# BioTrade2020plus

## Supporting a Sustainable European Bioenergy Trade Strategy

**Intelligent Energy Europe**

**IEE/13/577/SI2.675534**

## Assessment of sustainable lignocellulosic biomass export potentials from Brazil to the European Union

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# The BioTrade2020plus Project

**Objectives**

The main aim of BioTrade2020plus is to provide guidelines for the development of a **European Bioenergy Trade Strategy for 2020 and beyond** ensuring that imported biomass feedstock is sustainably sourced and used in an efficient way, while avoiding distortion of other (non-energy) markets. This will be accomplished by analyzing the potentials (technical, economical and sustainable) and assessing key sustainability risks of current and future lignocellulosic biomass and bioenergy carriers. Focus will be placed on wood chips, pellets, torrefied biomass and pyrolysis oil from current and potential future major sourcing regions of the world (Canada, US, Russia, Ukraine, Latin America, Asia and Sub-Saharan Africa).

BioTrade2020plus will thus provide support to the use of stable, sustainable, competitively priced and resource-efficient flows of imported biomass feedstock to the EU – a necessary pre-requisite for the development of the bio-based economy in Europe.

In order to achieve this objective close cooperation will be ensured with current international initiatives such as IEA Bioenergy Task 40 on "Sustainable International Bioenergy Trade - Securing Supply and Demand" and European projects such as Biomass Policies, S2BIOM, Biomass Trade Centers, DIA-CORE, and PELLCERT.

**Activities**

The following main activities are implemented in the framework of the BioTrade2020plus project:

- Assessment of **sustainable potentials of lignocellulosic biomass** in the main sourcing regions outside the EU
- Definition and application of sustainability criteria and indicators
- Analysis of the **main economic and market issues of biomass/bioenergy imports** to the EU from the target regions
- Development of a dedicated and **user friendly web-based GIS-tool** on lignocellulosic biomass resources from target regions
- **Information to European industries** to identify, quantify and mobilize sustainable lignocellulosic biomass resources from export regions
- **Policy advice on long-term strategies** to include sustainable biomass imports in European bioenergy markets
- **Involvement of stakeholders** through consultations and dedicated workshops

More information is available at the BioTrade2020plus website: **www.biotrade2020plus.eu**

## About this document

This report is a progress update of one of the six case studies to be developed under WP3 of the BioTrade2020+ project

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# List of abbreviations

## Acronyms

| | |
|---|---|
| BAU | Business As Usual |
| EU | European Union |
| GHG | Greenhouse Gas |
| GDP | Gross Domestic Product |
| IBGE | Instituto Brasileiro de Geografia e Estatística (Brazilian Geographic and Statistic Institute) |
| IBÁ | Indústria Brasileira de Árvores (Brazilian Tree Industry) |
| ABIB | Associação Brasileira das Indústrias de Biomassa e Energia Renovável (Brazilian Biomass Industry and Renewable Energy Association) |
| ABIPEL | Associação Brasileira das Indústrias de Pellets (Brazilian Pellet Industry Association) |
| SIFRECA | Sistema de Informações de Fretes (Cargo Information System) |
| NCC | nutrient compensation costs |
| Wp2 | work package 2 |
| Wp3 | work package 3 |
| RPR | Residue to Product Ratio |
| TPES | Total primary energy supply |
| EC | European Commission |
| EU RED | European Union Renewable Energy Directive |

## Units

| | |
|---|---|
| MJ | Megajoules ($10^6$ Joules) |
| GJ | Gigajoules ($10^9$ Joules) |
| TJ | Terajoules ($10^{12}$ Joules) |
| PJ | Petajoules ($10^{15}$ Joules) |
| EJ | Exajoules ($10^{18}$ Joules) |
| Mha | million hectares |
| ha | hectare |
| km | kilometre |
| kg | kilogram |
| t | tonne |
| tdm | tonne dry matter |
| toe | tonne oil equivalent |
| kt | kilotonne |
| Mt | Megatonne |
| KWh | kilowatt-hour |
| TWh | terawatt-hour |
| LHV | Lower Heating Value |
| L | litre |
| $m^3$ | cubic meter |
| MW | Megawatt ($10^6$ Joules/second) |
| yr | year |

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# 1. Introduction

The main objective of WP 3 is to analyse the main economic and market issues concerning biomass/bioenergy imports to the EU from each of the six selected sourcing regions. Main elements are the analysis of current and future production and consumption volumes of biomass , identification of on-going and possible future trade routes and delivered costs, and potential risks of competition with other industries (both local and not) utilizing the investigated feedstocks per region.

