuns	26	24	27	6	24	16	16
Sertão de Quixeramobim	19	18	20	4	18	10	10
Sertão de Senador Pompeu	10	9	6	1	9	1	1
Sobral	14	12	20	4	13	5	5
Uruburetama	0	0	0	0	0	0	0
Várzea Alegre	3	2	2	0	1	1	1
Distrito Federal	**12**	**11**	**21**	**5**	**12**	**14**	**15**
BrasÌlia	12	11	21	5	12	14	15
Espírito Santo	**794**	**457**	**434**	**96**	**456**	**242**	**254**
Afonso Cláudio	49	11	4	1	11	2	2
Alegre	56	13	1	0	12	2	2
Barra de São Francisco	131	59	12	3	59	14	15

Micro-region[a]	**Residual land[b]**	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential[d]**	**Suitable land[c]**	**Product. potential**	**Biofuel potential[d]**
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Cachoeiro de Itapemirim	48	14	4	1	13	4	4
Colatina	125	55	13	3	56	11	12
Guarapari	21	10	11	2	9	9	10
Itapemirim	50	50	76	17	49	56	59
Linhares	49	29	27	6	30	22	23
Montanha	97	95	166	37	96	62	65
Nova Venécia	71	58	15	3	58	12	13
Santa Teresa	46	12	2	0	12	3	3
São Mateus	32	31	64	14	32	20	21
Vitória	19	19	35	8	18	24	25
Goiás	**3,482**	**2,681**	**2,802**	**619**	**2,690**	**1,226**	**1,286**
Anápolis	152	78	11	2	79	12	12
Anicuns	96	62	3	1	62	5	5
Aragarças	94	66	15	3	69	16	17
Catalão	183	145	265	59	144	179	188
Ceres	141	85	52	11	84	18	19
Chapada dos Veadeiros	3	3	5	1	3	3	3
Entorno de Brasília	405	257	238	53	257	100	105
Goiânia	162	106	94	21	107	76	80
Iporá	76	38	5	1	37	5	5
Meia Ponte	286	249	397	88	248	135	141
Pires do Rio	165	131	123	27	130	111	117
Porangatu	244	188	115	25	188	78	82
Quirinópolis	252	243	460	102	243	101	106
Rio Vermelho	121	86	6	1	90	13	14
São Miguel do Araguaia	161	141	27	6	142	37	39
Sudoeste de Goiás	692	609	829	183	609	259	272
Vale do Rio dos Bois	196	166	104	23	166	43	45
Vão do Paranã	54	27	51	11	27	34	36
Maranhão	**1,879**	**937**	**762**	**168**	**937**	**486**	**510**
Aglomeração Urbana de São Luís	0	0	0	0	0	0	0
Alto Mearim e Grajaú	327	142	99	22	142	83	87
Baixada Maranhense	0	0	0	0	0	0	0
Baixo Parnaíba Maranhense	4	2	0	0	1	0	0
Caxias	17	8	1	0	8	1	1
Chapadas das Mangabeiras	351	132	102	23	132	66	70
Chapadas do Alto Itapecuru	111	34	26	6	34	16	16
Chapadinha	8	2	0	0	2	0	0
Codó	1	1	0	0	1	0	0
Coelho Neto	0	0	0	0	0	0	0
Gerais de Balsas	728	451	350	77	451	239	251
Gurupi	0	0	0	0	0	0	0
Imperatriz	12	7	6	1	7	6	6
Itapecuru Mirim	0	0	0	0	0	0	0
Lençois Maranhenses	36	35	16	4	35	14	15
Litoral Ocidental Maranhense	0	0	0	0	0	0	0
Médio Mearim	1	0	0	0	0	1	1
Pindaré	1	0	0	0	0	0	0

Micro-region[a]	Residual land[b]	Soybean			Jatropha		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Porto Franco	282	122	161	36	122	59	62
Presidente Dutra	0	0	0	0	0	0	0
Rosário	0	0	0	0	0	0	0
Mato Grosso	**1,835**	**1,024**	**684**	**151**	**1,044**	**826**	**866**
Alta Floresta	0	0	0	0	0	0	0
Alto Araguaia	67	63	62	14	63	25	27
Alto Guaporé	0	0	0	0	0	0	0
Alto Pantanal	50	19	3	1	17	10	11
Alto Paraguai	0	0	0	0	0	0	0
Alto Teles Pires	32	30	15	3	31	14	14
Arinos	0	0	0	0	0	0	0
Aripuanã	1	1	0	0	1	0	0
Canarana	282	174	197	44	181	193	203
Colíder	0	0	0	0	0	0	0
Cuiabá	231	90	60	13	90	95	100
Jauru	6	6	1	0	6	2	2
Médio Araguaia	96	56	8	2	69	65	68
Norte Araguaia	78	63	11	2	65	23	24
Paranatinga	70	47	11	2	48	39	41
Parecis	94	90	65	14	90	46	48
Primavera do Leste	248	87	64	14	88	122	128
Rondonópolis	180	145	95	21	145	71	74
Rosário Oeste	72	8	1	0	8	1	1
Sinop	0	0	0	0	0	0	0
Tangará da Serra	6	5	3	1	5	3	3
Tesouro	320	138	86	19	139	112	118
Mato Grosso do Sul	**1,427**	**1,411**	**2,079**	**459**	**1,421**	**1,100**	**1,154**
Alto Taquari	189	187	101	22	189	111	117
Aquidauana	7	5	12	3	6	6	6
Baixo Pantanal	14	6	3	1	13	23	24
Bodoquena	28	27	78	17	27	16	17
Campo Grande	174	173	334	74	174	96	100
Cassilândia	88	87	77	17	87	53	55
Dourados	193	191	514	114	192	81	85
Iguatemi	78	77	132	29	76	90	94
Nova Andradina	13	10	12	3	10	7	8
Paranaíba	230	229	362	80	229	271	284
Três Lagoas	417	417	456	101	417	345	362
Minas Gerais	**12,547**	**8,500**	**10,291**	**2,274**	**8,511**	**5,028**	**5,274**
Aimorés	209	71	18	4	72	14	15
Alfenas	141	83	56	12	83	45	47
Almenara	123	60	52	11	61	23	24
Andrelândia	131	68	19	4	71	21	23
Araçuaí	232	167	121	27	166	99	104
Araxá	306	173	283	63	173	39	41
Barbacena	196	114	28	6	115	36	38
Belo Horizonte	62	44	38	8	43	19	20
Bocaiúva	233	69	72	16	68	53	56

Micro-region[a]	Residual land[b]	Soybean			Jatropha		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Bom Despacho	186	159	275	61	160	66	70
Campo Belo	83	58	34	8	58	13	14
Capelinha	79	63	50	11	64	40	42
Caratinga	210	100	20	4	101	23	25
Cataguases	65	32	2	0	33	5	5
Conceição do Mato Dentro	59	26	3	1	26	6	6
Conselheiro Lafaiete	97	58	19	4	58	23	24
Curvelo	361	341	566	125	342	302	317
Diamantina	43	6	5	1	5	4	4
Divinópolis	198	149	133	29	150	97	102
Formiga	133	97	81	18	96	53	56
Frutal	414	411	891	197	410	294	309
Governador Valadares	410	230	50	11	230	40	42
Grão Mogol	35	3	9	2	3	5	5
Guanhães	81	25	2	0	25	5	5
Ipatinga	105	40	9	2	39	9	10
Itabira	150	42	6	1	43	10	11
Itaguara	115	61	19	4	61	11	12
Itajubá	43	2	1	0	2	1	1
Ituiutaba	118	114	195	43	114	77	81
Janaúba	147	103	193	43	104	66	70
Januária	500	498	600	133	498	423	444
Juiz de Fora	223	72	10	2	73	15	16
Lavras	142	110	82	18	110	43	45
Manhuaçu	89	27	1	0	28	4	4
Mantena	32	5	0	0	4	1	1
Montes Claros	628	546	911	201	546	324	340
Muriaé	62	24	2	0	24	5	5
Nanuque	199	139	44	10	139	31	32
Oliveira	138	72	25	6	72	23	25
Ouro Preto	12	6	0	0	6	1	1
Pará de Minas	64	42	35	8	44	16	16
Paracatu	659	489	932	206	490	451	473
Passos	101	66	22	5	65	16	16
Patos de Minas	159	45	50	11	45	7	7
Patrocínio	218	111	257	57	111	79	83
Peçanha	126	61	6	1	59	8	9
Pedra Azul	84	54	32	7	54	14	14
Pirapora	729	660	1,057	234	659	560	588
Piuí	37	13	6	1	14	2	2
Poços de Caldas	126	49	10	2	53	10	11
Ponte Nova	138	59	10	2	59	13	14
Pouso Alegre	103	21	7	2	24	8	8
Salinas	302	288	599	132	288	188	197
Santa Rita do Sapucaí	92	36	16	4	37	18	18
São João Del Rei	292	224	159	35	225	98	102
São Lourenço	104	34	14	3	34	14	14
São Sebastião do Paraíso	68	35	5	1	35	4	4