In this work package, methodology to determine a net sustainable export potential of biomass and related cost and GHG supply curves will be applied and tested to six different country case studies: Brazil, Colombia, Kenya, Indonesia, Ukraine and the USA. For these six case studies, various potentials (technical, sustainable, market etc.) will be determined.

The aim of this progress report is to highlight the status of the data collection and analysis until June 2015. In section 2, a summary of the methodology is presented. In section 3, the general case study description is presented (based on Deliverable 2.1). In section 4, a summary of the data collected and thus far and an overview of preliminary results are presented. Finally, in section 5, a short outlook on the further work and completion of the case study is given.

# 2. Methodology

The methodology chosen for the selection of the regions followed the overall general methodology (See the general report on methodology). The methodology is divided in three main areas: the selection of the regions, the considerations for the theoretical potential in each region according to selected feedstock and the overall background information of the regions.

The focus regions include the US, Ukraine, Brazil, Colombia, Indonesia and Kenya. The feedstock that will be considered are those which can produce different carriers such as wood chips, pellets, torrefied biomass and pyrolysis oil

The theoretical potential was calculated according to the availability of the selected feedstock and the residue production ratio identified in the literature as well as already calculated ratios and residues available.

The overall methodology is illustrated in **Error! Reference source not found.** an according to the general methodology the selection of case studies and their assessment include the technological, and market potential. sustainable potential (see report on methodology).

The background information for the selected countries helped to identify the regions in each country that were more promising for the availability of the feedstock but also that included some of the technological facilities (including transportation and other logistics). The information provided from the Advisory Board (AB) also contributed to better select the particular regions. **Error! Reference source not found.** shows the methodology and information followed in this report.