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Sete Lagoas	60	50	72	16	50	47	49
Teófilo Otoni	292	107	30	7	107	33	35
Três Marias	240	169	300	66	167	95	100
Ubá	170	113	20	4	113	32	33
Uberaba	239	218	429	95	218	142	149
Uberlândia	434	397	661	146	396	360	378
Unaí	533	456	533	118	456	354	372
Varginha	210	131	96	21	131	69	72
Viçosa	175	98	8	2	97	20	20
Pará	**No residual land assessed**						
Paraíba	**173**	**133**	**129**	**29**	**145**	**136**	**143**
Brejo Paraibano	0	0	0	0	0	0	0
Cajazeiras	2	2	3	1	2	1	1
Campina Grande	3	3	0	0	2	0	0
Cariri Ocidental	6	6	3	1	5	1	1
Cariri Oriental	4	4	1	0	4	1	1
Catolé do Rocha	3	3	1	0	3	0	0
Curimataú Ocidental	17	16	3	1	16	1	1
Curimataú Oriental	1	1	0	0	1	0	0
Esperança	0	0	0	0	0	0	0
Guarabira	0	0	0	0	0	0	0
Itabaiana	3	2	7	2	2	5	5
Itaporanga	4	3	0	0	3	0	0
João Pessoa	31	16	29	6	25	43	45
Litoral Norte	27	23	20	4	25	27	28
Litoral Sul	18	7	15	3	11	17	18
Patos	3	3	1	0	3	0	0
Piancó	7	7	0	0	7	0	0
Sapé	23	19	42	9	21	38	40
Seridó Ocidental Paraibano	0	0	0	0	0	0	0
Seridó Oriental Paraibano	8	8	0	0	2	0	0
Serra do Teixeira	2	1	0	0	1	0	0
Sousa	8	7	2	0	7	1	1
Umbuzeiro	3	2	0	0	2	0	0
Paraná	**1,306**	**1,130**	**1,274**	**282**	**1,064**	**347**	**364**
Apucarana	11	9	8	2	9	1	1
Assaí	32	28	34	8	29	7	7
Astorga	0	0	0	0	0	0	0
Campo Mourão	27	20	34	8	20	7	7
Capanema	7	6	6	1	7	1	1
Cascavel	47	37	31	7	37	3	3
Cerro Azul	13	6	3	1	5	2	2
Cianorte	14	14	21	5	13	13	14
Cornélio Procópio	15	12	29	6	13	3	3
Curitiba	114	103	79	17	91	24	25
Faxinal	4	3	4	1	3	0	0
Floraí	2	2	4	1	2	0	0
Foz do Iguaçu	3	3	5	1	3	1	1

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Francisco Beltrão	36	24	17	4	24	1	1
Goioerê	11	8	13	3	8	4	4
Guarapuava	83	60	59	13	56	5	5
Ibaiti	48	44	33	7	43	11	12
Irati	37	37	35	8	36	5	5
Ivaiporã	24	19	21	5	19	3	3
Jacarezinho	4	3	9	2	3	1	1
Jaguariaíva	76	72	81	18	73	39	41
Lapa	58	51	69	15	51	19	20
Londrina	6	6	7	2	6	1	1
Maringá	26	22	38	8	22	3	3
Palmas	37	35	23	5	4	0	0
Paranaguá	4	4	2	0	4	2	2
Paranavaí	54	49	59	13	50	30	31
Pato Branco	31	18	11	2	19	1	1
Pitanga	34	24	29	6	24	2	2
Ponta Grossa	122	115	196	43	115	52	55
Porecatu	10	10	19	4	10	2	2
Prudentópolis	63	56	58	13	58	18	18
Rio Negro	34	33	17	4	16	4	4
São Mateus do Sul	22	20	38	8	20	8	8
Telêmaco Borba	90	74	56	12	73	22	23
Toledo	12	10	25	6	11	4	4
Umuarama	22	22	28	6	22	21	23
União da Vitória	14	11	9	2	7	1	1
Wenceslau Braz	62	58	61	13	58	23	24
Pernambuco	**236**	**189**	**109**	**24**	**175**	**63**	**66**
Alto Capibaribe	0	0	0	0	0	0	0
Araripina	21	20	23	5	19	3	3
Brejo Pernambucano	15	11	5	1	11	5	5
Garanhuns	0	0	0	0	0	0	0
Itamaracá	1	0	0	0	0	0	0
Itaparica	22	21	7	2	17	3	3
Mata Meridional Pernambucana	0	0	0	0	0	0	0
Mata Setentrional Pernambucana	22	17	18	4	20	18	19
Médio Capibaribe	7	7	10	2	7	8	8
Pajeú	17	16	8	2	15	1	1
Petrolina	29	15	3	1	3	0	0
Recife	10	5	4	1	6	5	5
Salgueiro	28	27	8	2	27	1	1
Sertão do Moxotó	17	16	9	2	16	4	4
Suape	9	2	1	0	2	1	1
Vale do Ipanema	15	14	0	0	14	1	1
Vale do Ipojuca	2	2	0	0	2	0	0
Vitória de Santo Antão	21	16	13	3	16	13	14
Piauí	**1,138**	**579**	**421**	**93**	**571**	**251**	**263**
Alto Médio Canindé	33	26	12	3	20	1	1
Alto Médio Gurguéia	92	52	39	9	52	26	27

Micro-region[a]	Residual land[b]	Soybean			Jatropha		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Alto Parnaíba Piauiense	246	158	117	26	159	78	82
Baixo Parnaíba Piauiense	10	0	0	0	0	0	0
Bertolínia	131	41	31	7	41	19	20
Campo Maior	118	45	27	6	45	18	19
Chapadas do Extremo Sul Piauiense	6	5	4	1	3	4	4
Floriano	244	159	132	29	159	78	82
Litoral Piauiense	3	0	0	0	0	0	0
Médio Parnaíba Piauiense	15	9	6	1	9	4	4
Picos	48	9	7	2	9	4	4
Pio IX	19	18	11	2	18	3	3
São Raimundo Nonato	16	11	11	2	10	2	2
Teresina	31	10	1	0	10	1	1
Valença do Piauí	126	36	23	5	36	13	14
Rio de Janeiro	**779**	**384**	**280**	**62**	**384**	**195**	**205**
Bacia de São João	1	0	0	0	0	0	0
Baía da Ilha Grande	0	0	0	0	0	0	0
Barra do Piraí	71	42	11	2	41	7	7
Campos dos Goytacazes	149	83	128	28	83	88	93
Cantagalo-Cordeiro	25	8	1	0	7	1	1
Itaguaí	16	4	1	0	5	1	1
Itaperuna	67	33	18	4	32	8	8
Lagos	23	12	7	2	12	4	4
Macacu-Caceribu	5	4	1	0	4	1	1
Macaé	54	42	62	14	42	42	44
Nova Friburgo	33	8	1	0	7	2	2
Rio de Janeiro	62	28	13	3	29	9	10
Santa Maria Madalena	31	4	0	0	3	0	0
Santo Antônio de Pádua	57	30	6	1	30	5	5
Serrana	33	6	0	0	6	1	1
Três Rios	51	16	3	1	16	2	2
Vale do Paraíba Fluminense	56	39	18	4	40	15	16
Vassouras	43	23	5	1	25	7	7
Rio Grande do Norte	**128**	**110**	**102**	**23**	**101**	**39**	**41**
Agreste Potiguar	4	4	10	2	4	2	2
Angicos	4	3	0	0	3	0	0
Baixa Verde	8	8	19	4	7	2	2
Borborema Potiguar	12	9	16	4	10	1	1
Chapada do Apodi	9	8	2	0	8	1	1
Litoral Nordeste	2	2	3	1	2	1	1
Litoral Sul	14	14	13	3	13	10	10
Macaíba	19	19	19	4	18	12	12
Macau	6	6	5	1	5	1	1
Médio Oeste	13	11	5	1	11	3	3
Mossoró	12	4	0	0	1	0	0
Natal	3	3	3	1	3	2	2
Pau dos Ferros	4	3	2	0	3	1	1
Seridó Ocidental	0	0	0	0	0	0	0
Seridó Oriental	3	2	0	0	0	0	0

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Serra de Santana	5	4	0	0	1	0	0
Serra de São Miguel	0	0	0	0	0	0	0
Umarizal	3	2	1	0	3	1	1
Vale do Açu	8	7	1	0	7	0	0
Rio Grande do Sul	**1,112**	**887**	**2,063**	**456**	**832**	**577**	**605**
Cachoeira do Sul	19	19	67	15	19	29	31
Camaquã	44	41	136	30	42	55	57
Campanha Central	40	34	134	30	34	36	38
Campanha Meridional	51	44	165	36	44	29	31
Campanha Ocidental	54	38	141	31	36	59	62
Carazinho	14	13	11	2	12	1	1
Caxias do Sul	14	10	3	1	4	0	0
Cerro Largo	10	6	19	4	6	1	1
Cruz Alta	19	18	45	10	17	1	1
Erechim	18	3	1	0	3	0	0
Frederico Westphalen	19	5	3	1	4	0	0
Gado-Canela	9	6	14	3	5	5	5
Guaporé	24	9	3	1	9	1	1
Ijuí	16	15	28	6	15	1	1
Jaguarão	19	16	51	11	15	12	12
Lajeado-Estrela	12	8	24	5	8	10	10
Litoral Lagunar	1	0	0	0	0	0	0
Montenegro	13	12	37	8	11	14	15
Não-Me-Toque	0	0	0	0	0	0	0
Osório	44	25	24	5	26	13	14
Passo Fundo	58	34	34	8	35	3	3
Pelotas	99	92	246	54	92	60	63
Porto Alegre	71	69	228	50	69	98	102
Restinga Seca	8	7	25	6	7	12	12
Sananduva	19	12	12	3	13	1	1
Santa Cruz do Sul	12	9	22	5	8	8	8
Santa Maria	29	20	55	12	18	27	29
Santa Rosa	14	9	18	4	10	2	2
Santiago	26	22	37	8	22	5	5
Santo Ângelo	32	26	77	17	25	3	3
São Jerônimo	45	43	135	30	43	61	64
Serras de Sudeste	72	65	164	36	65	18	19
Soledade	48	38	61	13	38	3	3
Três Passos	17	8	12	3	7	1	1
Vacaria	124	105	28	6	57	3	3
Rondônia	**No residual land assessed**						
Roraima	**No residual land assessed**						
Santa Catarina	**576**	**463**	**223**	**49**	**255**	**92**	**97**
Araranguá	14	5	4	1	5	2	2
Blumenau	7	5	5	1	4	3	3
Campos de Lages	79	75	6	1	8	0	0
Canoinhas	69	64	44	10	47	11	12
Chapecó	42	22	8	2	23	1	1

Micro-region[a]	Residual land[b]	Soybean			Jatropha		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Concórdia	6	1	0	0	1	0	0
Criciúma	30	22	19	4	23	14	14
Curitibanos	46	44	19	4	4	0	0
Florianópolis	12	9	16	4	10	10	10
Itajaí	19	18	25	6	17	17	18
Ituporanga	14	11	3	1	10	3	3
Joaçaba	80	68	13	3	11	1	1
Joinville	12	11	7	2	11	7	7
Rio do Sul	34	26	7	2	25	7	7
São Bento do Sul	18	17	8	2	7	1	1
São Miguel do Oeste	20	9	6	1	9	1	1
Tabuleiro	1	0	0	0	0	0	0
Tijucas	3	2	6	1	2	3	3
Tubarão	42	24	11	2	25	9	10
Xanxerê	27	23	14	3	10	1	1
São Paulo	**3,305**	**3,099**	**5,607**	**1,239**	**3,101**	**3,157**	**3,312**
Adamantina	31	31	70	15	31	55	57
Amparo	44	30	3	1	31	4	4
Andradina	108	108	150	33	107	124	130
Araçatuba	88	88	155	34	88	111	117
Araraquara	33	32	92	20	33	27	29
Assis	80	79	226	50	80	39	41
Auriflama	28	27	47	10	27	38	40
Avaré	57	57	74	16	57	41	43
Bananal	22	10	0	0	10	1	1
Barretos	36	36	56	12	36	35	37
Batatais	8	7	9	2	7	1	1
Bauru	105	105	194	43	105	124	130
Birigui	92	91	195	43	91	137	143
Botucatu	48	48	57	13	48	29	30
Bragança Paulista	62	56	24	5	56	23	25
Campinas	121	119	270	60	119	103	108
Campos do Jordão	8	1	0	0	1	0	0
Capão Bonito	73	58	54	12	59	35	37
Caraguatatuba	5	2	1	0	2	1	1
Catanduva	41	41	114	25	40	78	82
Dracena	27	27	38	8	27	39	41
Fernandópolis	45	45	68	15	44	52	55
Franca	28	20	6	1	20	3	3
Franco da Rocha	3	3	1	0	3	1	1
Guaratinguetá	86	65	58	13	65	43	45
Guarulhos	21	20	12	3	21	12	13
Itanhaém	2	1	0	0	1	0	0
Itapecerica da Serra	14	13	17	4	13	7	8
Itapetininga	82	82	137	30	80	64	68
Itapeva	77	76	89	20	75	49	51
Ituverava	44	38	91	20	38	10	11
Jaú	18	18	42	9	18	5	5

Micro-region[a]	**Residual land**[b]	**Soybean**			**Jatropha**		
		Suitable land[c]	**Product. potential**	**Biofuel potential**[d]	**Suitable land**[c]	**Product. potential**	**Biofuel potential**[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Jaboticabal	61	61	164	36	59	101	106
Jales	21	21	32	7	21	32	33
Jundiaí	32	32	43	10	31	29	31
Limeira	39	38	99	22	38	58	61
Lins	65	65	160	35	64	109	115
Marília	51	49	80	18	48	58	61
Mogi das Cruzes	34	31	11	2	30	9	10
Moji Mirim	14	14	23	5	13	13	14
Nhandeara	32	32	71	16	31	50	53
Novo Horizonte	25	25	76	17	25	51	53
Osasco	5	5	2	0	5	2	2
Ourinhos	95	94	218	48	94	38	40
Paraibuna/Paraitinga	106	49	4	1	49	5	5
Piedade	38	34	32	7	34	17	18
Piracicaba	123	123	261	58	122	108	113
Pirassununga	36	35	96	21	36	53	55
Presidente Prudente	192	192	322	71	192	230	241
Registro	0	0	0	0	0	0	0
Ribeirão Preto	0	0	1	0	0	0	0
Rio Claro	71	68	129	29	69	80	84
São Carlos	30	30	64	14	30	41	43
São João da Boa Vista	27	22	35	8	22	13	14
São Joaquim da Barra	6	6	17	4	6	2	2
São José do Rio Preto	175	175	381	84	174	267	280
São José dos Campos	140	119	135	30	120	99	104
São Paulo	12	10	8	2	11	5	5
Santos	3	1	0	0	1	0	0
Sorocaba	169	167	381	84	167	184	193
Tatuí	106	105	265	59	106	109	114
Tupã	17	16	41	9	16	29	30
Votuporanga	53	53	101	22	52	72	75
Sergipe	**46**	**43**	**4**	**1**	**43**	**6**	**6**
Agreste de Itabaiana	2	2	0	0	2	0	0
Agreste de Lagarto	1	1	0	0	1	0	0
Aracaju	8	7	2	0	7	2	2
Baixo Cotinguiba	5	5	0	0	5	1	1
Boquim	2	2	0	0	2	0	0
Carira	0	0	0	0	0	0	0
Cotinguiba	1	1	0	0	1	0	0
Estância	14	13	1	0	13	3	3
Japaratuba	6	6	1	0	5	1	1
Nossa Senhora das Dores	0	0	0	0	0	0	0
Propriá	1	1	0	0	1	0	0
Sergipana do Sertão do São Francisco	4	3	0	0	4	1	1
Tobias Barreto	3	2	0	0	2	0	0
Tocantins	**2,550**	**1,480**	**729**	**161**	**1,486**	**977**	**1,025**
Araguaína	85	11	7	2	11	7	8
Bico do Papagaio	26	9	18	4	9	5	5

Micro-region[a]	Residual land[b]	Soybean			Jatropha		
		Suitable land[c]	Product. potential	Biofuel potential[d]	Suitable land[c]	Product. potential	Biofuel potential[d]
	1000 ha	1000 ha	1000 ton grain DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Dianópolis	402	304	120	27	305	148	155
Gurupi	317	292	74	16	294	93	98
Jalapão	1,166	444	369	82	444	482	505
Miracema do Tocantins	121	71	30	7	71	51	53
Porto Nacional	192	141	49	11	142	85	89
Rio Formoso	241	206	61	13	211	109	114
Total Brazil	**37,799**	**27,315**	**33,481**	**7,399**	**27,124**	**17,051**	**17,886**

a Rondônia, Acre, Amazonas, Roraima, Pará and Amapá are states located in legal Amazonas biome. Residual land in this states is excluded due definition (see b)

b Residual land is defined as remaining fraction currently not in use for agriculture or other economic purpose, not under forest not in pasture land and is not legally protected or has high biodiversity values. Furthermore residual land is not located in the Amazonas biome. Source: Brazilian 1 km land use database (Lossau et al. 2015)

c Only the best land is assumed to be used for high level input farming, moderately suitable and marginal lands are assumed to be used at intermediate or low level input and management circumstances. Not suitable land is not considerd

d sugarcane (677 litre bioethanol / ton sugar), cassava (391 litre bioethanol / ton cassava roots (DW)), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), soybean (221 litre biodiesel / ton soybean seed (DW), jatropha (1049 litre biodiesel / ton jatropha oil)

AGB: Above Ground Biomas

DW: Dry Weight

Table A-2 Brazilian residual land suitability for biodiesel feedstocks by micro-region

Appendix C

Indian culturable wasteland suitability for different biofuel feedstocks by district

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Andaman and Nicobar	**12.041**	**6.843**	**14.600**	**9.884**	**7.342**	**84.929**	**25.479**	**7.342**	**10.955**	**11.492**
Andhra Pradesh	**511.748**	**336.985**	**551.513**	**373.374**	**365.288**	**4,650.437**	**1,395.131**	**384.534**	**580.633**	**609.084**
Anantapur	56.115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chittoor	42.151	42.151	91.986	62.275	42.151	565.736	169.721	42.151	81.219	85.199
Cuddapah	50.083	0.000	0.000	0.000	14.884	128.766	38.630	33.236	25.741	27.002
East Godavari	16.995	16.995	34.475	23.340	16.995	243.468	73.040	16.995	36.564	38.356
Guntur	34.420	34.420	47.624	32.241	34.420	432.131	129.639	34.420	47.488	49.815
Krishna	26.845	26.845	46.126	31.227	26.845	359.413	107.824	26.845	47.344	49.663
Kurnool	52.541	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nellore	116.618	116.618	164.969	111.684	116.618	1,415.838	424.751	116.618	180.478	189.321
Prakasam	81.273	68.756	92.558	62.661	81.273	1,005.967	301.790	81.273	90.493	94.927
Srikakulam	0.659	0.659	1.760	1.191	0.659	10.761	3.228	0.659	1.766	1.853
Vishakhapatnam	10.863	7.356	13.906	9.415	8.258	112.197	33.659	9.153	16.697	17.515
Vizianagaram	3.680	3.680	9.827	6.653	3.680	61.017	18.305	3.680	9.624	10.096
West Godavari	19.505	19.505	48.282	32.687	19.505	315.142	94.543	19.505	43.219	45.337
Arunachal Pradesh	**37.437**	**17.586**	**112.239**	**75.986**	**17.586**	**356.463**	**106.939**	**17.586**	**46.823**	**49.117**
Changlang	1.525	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
East Siang	6.673	6.673	47.840	32.387	6.673	138.186	41.456	6.673	17.978	18.859
Lohit	3.136	3.136	13.989	9.471	3.136	41.349	12.405	3.136	5.935	6.226
Lower Dibang Valley	1.892	1.892	8.692	5.885	1.892	33.637	10.091	1.892	4.190	4.395
Lower Subansiri	3.136	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Papum Pare	5.885	5.885	41.718	28.243	5.885	143.291	42.987	5.885	18.720	19.637
Tirap	12.175	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Siang	3.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Assam	**76.631**	**76.631**	**314.267**	**212.759**	**76.631**	**677.765**	**203.330**	**76.631**	**93.549**	**98.133**
Barpeta	1.608	1.608	6.931	4.692	1.608	29.706	8.912	1.608	4.137	4.339
Bongaigaon	5.033	5.033	22.513	15.241	5.033	84.892	25.467	5.033	11.622	12.191
Cachar	2.037	2.037	4.363	2.954	2.037	0.156	0.047	2.037	0.022	0.023
Darrang	7.458	7.458	37.847	25.623	7.458	103.035	30.910	7.458	14.560	15.274
Dhemaji	17.064	17.064	76.934	52.085	17.064	112.237	33.671	17.064	14.353	15.056
Dhuburi	3.872	3.872	12.542	8.491	3.872	51.878	15.563	3.872	7.813	8.195
Dibrugarh	7.126	7.126	29.104	19.703	7.126	69.164	20.749	7.126	8.366	8.776
Goalpara	0.675	0.675	1.195	0.809	0.675	0.000	0.000	0.675	0.000	0.000
Golaghat	5.801	5.801	20.196	13.673	5.801	29.752	8.926	5.801	4.436	4.653
Hailakandi	0.275	0.275	0.575	0.390	0.275	0.000	0.000	0.275	0.000	0.000
Jorhat	6.686	6.686	43.014	29.120	6.686	101.396	30.419	6.686	12.925	13.559
Kamrup	3.578	3.578	8.579	5.808	3.578	12.576	3.773	3.578	1.963	2.059
Karbi Anglong	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karimganj	2.100	2.100	4.510	3.053	2.100	0.000	0.000	2.100	0.000	0.000