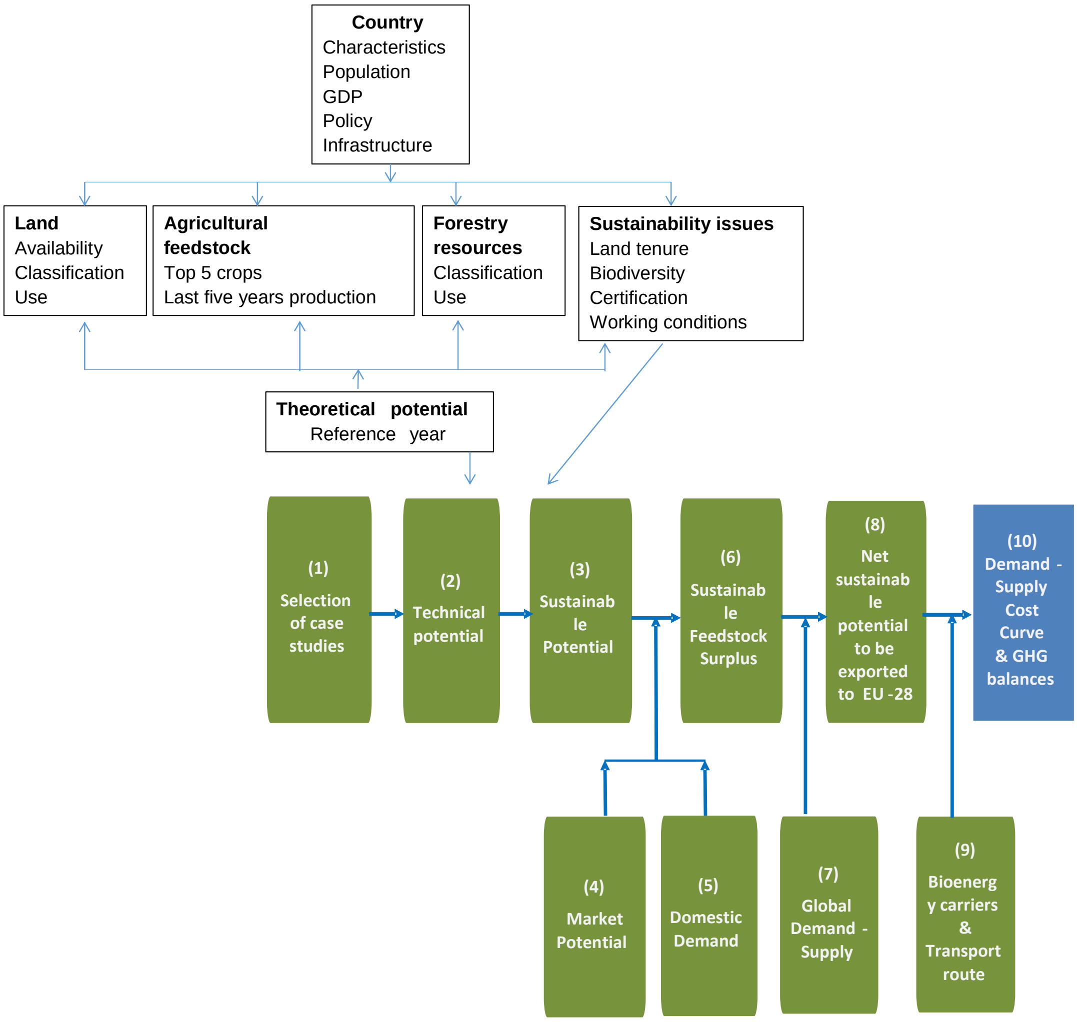


Figure 1- Overall methodology of the Biotrade2020+ project

The following section presents the information collected for the selected countries and regions. This was based in literature review, partners' previous work in the selected countries and information provided by the Advisory board members.

The detailed information and technical, sustainability and market potentials along with scenarios, is included in the specific case studies as the information needed requires more detail and in some cases field work provided mainly by students working in the regions.

Additional socio-economic issues such as the willingness to harvest and the management of the forests, in terms of the use of the resources (e.g. recreational, conservation, market) are not discussed in this report but considered in the specific case studies.

The summary of the countries and feedstock potential presented in this report is shown in

Table 1- Summary of countries and feedstock potential.

**Table 1- Summary of countries and feedstock potential**

| Country | Feedstock | | | | |
|---|---|---|---|---|---|
| | Forest residues | Agricultural residues | Forest plantations | Biomass crops | New forest plantations |
| Brazil | | √ | | √ | √ |
| Colombia | | √ | | √ | |
| Kenya | | √ | √ | √ | |
| Indonesia | | √ | | | |
| United States | √ | | √ | | √ |
| Ukraine | √ | √ | | √ | |

# 3. General case study description: Brazil1

## 3.1 General country overview

**Population and economy**

The Federative State of Brazil is a country located in the eastern part of South-America. It is the


[1] This

largest country in South-America and the Latin-American region (including Central-America) and is the world's fifth largest country in terms of area- as well as population size (Philander, 2008). Brazil is divided into 26 Federal Units or states (figure 3), the Distrito Federal with the capital Brasília, and 5,570 municipalities. As of March 24 2015 Brazil has 204,014,639 inhabitants (IBGE, 2015c). The majority of Brazilians, 56.9%, live in the southeast and south. The average annual population growth rate was 1.04% in the last decade, but has been declining in every consecutive year (IBGE, 2013).

**Land use**

Brazil is made up of a total area of 8,515,770 $km^2$, 60 % of the largest rainforest on the planet, the Amazon, lies within the borders of Brazil, covering 18.3% of Brazil's total land surface (IBGE, 2015a). Despite rapid deforestation of the native tropical rainforest, in 2009 still 60.5% (~5,151,000 $km^2$) of the total surface area of Brazil was covered with native or planted forest (FAO, 2009). The second biggest biome in Brazil is the Cerrado, a tropical savannah in the centre of the country that covers about 20% of the total Brazilian surface area (WWF, 2015).

Figure 4 gives a visualization of the land use in Brazil. The majority of the total land mass is covered with native forest and savannah, accounting for 65% or more than 550 million hectares. 23% of the land surface of Brazil is used for permanent meadows and pastures and only 7% for agriculture. However, taking into account the massive size of Brazil (more than 850 million hectares) this 7% results in more than 68 million hectares cultivated with permanent and temporary crops. Brazil has the world's 5th largest area under agricultural cultivation (CIA, 2012).

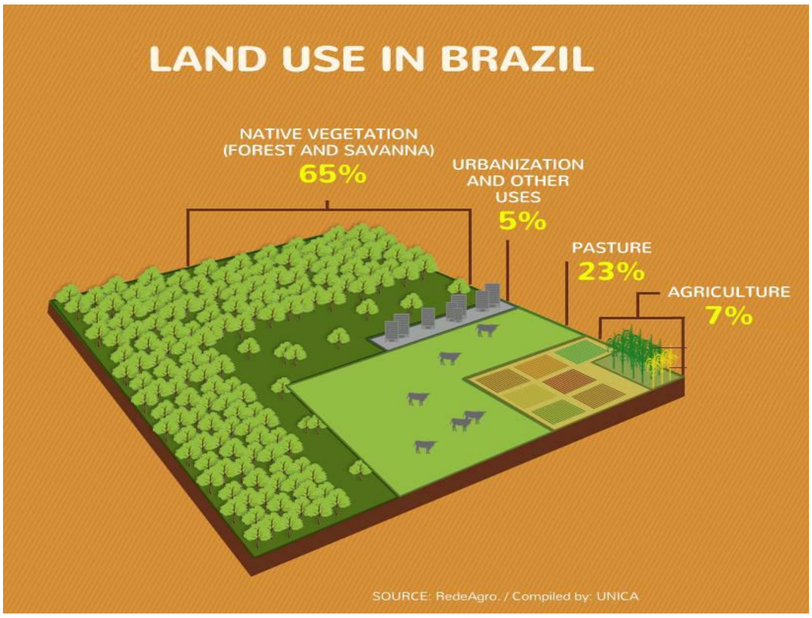


Figure 3 - Land use in Brazil (UNICA, n.d.)

The 198 million hectares that are permanent meadows and pastures consist of land permanently (for a period longer than 5 years) used for herbaceous forage crops (either natural or cultivated), as defined by the FAO (2015a). Usually these lands are used for natural grasses and grazing of livestock.

**Energy sector**

In 2013 the reserves (measured and estimated) of petroleum, natural gas and coal in Brazil amounted to 4,798,620 thousand $m^3$, 839,482,000 $m^3$, and 32,285,000 t, respectively (EPE, 2014). Brazil is the world's 12th largest oil producer, with 3.05% of the global market share (IEA, 2014), however it's coal and natural gas production is not of a significant share.

After the discovery of a very large oil field in pre-salt layers under the ocean floor in 2006, and with deep ocean drilling techniques becoming more and more economical competitive, production from these oceanic fields have gained a share of 15% in Brazil's petroleum production (Petrobras, 2015; EIA, 2015). Several new fields have been found in the pre-salt layers; estimates are that the total reserves could be 50 million barrels of oil, four times as large as Brazil's current national resreves (EIA, 2015).

Renewable energy has also an important role in Brazil. Despite the discovery of large fossil fuel reserves, Brazil's electricity is mostly still generated using renewable energy. Of the 79.3% share of renewable resources, by far the largest share is hydroelectricity (70.6%)(EPE, 2014). Brazil's geographical features, including many large river systems, give a prime opportunity for developing hydropower plants. Currently, Brazil has the largest water retention capacity in the world. The Itaipu plant, on the border of Brazil and Paraguay, has an installed capacity of 14 GW, and is both owned by Paraguay as well as Brazil. In terms of electricity generated, Itaipu is the second largest hydroelectric power plant in the world after the Chinese Three Gorges Dam, with 87.8 TWh produced in 2014 (Itaipu Binacional, 2015). Hydroelectricity gives Brazil a relatively cheap source of energy with very low GHG emissions. However, it is not without its downsides. The two major concerns with hydroelectricity are the damage done to the environment by building dams in rivers and the insecurity of supply in cases of prolonged periods of drought.