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Kokrajhar	2.065	2.065	7.908	5.354	2.065	26.257	7.877	2.065	4.041	4.239
Lakhimpur	2.030	2.030	5.362	3.630	2.030	0.000	0.000	2.030	0.000	0.000
Marigaon	0.960	0.960	2.153	1.458	0.960	2.478	0.743	0.960	0.403	0.422
Nagaon	3.523	3.523	19.611	13.277	3.523	52.687	15.806	3.523	8.707	9.134
Nalbari	1.107	1.107	2.356	1.595	1.107	1.553	0.466	1.107	0.202	0.212
North Cachar Hills	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sibsagar	1.820	1.820	4.312	2.919	1.820	0.000	0.000	1.820	0.000	0.000
Sonitpur	0.227	0.227	0.518	0.350	0.227	0.000	0.000	0.227	0.000	0.000
Tinsukia	1.586	1.586	3.743	2.534	1.586	0.000	0.000	1.586	0.000	0.000
Bihar	**40.072**	**34.883**	**65.761**	**44.520**	**40.072**	**513.822**	**154.146**	**40.072**	**77.720**	**81.528**
Araria	0.564	0.564	2.176	1.473	0.564	10.355	3.107	0.564	1.572	1.649
Aurangabad	1.899	0.000	0.000	0.000	1.899	16.995	5.099	1.899	1.865	1.956
Banka	7.954	7.954	14.159	9.586	7.954	106.190	31.857	7.954	17.093	17.930
Begusarai	0.040	0.040	0.087	0.059	0.040	0.557	0.167	0.040	0.094	0.098
Bhabua	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bhagalpur	2.337	2.337	4.298	2.910	2.337	30.269	9.081	2.337	5.129	5.380
Bhojpur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Buxar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Darbhanga	0.138	0.138	0.396	0.268	0.138	2.226	0.668	0.138	0.362	0.380
Gaya	3.290	0.000	0.000	0.000	3.290	35.028	10.509	3.290	3.773	3.958
Gopalganj	1.422	1.422	2.829	1.915	1.422	19.494	5.848	1.422	2.651	2.780
Jamui	10.461	10.461	9.841	6.663	10.461	111.623	33.487	10.461	17.066	17.902
Jehanabad	0.247	0.247	0.300	0.203	0.247	2.629	0.789	0.247	0.322	0.338
Katihar	0.789	0.789	2.468	1.671	0.789	13.128	3.939	0.789	2.125	2.229
Khagaria	0.638	0.638	1.402	0.949	0.638	9.124	2.737	0.638	1.530	1.605
Kishanganj	1.236	1.236	5.162	3.495	1.236	23.329	6.999	1.236	3.426	3.594
Lakhisarai	0.719	0.719	1.515	1.026	0.719	10.137	3.041	0.719	1.397	1.465
Madhepura	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Madhubani	0.510	0.510	1.589	1.076	0.510	8.324	2.497	0.510	1.354	1.420
Munger	0.948	0.948	1.977	1.339	0.948	13.160	3.948	0.948	2.204	2.312
Muzaffarpur	0.330	0.330	0.788	0.534	0.330	4.747	1.424	0.330	0.813	0.852
Nalanda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nawada	1.144	1.144	1.689	1.143	1.144	13.527	4.058	1.144	1.731	1.816
Pashchim Champaran	1.317	1.317	3.169	2.145	1.317	19.133	5.740	1.317	3.296	3.458
Patna	0.764	0.764	1.066	0.722	0.764	8.805	2.641	0.764	1.122	1.176
Purba Champaran	0.292	0.292	0.728	0.493	0.292	4.260	1.278	0.292	0.728	0.763
Purnia	1.159	1.159	3.699	2.504	1.159	19.624	5.887	1.159	3.150	3.304
Rohtas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Saharsa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Samastipur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Saran	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sheikhpura	0.240	0.240	0.485	0.328	0.240	3.313	0.994	0.240	0.435	0.457
Sitamarhi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sivhar	0.022	0.022	0.051	0.034	0.022	0.323	0.097	0.022	0.052	0.055
Siwan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Supaul	1.556	1.556	5.796	3.924	1.556	26.841	8.052	1.556	4.337	4.550