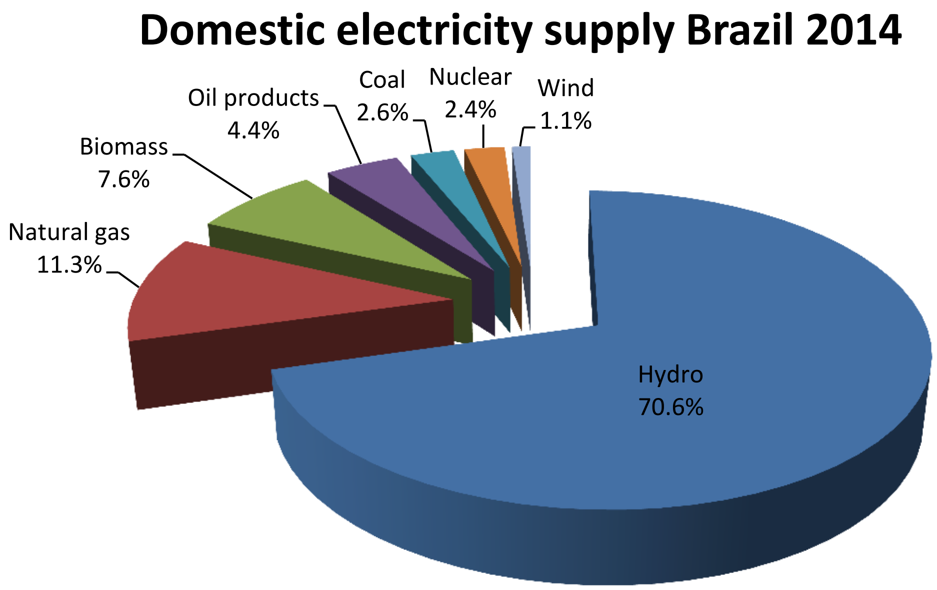


**Figure 4 - Domestic electricity supply by source** (Emprese de Pesquisa Energética, 2014)

**Social development, economy, and industry**

Brazil is part of the BRICS countries, a group of major emerging national economies consisting of Brazil, Russia, India, China, India and South-Africa. As of 2013, Brazil was globally the 7th largest economy both in terms of GDP as of purchasing power parity (World Bank, 2013a, 2013b). In 2014 Brazil's GDP was USD 2,244 billion (IMF, 2014). Not everyone is benefiting from the economic growth though. Income inequality between the poor and the rich is still a big problem in Brazil. With a Gini index of 52.7 in 2012 (0 being 100% equal, 100 being 100% unequal) Brazil is globally the 16th most unequal country in terms of income distribution (CIA, 2014; World Bank, 2015a). The Human Development Index of Brazil is 0.74 (scale 0-1, the higher the better), ranking world's 79th (UNDP, 2013). In 2013, 8.9% of the population was living under the national poverty line (noteworthy: in 2009 it was still 21.4%) (World Bank, 2015b).

Estimates from 2013 indicate that services contributed 68.1% to the GDP, industry 26.4% and agriculture 5.5% (25% when including agribusiness). Looking at export value alone, agricultural products make up 36% (CIA, 2014), with the main agricultural products are soybeans, coffee, beef, citrus, sugarcane, rice, corn and cocoa. Brazil had a small export surplus of USD 2.6 billion: exports reached USD 242.2 billion and imports USD 239.6 billion (MDIC, 2013). Major export destinations are China (19.0%), United States (10.3%), Argentina (8.1%), the Netherlands (7.2%) and Japan (3.3%) (MDIC, 2013).

In 2002, the government of Brazil created the 'Programa de Incentivo a Fontes Alternativas de Energia Elétrica' (Program of Incentives for Alternative Electricity Sources - PROINFA). The programme is still in power and aims to diversify the Brazilian energy matrix and increase the share of wind power, biomass, and small hydropower systems (SHP). The measures need to increase security of supply and the valorisation of local and regional potential. The electricity is brought onto the grid by autonomous independent producers and financed by the end-use consumers by means of an increase in the electricity bill (with the exemption of low income households) (IEA, 2015b; MME, 2015). The program has been proven to be a success especially for wind power. By 2015, 131 plants have been installed, adding an estimated 11.1 TWh to the grid. This capacity is supplied by 60 SHP systems, 52 wind farms, and 19 biomass plants (Portal CPH, 2014). Ultimately, by 2022, the alternative electricity sources must supply 10% of total annual consumption.

## 3.2 Bioenergy and biomass

Another source of renewable energy that has the potential of increasing its share in the energy matrix is the co-generation of sugarcane bagasse. Firing bagasse in steam boilers has become a widespread practice in the sugarcane industry in the last decade. Every tonne of crushed sugarcane produces around 300 kg of bagasse. Sugarcane mills fire the bagasse in boilers and become fully energy self-sufficient. Figure 6 shows the increase of final energy consumption from biomass resources. The majority of the increase is the result of the increase in bagasse firing.

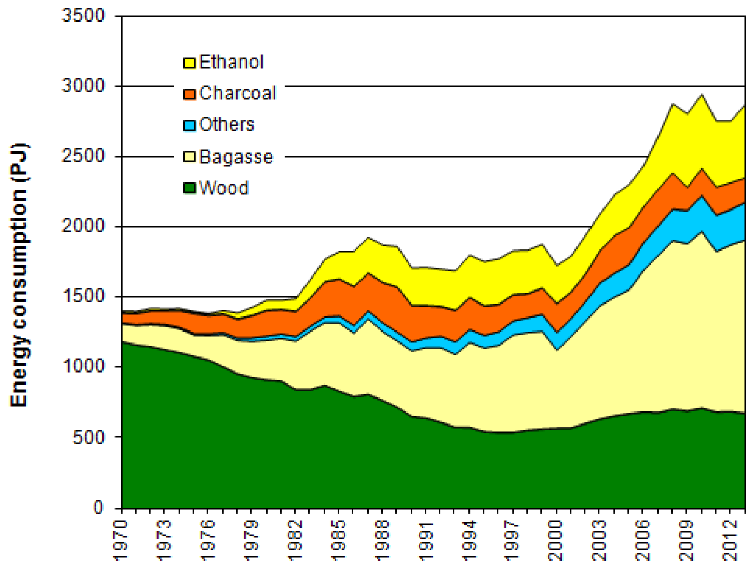


**Figure 5 - Final energy consumption of biomass resources** (Emprese de Pesquisa Energética, 2014)

A striking feature is the contribution of sugarcane products to the domestic energy supply and primary energy production: respectively 16.1% and 19.1%. Sugarcane has been cultivated in Brazil since 1532, and already in 1931 a Federal Law required 5% domestic anhydrous ethanol (containing 0% water) to be blended with imported gasoline (UNICA, 2012). In 1975, just two years after the global oil crisis, the military government took action and set up the 'Programa Nacional do Álcool' (National Pro-Alcohol Programme). Incentives were given to substitute petroleum-based fuels with ethanol, starting by using anhydrous ethanol as an additive to gasoline instead of the imported and highly polluting tetraethyl lead. After the second global oil crisis of 1979, an agreement was signed with the car manufacturing industry to increase the production of cars that could run on pure hydrous ethanol, tax reductions were given to ethanol-fuelled cars, and the price of ethanol at the pumped was fixed at 64,5% of the price of gasoline.

In 1987 the first contract to sell surplus electricity from the cogeneration of sugarcane bagasse was signed between the São Francisco sugarcane mill in Sertãozinho, São Paulo, and Companhia Paulista de Força e Luz (UNICA, 2012). Following the liberalization of exports the Brazilian export of sugar increased rapidly and in the harvest season 1995/1996 Brazil became the world's largest exporter of sugar. The introduction of the flex fuel car, a car able to run on either gasoline, hydrous ethanol (95% ethanol, 5% water) or a mixture of the two meant a new impulse for ethanol fuel consumption. By 2010, 95% of new cars sold in Brazil were flex vehicles. Since 2015 regular gasoline has to be blended with at least 27% ethanol (Amato & Matoso, 2015).

## 3.3 Sustainability issues

**Land tenure**

According to Bolanos (2014), although Indigenous Peoples and local communities in Latin America legally own or control almost 40 percent of the region's forest, the lack of political will to clarify and safeguard these rights has created a tenure system with several conflicts mainly contesting land.

Insecurity in local forest tenure not only endangers the welfare of the communities living in the forests but reduces their effectivity to safeguard these ecosystems.
Brazil hosts extensive forests, grasslands, and wetland ecosystems. Despite legal provisions to provide protection to an estimated 3.7 million square kilometers of public and private lands, there are significant human and development pressures on all of these areas. An estimated 1% of the population owns 45% of all land in Brazil while nearly five million families are landless (USAID, 2012).

**Biodiversity**
Brazil is a member of all the major international environmental treaties/conventions/protocols, a significant indicator of the country's sensitivity to biodiversity and conservation issues. The last report to the Convention on Biological Diversity (CBD) was in 2005. More than 20 percent of Brazil is under protected area status (ten percent is a general internationally recognized standard), although it is unclear how much of these areas have formal and workable management plans. Ecofys (2010) noted that High Conservation Value areas (HCV) were known in the country and that steps were being undertaken to include them under Brazil's protected area system.