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Vaishali	0.055	0.055	0.090	0.061	0.055	0.679	0.204	0.055	0.095	0.100
Chandigarh	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Chhattisgarh	**349.770**	**200.651**	**399.268**	**270.304**	**248.607**	**3,374.791**	**1,012.437**	**346.048**	**541.783**	**568.331**
Bastar	58.887	55.655	130.371	88.261	57.301	881.176	264.353	58.887	134.209	140.785
Bilaspur	15.340	1.286	1.896	1.284	6.199	71.178	21.353	15.340	17.440	18.295
Dantewada	123.607	108.768	218.041	147.614	116.679	1,654.927	496.478	122.095	235.217	246.742
Dhamtari	3.581	1.087	1.236	0.837	1.871	18.310	5.493	3.581	3.393	3.559
Durg	24.588	0.000	0.000	0.000	0.000	0.000	0.000	24.588	23.884	25.054
Janjgir-Champa	10.247	0.000	0.000	0.000	3.369	32.776	9.833	10.247	9.688	10.163
Jashpur	6.695	6.695	10.071	6.818	6.695	76.243	22.873	6.695	9.438	9.901
Kanker	23.692	8.102	12.574	8.512	12.241	150.002	45.001	23.692	28.087	29.463
Kawardha	3.236	0.000	0.000	0.000	0.471	3.434	1.030	3.236	3.044	3.193
Korba	13.426	0.714	0.689	0.466	6.894	69.209	20.763	11.217	11.219	11.769
Koriya	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mahasamund	5.359	3.440	4.674	3.164	5.359	62.151	18.645	5.359	6.230	6.536
Raigarh	7.852	6.002	8.858	5.997	7.852	100.279	30.084	7.852	10.177	10.676
Raipur	34.598	8.902	10.857	7.350	23.675	255.107	76.532	34.598	35.129	36.851
Raj Nandgaon	18.662	0.000	0.000	0.000	0.000	0.000	0.000	18.662	14.628	15.345
Surguja	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dadra and Nagar Haveli	**0.150**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Daman and Diu	**0.059**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Daman	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Junagadh	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Delhi	**9.893**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Delhi	9.893	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Goa	**52.829**	**0.000**	**0.000**	**0.000**	**13.875**	**30.832**	**9.250**	**14.800**	**3.245**	**3.404**
Gujarat	**1,903.730**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Ahmadabad	25.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amreli	11.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Anand	10.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Banas Kantha	17.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bharuch	35.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bhavnagar	23.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dahod	2.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gandhinagar	4.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jamnagar	32.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Junagadh	8.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kachchh	1,591.230	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kheda	2.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mahesana	4.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Narmada	3.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Navsari	6.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panch Mahals	11.900	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Patan	15.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Porbandar	4.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rajkot	13.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Sabar Kantha	14.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Surat	33.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Surendranagar	15.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
The Dangs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vadodara	6.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Valsad	6.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Haryana	**57.257**	**2.723**	**4.671**	**3.162**	**3.408**	**38.475**	**11.542**	**3.408**	**6.904**	**7.242**
Ambala	0.187	0.187	0.311	0.211	0.187	3.011	0.903	0.187	0.424	0.445
Bhiwani	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Faridabad	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fatehabad	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gurgaon	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hisar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jhajjar	9.929	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jind	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kaithal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karnal	0.685	0.000	0.000	0.000	0.685	0.880	0.264	0.685	0.561	0.588
Kurukshetra	0.163	0.163	0.230	0.156	0.163	2.033	0.610	0.163	0.262	0.274
Mahendragarh	1.421	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panchkula	2.132	2.132	3.661	2.478	2.132	28.514	8.554	2.132	5.076	5.325
Panipat	1.509	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rewari	15.478	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rohtak	11.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sirsa	13.473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sonepat	0.906	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Yamuna Nagar	0.241	0.241	0.469	0.318	0.241	4.038	1.211	0.241	0.582	0.610
Himachal Pradesh	**134.323**	**49.018**	**83.178**	**56.312**	**53.612**	**563.923**	**169.177**	**53.178**	**82.051**	**86.072**
Bilaspur	6.218	2.092	1.434	0.971	2.652	17.746	5.324	2.652	1.802	1.891
Chamba	6.372	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hamirpur	10.759	8.884	6.450	4.367	10.600	60.784	18.235	10.600	4.577	4.801
Kangra	27.402	10.328	19.673	13.319	11.680	133.562	40.069	11.426	19.748	20.716
Kinnaur	3.444	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kullu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lahul and Spiti	0.597	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mandi	4.508	0.065	0.058	0.039	0.211	1.719	0.516	0.123	0.162	0.170
Shimla	21.329	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sirmaur	15.968	0.969	0.829	0.561	1.366	13.918	4.175	1.287	2.320	2.434
Solan	14.544	3.498	7.298	4.941	3.922	54.239	16.272	3.908	8.841	9.274
Una	23.182	23.182	47.435	32.114	23.182	281.955	84.587	23.182	44.601	46.786
Jammu and Kashmir	**138.968**	**24.729**	**103.273**	**69.916**	**62.876**	**1,026.444**	**307.933**	**25.353**	**81.816**	**85.825**
Anantnag	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Badgam	4.578	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Baramulla	10.831	10.207	33.326	22.562	10.831	197.948	59.384	10.831	34.708	36.409
Doda	22.315	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jammu	31.487	0.000	0.000	0.000	31.487	444.861	133.458	0.000	0.000	0.000
Kargil	3.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Districts	**Culturable wasteland[a]**	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential[c]**	**Suitable land[b]**	**Product. potential**	**Biofuel potential[c]**	**Suitable land[b]**	**Product. potential**	**Biofuel potential[c]**
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Kathua	13.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kupwara	2.575	2.575	10.896	7.377	2.575	49.626	14.888	2.575	8.303	8.710
Leh	4.410	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Poonch	7.313	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pulwama	6.036	0.000	0.000	0.000	6.036	84.699	25.410	0.000	0.000	0.000
Rajauri	11.947	11.947	59.051	39.978	11.947	249.310	74.793	11.947	38.805	40.707
Srinagar	3.862	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Udhampur	17.402	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jharkhand	**334.037**	**271.778**	**415.625**	**281.378**	**318.569**	**3,559.309**	**1,067.793**	**334.037**	**534.890**	**561.099**
Bokaro	8.459	8.459	13.960	9.451	8.459	110.499	33.150	8.459	17.000	17.833
Chatra	4.186	2.906	3.334	2.257	4.186	44.281	13.284	4.186	5.175	5.429
Deoghar	17.225	17.225	32.826	22.223	17.225	241.754	72.526	17.225	38.094	39.961
Dhanbad	11.377	11.377	19.043	12.892	11.377	148.913	44.674	11.377	23.617	24.775
Dumka	22.482	22.482	42.258	28.609	22.482	307.325	92.197	22.482	49.070	51.474
Garhwa	6.467	0.000	0.000	0.000	0.000	0.000	0.000	6.467	6.417	6.731
Giridih	18.084	18.084	29.340	19.863	18.084	237.835	71.351	18.084	34.520	36.211
Godda	9.239	9.239	17.044	11.539	9.239	122.881	36.864	9.239	20.167	21.155
Gumla	31.477	17.375	19.691	13.331	30.073	306.448	91.934	31.477	38.643	40.537
Hazaribag	9.197	8.966	15.401	10.426	9.152	112.773	33.832	9.197	15.582	16.345
Jamtara	14.862	14.862	25.607	17.336	14.862	196.266	58.880	14.862	31.178	32.706
Koderma	5.502	5.502	3.254	2.203	5.502	27.181	8.154	5.502	3.771	3.955
Latehar	5.109	5.109	7.630	5.165	5.109	65.234	19.570	5.109	7.968	8.359
Lohardaga	4.947	4.873	6.778	4.589	4.947	60.734	18.220	4.947	8.134	8.532
Pakur	10.130	10.130	25.422	17.211	10.130	148.055	44.416	10.130	24.207	25.393
Palamu	7.085	0.000	0.000	0.000	3.634	21.771	6.531	7.085	7.196	7.549
Pashchim Singhbhum	33.527	25.937	33.440	22.639	29.425	265.927	79.778	33.527	39.856	41.809
Purba Singhbhum	44.518	39.039	42.153	28.537	44.518	331.837	99.551	44.518	49.602	52.032
Ranchi	32.904	12.954	10.633	7.198	32.904	322.424	96.727	32.904	42.132	44.197
Sahibganj	8.072	8.072	17.788	12.043	8.072	113.682	34.105	8.072	18.782	19.703
Saraikela Kharsawan	11.700	11.700	19.244	13.028	11.700	130.506	39.152	11.700	20.034	21.016
Simdega	17.488	17.488	30.781	20.839	17.488	242.981	72.894	17.488	33.743	35.397
Karnataka	**416.493**	**327.370**	**886.375**	**600.076**	**330.879**	**5,346.414**	**1,603.924**	**390.407**	**893.872**	**937.671**
Bagalkot	2.035	2.035	2.807	1.900	2.035	17.882	5.365	2.035	1.962	2.058
Bangalore Rural	5.076	5.076	16.241	10.995	5.076	95.439	28.632	5.076	15.226	15.972
Bangalore Urban	4.442	4.442	14.221	9.627	4.442	84.265	25.280	4.442	13.409	14.066
Belgaum	12.761	12.761	32.091	21.725	12.761	214.111	64.233	12.761	34.870	36.579
Bellary	24.839	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bidar	19.382	0.000	0.000	0.000	0.000	0.000	0.000	19.382	17.755	18.625
Bijapur	5.502	0.000	0.000	0.000	0.000	0.000	0.000	5.502	2.851	2.990
Chamrajnagar	7.637	7.637	27.547	18.650	7.637	134.017	40.205	7.637	21.640	22.700
Chikmagalur	19.404	19.404	55.043	37.264	19.404	339.508	101.852	19.404	53.698	56.329
Chitradurga	21.615	9.354	12.432	8.416	12.054	106.292	31.888	21.615	23.517	24.669
Dakshin Kannad	31.467	31.467	60.956	41.267	31.467	412.911	123.873	31.467	64.461	67.619
Davanagere	8.525	8.525	21.138	14.310	8.525	146.237	43.871	8.525	23.492	24.643
Dharwad	2.669	2.669	7.628	5.164	2.669	49.276	14.783	2.669	7.726	8.105
Gadag	1.010	1.010	2.416	1.635	1.010	15.367	4.610	1.010	2.557	2.682

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Gulbarga	11.802	0.000	0.000	0.000	0.000	0.000	0.000	11.802	8.628	9.050
Hassan	14.142	14.142	54.883	37.156	14.142	286.226	85.868	14.142	43.953	46.107
Haveri	2.989	2.989	7.881	5.335	2.989	55.563	16.669	2.989	8.757	9.186
Kodagu	9.828	9.828	16.902	11.443	9.828	138.134	41.440	9.828	22.914	24.036
Kolar	12.540	12.540	33.096	22.406	12.540	209.342	62.803	12.540	34.291	35.971
Koppal	2.568	0.000	0.000	0.000	0.000	0.000	0.000	2.568	1.322	1.386
Mandya	41.955	41.955	145.566	98.548	41.955	763.524	229.057	41.955	121.167	127.104
Mysore	21.460	21.460	95.793	64.852	21.460	432.322	129.696	21.460	67.866	71.192
Raichur	10.712	0.000	0.000	0.000	0.000	0.000	0.000	10.712	5.610	5.885
Shimoga	16.307	16.307	48.613	32.911	16.307	287.793	86.338	16.307	45.905	48.155
Tumkur	62.642	62.642	147.668	99.971	62.642	970.331	291.099	62.642	152.980	160.476
Udupi	36.727	36.727	75.679	51.234	36.727	525.390	157.617	36.727	87.652	91.947
Uttar Kannand	6.457	4.400	7.775	5.264	5.208	62.485	18.745	5.210	9.662	10.135
Kerala	**90.288**	**88.098**	**246.396**	**166.810**	**88.496**	**1,239.343**	**371.803**	**88.461**	**194.210**	**203.726**
Alappuzha	12.624	12.624	74.962	50.749	12.624	271.325	81.398	12.624	43.245	45.364
Ernakulam	8.754	8.754	25.953	17.570	8.754	121.569	36.471	8.754	20.994	22.023
Idukki	1.517	0.772	1.459	0.988	0.978	9.052	2.716	0.943	1.298	1.362
Kannur	5.108	5.108	9.479	6.417	5.108	61.746	18.524	5.108	9.964	10.452
Kasaragod	10.842	10.842	17.595	11.912	10.842	125.155	37.546	10.842	17.713	18.581
Kollam	0.697	0.697	2.298	1.556	0.697	10.463	3.139	0.697	1.572	1.649
Kottayam	7.231	7.231	30.233	20.468	7.231	127.560	38.268	7.231	20.086	21.070
Kozhikode	1.304	1.304	2.547	1.725	1.304	15.719	4.716	1.304	2.623	2.751
Malappuram	7.663	7.663	19.274	13.048	7.663	110.903	33.271	7.663	16.917	17.746
Palakkad	23.591	23.591	38.431	26.018	23.591	263.682	79.104	23.591	39.646	41.589
Pattanamtitta	3.205	1.760	4.344	2.941	1.952	21.868	6.560	1.952	3.279	3.440
Thiruvananthapuram	0.564	0.564	2.393	1.620	0.564	9.041	2.712	0.564	1.510	1.584
Thrissur	5.482	5.482	12.447	8.427	5.482	62.582	18.774	5.482	10.434	10.945
Wayanad	1.706	1.706	4.982	3.373	1.706	28.679	8.604	1.706	4.930	5.172
Lakshadweep	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Kavaratti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Madhya Pradesh	**1,176.732**	**0.000**	**0.000**	**0.000**	**43.559**	**432.330**	**129.699**	**261.669**	**182.001**	**190.919**
Anuppur	28.832	0.000	0.000	0.000	28.832	321.707	96.512	28.832	32.432	34.022
Ashoknagar	25.372	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Balaghat	9.792	0.000	0.000	0.000	3.777	29.215	8.764	9.792	7.134	7.484
Barwani	28.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Betul	40.928	0.000	0.000	0.000	0.000	0.000	0.000	21.718	8.282	8.688
Bhind	11.825	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bhopal	4.701	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Burhanpur	0.870	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chhatarpur	70.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chhindwara	17.612	0.000	0.000	0.000	0.000	0.000	0.000	13.423	7.069	7.415
Damoh	13.597	0.000	0.000	0.000	0.000	0.000	0.000	2.096	1.127	1.182
Datia	10.328	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dewas	2.954	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dhar	14.641	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dindori	14.357	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
East Nimar	0.157	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Guna	76.525	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gwalior	23.194	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harda	5.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hoshangabad	25.304	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Indore	13.876	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jabalpur	22.579	0.000	0.000	0.000	0.000	0.000	0.000	11.737	6.926	7.265
Jhabua	25.814	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Katni	39.454	0.000	0.000	0.000	0.000	0.000	0.000	18.141	9.303	9.758
Mandla	21.463	0.000	0.000	0.000	5.601	44.015	13.204	14.550	9.192	9.643
Mandsaur	15.667	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Morena	22.508	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Narsinghpur	14.622	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Neemuch	19.684	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panna	60.066	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Raisen	12.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rajgarh	28.831	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ratlam	15.260	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rewa	5.454	0.000	0.000	0.000	0.000	0.000	0.000	3.426	2.290	2.402
Sagar	10.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Satna	48.875	0.000	0.000	0.000	0.000	0.000	0.000	0.767	0.414	0.435
Sehore	12.948	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Seoni	40.202	0.000	0.000	0.000	5.349	37.393	11.218	40.202	22.232	23.322
Shahdol	40.791	0.000	0.000	0.000	0.000	0.000	0.000	26.580	19.539	20.497
Shajapur	10.422	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sheopur	39.927	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shivpuri	74.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sidhi	65.693	0.000	0.000	0.000	0.000	0.000	0.000	65.693	52.421	54.990
Tikamgarh	22.835	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ujjain	9.148	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Umaria	16.602	0.000	0.000	0.000	0.000	0.000	0.000	4.713	3.639	3.817
Vidisha	17.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Nimar	25.695	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maharashtra	**913.700**	**126.800**	**166.821**	**112.938**	**285.170**	**2,258.202**	**677.461**	**730.415**	**548.410**	**575.282**
Ahmednagar	20.000	0.000	0.000	0.000	0.000	0.000	0.000	20.000	21.643	22.703
Akola	3.100	0.000	0.000	0.000	0.000	0.000	0.000	1.487	0.665	0.697
Amravati	9.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aurangabad	15.500	0.000	0.000	0.000	0.000	0.000	0.000	15.500	7.846	8.231
Bhandara	11.800	0.000	0.000	0.000	0.000	0.000	0.000	8.755	5.247	5.505
Bid	40.800	0.000	0.000	0.000	0.000	0.000	0.000	40.800	20.374	21.372
Buldana	26.300	0.000	0.000	0.000	0.000	0.000	0.000	26.300	12.343	12.947
Chandrapur	36.600	0.000	0.000	0.000	0.000	0.000	0.000	2.501	1.172	1.230
Dhule	1.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Garhchiroli	22.000	0.000	0.000	0.000	1.201	11.703	3.511	15.992	11.707	12.281
Gondiya	16.300	0.000	0.000	0.000	0.000	0.000	0.000	9.451	6.013	6.307
Hingoli	11.300	0.000	0.000	0.000	0.000	0.000	0.000	11.300	9.147	9.595
Jalgaon	6.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jalna	15.900	0.000	0.000	0.000	0.000	0.000	0.000	15.900	7.492	7.859

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Kolhapur	36.400	36.400	49.017	33.185	36.400	351.608	105.482	36.400	46.435	48.710
Latur	24.100	0.000	0.000	0.000	0.000	0.000	0.000	24.100	12.762	13.388
Mumbai Suburban	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nagpur	38.500	0.000	0.000	0.000	0.000	0.000	0.000	2.422	1.135	1.190
Nanded	35.900	0.000	0.000	0.000	0.000	0.000	0.000	35.900	27.316	28.655
Nandurbar	2.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nashik	20.100	0.000	0.000	0.000	0.000	0.000	0.000	8.441	4.476	4.695
Osmanabad	48.900	0.000	0.000	0.000	0.000	0.000	0.000	48.900	25.198	26.433
Parbhani	22.800	0.000	0.000	0.000	0.000	0.000	0.000	22.800	11.103	11.647
Pune	38.200	38.200	46.081	31.197	38.200	489.129	146.739	38.200	43.482	45.613
Raigarh	38.000	0.000	0.000	0.000	0.581	2.407	0.722	33.509	26.686	27.993
Ratnagiri	135.600	0.000	0.000	0.000	90.587	331.022	99.307	135.600	84.435	88.572
Sangli	14.200	14.200	19.782	13.392	14.200	122.216	36.665	14.200	14.686	15.406
Satara	38.000	38.000	51.942	35.164	38.000	401.010	120.303	38.000	49.297	51.713
Sindhudurg	66.000	0.000	0.000	0.000	66.000	549.107	164.732	66.000	63.900	67.032
Solapur	39.200	0.000	0.000	0.000	0.000	0.000	0.000	39.200	22.408	23.506
Thane	34.200	0.000	0.000	0.000	0.000	0.000	0.000	11.344	7.969	8.360
Wardha	15.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Washim	5.700	0.000	0.000	0.000	0.000	0.000	0.000	5.700	2.746	2.881
Yavatmal	22.800	0.000	0.000	0.000	0.000	0.000	0.000	1.713	0.725	0.761
Manipur	**1.000**	**0.030**	**0.023**	**0.015**	**0.049**	**0.112**	**0.034**	**0.045**	**0.013**	**0.014**
Meghalaya	**450.169**	**144.627**	**365.319**	**247.321**	**192.930**	**1,907.597**	**572.279**	**171.254**	**264.192**	**277.137**
East Garo Hills	47.656	21.202	54.513	36.906	23.981	254.410	76.323	23.981	42.772	44.868
East Khasi Hills	57.384	7.671	10.816	7.322	22.016	171.902	51.571	9.414	6.999	7.342
Jaintia Hills	120.001	48.522	156.194	105.743	54.910	578.310	173.493	54.910	83.879	87.989
Ri-Bhoi	56.551	15.545	45.977	31.126	18.935	201.948	60.585	18.935	31.534	33.080
South Garo Hills	23.065	5.207	9.293	6.291	6.713	58.923	17.677	6.713	9.852	10.334
West Garo Hills	35.982	25.587	51.368	34.776	28.604	322.419	96.726	28.604	56.325	59.085
West Khasi Hills	109.530	20.893	37.158	25.156	37.770	319.685	95.905	28.697	32.830	34.439
Mizoram	**523.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Nagaland	**63.971**	**2.762**	**2.020**	**1.367**	**3.786**	**9.065**	**2.720**	**3.692**	**1.355**	**1.422**
Dimapur	2.511	2.146	1.670	1.131	2.327	6.478	1.943	2.327	1.045	1.096
Kohima	20.746	0.468	0.245	0.166	0.975	1.595	0.478	0.897	0.195	0.205
Mokokchung	2.482	0.000	0.000	0.000	0.052	0.101	0.030	0.052	0.012	0.012
Mon	5.000	0.147	0.104	0.071	0.288	0.626	0.188	0.273	0.071	0.075
Phek	6.748	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tuensang	20.178	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wokha	4.150	0.000	0.000	0.000	0.142	0.265	0.079	0.142	0.033	0.034
Zunheboto	2.156	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Orissa	**374.851**	**351.795**	**852.351**	**577.042**	**355.310**	**5,373.026**	**1,611.908**	**355.844**	**818.025**	**858.108**
Angul	19.000	19.000	37.827	25.609	19.000	272.646	81.794	19.000	42.569	44.655
Baleshwar	9.000	9.000	21.569	14.602	9.000	125.531	37.659	9.000	20.574	21.582
Baragarh	11.000	11.000	19.673	13.319	11.000	143.495	43.048	11.000	17.996	18.878
Bhadrak	18.000	18.000	64.158	43.435	18.000	309.442	92.833	18.000	51.581	54.108
Bolangir	20.000	20.000	45.257	30.639	20.000	304.620	91.386	20.000	43.457	45.587
Boudh	15.000	15.000	33.580	22.734	15.000	229.388	68.817	15.000	33.582	35.227
Cuttack	10.000	10.000	22.803	15.438	10.000	146.624	43.987	10.000	18.838	19.761

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Deogarh	6.000	5.078	10.664	7.219	5.178	75.547	22.664	5.628	11.639	12.209
Dhenkanal	4.000	4.000	9.981	6.757	4.000	63.207	18.962	4.000	9.982	10.471
Gajapati	4.000	1.944	3.405	2.305	2.294	26.650	7.995	2.294	4.018	4.215
Ganjam	11.000	11.000	28.104	19.027	11.000	175.213	52.564	11.000	28.146	29.525
Jagatsinghpur	6.000	6.000	17.080	11.563	6.000	87.558	26.267	6.000	15.035	15.772
Jajpur	4.000	4.000	9.732	6.589	4.000	60.751	18.225	4.000	9.486	9.951
Jharsuguda	15.000	15.000	25.303	17.130	15.000	188.951	56.685	15.000	24.134	25.317
Kalahandi	21.000	21.000	53.754	36.392	21.000	344.065	103.219	21.000	53.338	55.952
Kandhamal	14.000	6.503	13.776	9.326	7.328	105.149	31.545	7.328	16.774	17.596
Kendrapara	6.000	6.000	17.301	11.713	6.000	92.105	27.631	6.000	15.097	15.837
Keonjhar	26.000	26.000	63.071	42.699	26.000	398.474	119.542	26.000	62.984	66.070
Khordha	8.000	8.000	18.526	12.542	8.000	118.706	35.612	8.000	17.775	18.646
Koraput	44.000	44.000	137.718	93.235	44.000	765.149	229.545	44.000	123.782	129.848
Malkangiri	4.000	3.769	9.153	6.197	3.971	62.786	18.836	3.971	9.828	10.310
Mayurbhanj	10.000	10.000	29.373	19.885	10.000	167.537	50.261	10.000	26.880	28.198
Nabarangpur	15.000	15.000	45.899	31.073	15.000	269.929	80.979	15.000	42.267	44.338
Nayagarh	5.000	5.000	11.722	7.936	5.000	77.108	23.132	5.000	11.809	12.388
Nuapada	2.000	2.000	4.384	2.968	2.000	29.265	8.780	2.000	4.081	4.281
Puri	2.851	2.851	1.902	1.288	2.851	18.406	5.522	2.851	2.118	2.222
Rayagada	22.000	9.650	17.385	11.770	11.689	157.368	47.210	11.772	24.672	25.880
Sambalpur	19.000	19.000	33.415	22.622	19.000	247.641	74.292	19.000	33.815	35.472
Sonepur	8.000	8.000	12.558	8.502	8.000	80.610	24.183	8.000	10.772	11.300
Sundargarh	16.000	16.000	33.278	22.529	16.000	229.109	68.733	16.000	30.995	32.514
Puducherry	**4.145**	**1.617**	**1.887**	**1.278**	**4.145**	**50.297**	**15.089**	**4.145**	**4.976**	**5.220**
Karaikal	2.528	0.000	0.000	0.000	2.528	35.145	10.543	2.528	3.336	3.500
Mahe	0.013	0.013	0.035	0.024	0.013	0.180	0.054	0.013	0.026	0.027
Puducherry	1.583	1.583	1.835	1.242	1.583	14.785	4.435	1.583	1.593	1.671
Yanam	0.021	0.021	0.017	0.012	0.021	0.187	0.056	0.021	0.022	0.023
Punjab	**4.375**	**2.262**	**7.040**	**4.766**	**2.262**	**34.836**	**10.451**	**2.347**	**5.451**	**5.718**
Amritsar	0.254	0.254	0.984	0.666	0.254	4.050	1.215	0.254	0.768	0.806
Bathinda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Faridkot	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fatehgarh Sahib	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Firozpur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gurdaspur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hoshiarpur	0.174	0.174	0.772	0.523	0.174	3.570	1.071	0.174	0.550	0.577
Jalandhar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kapurthala	0.026	0.026	0.076	0.051	0.026	0.518	0.155	0.026	0.078	0.082
Ludhiana	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mansa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Moga	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Muktsar	2.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nawan Shehar	1.058	1.058	2.012	1.362	1.058	11.991	3.597	1.058	1.839	1.929
Patiala	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rupnagar	0.750	0.750	3.196	2.164	0.750	14.706	4.412	0.750	2.216	2.325
Sangrur	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.085	0.000	0.000
Rajasthan	**4,611.213**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Ajmer	73.886	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Alwar	7.734	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Banswara	29.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Baran	18.240	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barmer	194.254	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bharatpur	3.092	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bhilwara	133.834	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bikaner	824.426	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bundi	29.652	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chittaurgarh	137.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Churu	10.392	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dausa	7.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dhaulpur	10.847	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dungarpur	22.525	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ganganagar	18.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hanumangarh	4.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jaipur	36.453	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jaisalmer	2,481.510	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jalor	31.188	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jhalawar	47.284	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jhunjhunun	6.873	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jodhpur	66.885	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karauli	13.286	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kota	22.396	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nagaur	16.919	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pali	42.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rajsamand	118.784	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sawai Madhopur	11.318	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sikar	9.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sirohi	10.496	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tonk	43.828	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Udaipur	128.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sikkim	**3.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Tamil Nadu	**352.526**	**310.018**	**984.466**	**666.483**	**340.698**	**5,254.614**	**1,576.384**	**350.697**	**796.580**	**835.612**
Chennai	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coimbatore	13.464	13.464	34.188	23.145	13.464	184.529	55.359	13.464	34.313	35.994
Cuddalore	5.877	5.877	5.106	3.456	5.877	47.264	14.179	5.877	7.014	7.358
Dharmapuri	10.075	10.075	25.701	17.400	10.075	149.110	44.733	10.075	24.204	25.390
Dindigul	8.931	8.931	33.798	22.881	8.931	167.761	50.328	8.931	27.345	28.685
Erode	0.558	0.558	1.566	1.060	0.558	10.213	3.064	0.558	1.608	1.686
Kancheepuram	10.726	10.726	16.102	10.901	10.726	140.202	42.061	10.726	19.129	20.066
Kanniyakumari	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karur	67.774	67.774	213.444	144.501	67.774	1,295.240	388.572	67.774	190.564	199.902
Madurai	6.855	6.855	27.870	18.868	6.855	141.341	42.402	6.855	21.650	22.711
Nagapattinam	3.837	0.000	0.000	0.000	3.837	32.005	9.602	3.837	3.625	3.803
Namakkal	4.861	4.861	11.064	7.490	4.861	83.671	25.101	4.861	12.286	12.888
Nilgiris	2.023	0.000	0.000	0.000	0.603	4.459	1.338	0.194	0.171	0.179

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Perambalur	9.234	0.000	0.000	0.000	9.234	100.978	30.293	9.234	11.054	11.595
Pudukkottai	10.408	0.000	0.000	0.000	0.000	0.000	0.000	10.408	4.353	4.566
Ramanathapuram	4.246	4.246	3.612	2.445	4.246	24.453	7.336	4.246	4.505	4.726
Salem	5.548	5.548	11.592	7.848	5.548	86.594	25.978	5.548	12.706	13.329
Sivaganga	14.330	14.330	31.453	21.294	14.330	183.718	55.115	14.330	33.933	35.596
Thanjavur	13.797	0.000	0.000	0.000	13.797	146.532	43.960	13.797	16.360	17.161
Theni	3.986	3.986	22.222	15.044	3.986	85.948	25.784	3.986	13.001	13.638
Thiruvallur	8.130	8.130	18.038	12.212	8.130	114.413	34.324	8.130	15.892	16.670
Thiruvarur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Thoothukudi	56.640	56.640	323.607	219.082	56.640	1,170.985	351.296	56.640	168.000	176.232
Tiruchchirappalli	9.000	5.791	5.873	3.976	9.000	120.541	36.162	9.000	14.687	15.407
Tirunelveli Kattabo	41.612	41.612	132.064	89.407	41.612	485.083	145.525	41.612	86.304	90.533
Tiruvannamalai	14.963	14.963	23.875	16.163	14.963	198.322	59.497	14.963	30.029	31.500
Vellore	5.944	5.944	12.253	8.295	5.944	76.987	23.096	5.944	11.772	12.349
Villupuram	10.044	10.044	16.340	11.062	10.044	139.386	41.816	10.044	20.537	21.543
Virudhunagar	9.663	9.663	14.699	9.951	9.663	64.879	19.464	9.663	11.537	12.102
Telangana	**183.747**	**20.631**	**35.372**	**23.947**	**30.823**	**387.517**	**116.255**	**182.920**	**185.638**	**194.734**
Adilabad	14.937	0.000	0.000	0.000	0.000	0.000	0.000	14.110	9.520	9.987
Hyderabad	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karimnagar	18.375	0.000	0.000	0.000	0.000	0.000	0.000	18.375	13.283	13.934
Khammam	20.631	20.631	35.372	23.947	20.631	255.343	76.603	20.631	31.407	32.946
Mahbubnagar	21.766	0.000	0.000	0.000	0.000	0.000	0.000	21.766	23.694	24.855
Medak	31.613	0.000	0.000	0.000	0.000	0.000	0.000	31.613	34.449	36.137
Nalgonda	29.363	0.000	0.000	0.000	0.000	0.000	0.000	29.363	31.514	33.059
Nizamabad	16.991	0.000	0.000	0.000	0.000	0.000	0.000	16.991	8.180	8.581
Rangareddi	19.879	0.000	0.000	0.000	0.000	0.000	0.000	19.879	20.990	22.019
Warangal	10.192	0.000	0.000	0.000	10.192	132.174	39.652	10.192	12.600	13.217
Tripura	**1.000**	**0.714**	**2.585**	**1.750**	**0.754**	**9.463**	**2.839**	**0.754**	**1.310**	**1.374**
Uttar Pradesh	**439.874**	**22.495**	**49.090**	**33.234**	**38.937**	**457.575**	**137.272**	**148.635**	**125.764**	**131.926**
Agra	2.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aligarh	5.422	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Allahabad	12.363	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ambedkar Nagar	4.362	0.000	0.000	0.000	0.000	0.000	0.000	4.362	1.806	1.895
Auraiya	5.099	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Azamgarh	6.367	0.000	0.000	0.000	0.000	0.000	0.000	6.367	3.970	4.164
Badaun	5.240	0.000	0.000	0.000	0.000	0.000	0.000	5.240	4.960	5.203
Baghpat	1.989	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bahraich	2.113	0.000	0.000	0.000	2.113	27.749	8.325	2.113	2.148	2.253
Ballia	1.498	1.498	2.171	1.470	1.498	18.670	5.601	1.498	1.978	2.075
Balrampur	2.026	0.000	0.000	0.000	0.063	0.566	0.170	2.026	2.090	2.192
Banda	11.584	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bara Banki	9.525	0.000	0.000	0.000	0.000	0.000	0.000	9.525	7.334	7.694
Bareilly	1.679	1.679	2.822	1.910	1.679	21.339	6.402	1.679	2.702	2.835
Basti	4.446	0.000	0.000	0.000	0.000	0.000	0.000	4.446	1.754	1.840
Bijnor	3.977	3.977	13.849	9.376	3.977	81.351	24.405	3.977	11.740	12.315
Bulandshahr	5.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chandauli	1.191	0.000	0.000	0.000	0.000	0.000	0.000	1.191	1.041	1.092

Districts	Culturable wasteland[a]	Sugarcane			Miscanthus			Jatropha		
		Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]	Suitable land[b]	Product. potential	Biofuel potential[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Chitrakoot	10.355	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Deoria	1.850	1.850	2.294	1.553	1.850	23.072	6.922	1.850	2.894	3.036
Etah	23.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Etawah	7.563	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Faizabad	3.222	0.000	0.000	0.000	0.000	0.000	0.000	3.222	2.409	2.527
Farrukhabad	2.978	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fatehpur	10.782	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Firozabad	2.986	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gautam Buddha Nagar	2.476	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ghaziabad	3.228	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ghazipur	3.599	0.000	0.000	0.000	0.000	0.000	0.000	3.599	1.546	1.622
Gonda	7.987	0.000	0.000	0.000	0.000	0.000	0.000	7.987	6.412	6.726
Gorakhpur	2.378	0.000	0.000	0.000	2.378	14.127	4.238	2.378	1.615	1.694
Hamirpur	4.525	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hardoi	14.055	0.000	0.000	0.000	0.000	0.000	0.000	14.055	5.084	5.333
Hathras	1.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jalaun	1.829	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jaunpur	7.992	0.000	0.000	0.000	0.000	0.000	0.000	7.992	2.075	2.177
Jhansi	15.722	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jyotiba Phule Nagar	0.906	0.906	1.853	1.254	0.906	13.221	3.966	0.906	1.651	1.732
Kannauj	6.684	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kanpur	4.258	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kanpur Dehat	9.707	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kaushambi	3.990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kushinagar	1.775	1.775	2.455	1.662	1.775	12.781	3.834	1.775	1.775	1.862
Lakhimpur Kheri	2.960	2.199	4.347	2.943	2.960	41.060	12.318	2.960	5.368	5.631
Lalitpur	61.756	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lucknow	6.569	0.000	0.000	0.000	0.000	0.000	0.000	2.240	0.578	0.606
Maharajganj	0.507	0.507	0.444	0.300	0.507	1.831	0.549	0.507	0.252	0.265
Mahoba	10.737	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mainpuri	7.467	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mathura	5.523	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mau	2.295	0.000	0.000	0.000	2.295	13.148	3.944	2.295	1.463	1.535
Meerut	2.630	0.000	0.000	0.000	0.000	0.000	0.000	2.630	0.465	0.488
Mirzapur	14.536	0.000	0.000	0.000	0.000	0.000	0.000	14.536	10.223	10.724
Moradabad	1.532	1.532	3.708	2.510	1.532	20.308	6.092	1.532	3.652	3.831
Muzaffarnagar	2.458	2.458	4.807	3.254	2.458	33.705	10.111	2.458	4.275	4.484
Pilibhit	3.262	3.262	7.915	5.358	3.262	51.024	15.307	3.262	8.617	9.039
Pratapgarh	7.398	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rae Bareli	16.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rampur	0.120	0.120	0.306	0.207	0.120	1.822	0.547	0.120	0.318	0.334
Saharanpur	0.732	0.732	2.121	1.436	0.732	14.809	4.443	0.732	2.113	2.217
Sant Kabir Nagar	2.628	0.000	0.000	0.000	2.291	12.660	3.798	2.628	2.173	2.280
Sant Ravi Das Nagar	0.430	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shahjahanpur	3.675	0.000	0.000	0.000	3.675	46.188	13.857	3.675	3.602	3.778
Shravasti	0.494	0.000	0.000	0.000	0.000	0.000	0.000	0.494	0.502	0.527

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre
Siddharth Nagar	2.866	0.000	0.000	0.000	2.866	8.146	2.444	2.866	0.762	0.799
Sitapur	6.340	0.000	0.000	0.000	0.000	0.000	0.000	6.340	5.062	5.310
Sonbhadra	10.158	0.000	0.000	0.000	0.000	0.000	0.000	10.158	7.744	8.124
Sultanpur	9.725	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unnao	11.971	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Varanasi	3.014	0.000	0.000	0.000	0.000	0.000	0.000	3.014	1.609	1.688
Uttarakhand	**366.713**	**39.535**	**154.984**	**104.924**	**42.758**	**756.759**	**227.028**	**41.222**	**115.933**	**121.614**
Almora	38.756	0.315	0.392	0.266	1.315	13.641	4.092	0.739	0.587	0.616
Bageshwar	15.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chamoli	49.808	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Champawat	14.200	0.000	0.000	0.000	0.164	1.053	0.316	0.000	0.000	0.000
Dehra Dun	60.390	23.342	106.096	71.827	24.375	492.436	147.731	24.014	77.912	81.730
Haridwar	1.641	1.641	3.825	2.589	1.641	27.047	8.114	1.641	3.946	4.139
Naini Tal	23.403	10.712	33.087	22.400	11.117	162.019	48.606	10.971	23.892	25.063
Pauri Garhwal	34.718	0.184	0.180	0.122	0.804	6.247	1.874	0.516	0.693	0.727
Pithoragarh	40.759	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rudra Prayag	4.065	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tehri Garhwal	77.835	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Udham Singh Nagar	3.341	3.341	11.404	7.721	3.341	54.315	16.294	3.341	8.903	9.339
Uttarkashi	2.768	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Bengal	**33.048**	**32.271**	**83.531**	**56.551**	**32.303**	**465.318**	**139.595**	**32.285**	**74.730**	**78.392**
Bankura	1.568	1.568	4.374	2.961	1.568	24.805	7.441	1.568	3.972	4.167
Barddhaman	6.920	6.920	20.444	13.841	6.920	110.207	33.062	6.920	17.899	18.776
Birbhum	3.087	3.087	7.894	5.344	3.087	47.070	14.121	3.087	7.567	7.938
Dakshin Dinajpur	0.078	0.078	0.373	0.253	0.078	1.401	0.420	0.078	0.227	0.238
Darjiling	1.467	0.689	2.060	1.395	0.722	9.480	2.844	0.704	1.564	1.641
East Midnapore	0.304	0.304	0.891	0.603	0.304	4.637	1.391	0.304	0.763	0.801
Haora	0.060	0.060	0.258	0.175	0.060	1.078	0.323	0.060	0.175	0.184
Hugli	1.490	1.490	0.763	0.517	1.490	0.000	0.000	1.490	0.000	0.000
Jalpaiguri	0.056	0.056	0.256	0.173	0.056	1.093	0.328	0.056	0.163	0.171
Kochbihar	0.833	0.833	4.945	3.347	0.833	17.664	5.299	0.833	2.761	2.896
Maldah	0.093	0.093	0.000	0.000	0.093	0.000	0.000	0.093	0.000	0.000
Murshidabad	0.863	0.863	1.545	1.046	0.863	7.351	2.205	0.863	1.234	1.294
Nadia	0.234	0.234	1.128	0.763	0.234	3.962	1.189	0.234	0.654	0.686
North 24 Parganas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Puruliya	8.937	8.937	22.954	15.540	8.937	139.142	41.743	8.937	22.038	23.118
South 24 Parganas	0.740	0.740	2.237	1.515	0.740	9.710	2.913	0.740	1.553	1.629
Uttar Dinajpur	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
West Midnapore	6.318	6.318	13.409	9.078	6.318	87.718	26.316	6.318	14.160	14.854
Total India	**13,668.790**	**2,492.85**	**5,902.66**	**3,996.10**	**3,000.72**	**38,859.66**	**11,657.90**	**4,067.78**	**6,272.83**	**6,580.20**

a Source: Department of Agriculture and Cooperation National Information Center (DACNET 2007). District Wise Land Use Statistics from the year 2006/2007. Due to lack of data, statistic of the year 2005/2006 were used for Chatisgarh and Maharastrah, statistics of the year 1999/2000 for Lakshadweep and statistics of the year 2007/2008 for Nagaland

b The farming system is market oriented; commercial production is the main management objective; production is based on currently available best-yielding cultivars, is fully mechanized with low labor intensity, and provides adequate applications of nutrients and chemical pest, disease and weed control

c sugarcane (677 litre bioethanol / ton sugar), miscanthus (300 litre bioethanol / ton miscanthus ABG (DW)), jatropha (1049 litre biodiesel /

Districts	**Culturable wasteland**[a]	**Sugarcane**			**Miscanthus**			**Jatropha**		
		Suitable land[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]	**Suitable land**[b]	**Product. potential**	**Biofuel potential**[c]
	1000 ha	1000 ha	1000 ton sugar	Mio litre	1000 ha	1000 ton AGB DW	Mio litre	1000 ha	1000 ton oil	Mio litre

ton jatropha oil)
AGB Above Ground Biomass
DW Dry Weights

Table A-3 Indian culturable wasteland suitability for different biofuel feedstocks by district