**Food security**
Brazil has improved the per capita food intake as well as reduced undernutrition in the last 10 years (see Table 1). Food production is growing as well. Brazil has made great strides in food security and nutrition governance over the last ten years, with laws and institutions that are the legacy of the Zero Hunger programme. Significant advances in poverty and hunger alleviation demonstrate the success of this intersectoral, participatory and well-coordinated approach (FAO, 2014).

**Table 2 - Food supply per capita (A) and prevalence of undernutrition (B) in Brazil (FAO, 2015)**

| **Per capita food supply** | | | | | **Prevalence of undernutrition** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quantity (kcal/capita/day) | | | | | Prevalence (%) | | | |
| | **1996** | **2001** | **2006** | **2011** | | **99-01** | **04-06** | **07-09** | **10-12** |
| **Food Supply** | 2840 | 2892 | 3096 | 3287 | Undernutrition | 12 | 9 | 8 | 7 |

**Social issues**
The current state of the ILO conventions in Brazil is shown in Table 2. The ratification of conventions needs to be translated into the legal system of the country. Therefore a link to the enforcement of legislation is also in place and can be seen in table 3 below. It must be mentioned that ILO 87 is not ratified because union organisation is mandatory according to the Brazil constitution, not voluntary. Labourers are automatically assigned to a union, there is one union per economic activity, and contributions are automatically deduced from salaries.

**Table 3 - ILO Conventions and state in Brazil (ILO)**

| ILO Number | Name of Convention | Ratified |
|---|---|---|
| 29 | Forced or Compulsory Labour | √ |
| 87 | Freedom of Association and Protection of the Right to Organise | N |
| 98 | Right to Organise and to Bargain Collectively | √ |

| | | |
|---|---|---|
| 100 | Equal Remuneration of Men and Women Workers for Work of Equal Value | √ |
| 105 | Abolition of Forced Labour | √ |
| 111 | Discrimination in Respect of Employment and Occupation | √ |
| 129 | Inspection of Agriculture | √ |
| 138 | Minimum Age for Admission to Employment | √ |
| 182 | Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour | √ |

**Table 4 - Compliance with legislation indices for Brazil (Ecofys, 2010)**

| Indicator | Score | Description |
|---|---|---|
| CPI – Corruption Perception Index | 3.7/10 | Corruption is perceived medium |
| GII – Global Integrity Index | 7.6/10 | Anti corruption framework is moderate |
| ID – Index of Democray | 7.1/10 | Classifed as "flawed democracy" |
| EI – Enforcement Index | 6.1/10 | Potential to enforce legislation is intermediate |
| RLI – Rule of Law Index | | Not reported |

Although progress has been made, the incidence of child labour in Brazil is still significant. Currently, child labour tends to occur mostly in the form of domestic service, family agriculture, commerce, and services in the urban informal sector (Chianca et al, 2011). According to USAID (2012), forced labor is a serious concern, exacerbated by the high concentration of land ownership. Forced labor is used in logging operations, alcohol and sugar refineries, and on large coffee estates (*fazendas*). Chianca et al (2011) reported a committee set up in Bahia considered that forced labour will continue to exist as long as it remains profitable.

In June 2009 the National Commitment for the Improvement of Labor Conditions in Sugarcane Production was launched by the Brazilian federal government, UNICA, the Federation of Rural Workers in the State of São Paulo (FERAESP), the National Confederation of Workers in Agriculture (CONTAG) and the National Sugar-Energy Forum to encourage and recognize best labor practices in the sugarcane industry (Ribas Chadad, 2010). Today 98% of all workers are fully documented and it is estimated that forced labor may occur in 1% of the industry (personal communication UNICA).

An additional programme called Renovação created by UNICA in partnership with the Federation of Rural Workers of the State of São Paulo (FERAESP) in 2009 aimed to train every year 7,000 workers from local communities in six sugarcane production areas in the state of São Paulo as a preparation for mechanisation in the sector.

## 3.4 Agriculture

**Agricultural history**

Agriculture is historically the stronghold of Brazil's economic foundation. Its size, climate and weather, fertile soil, and available financial and labour resources make Brazil a world player on the agro commodities market. Brazil has grown to be the world's largest producer of, among others, sugarcane, coffee and oranges, as well as the world's largest exporter of, among others, orange juice, coffee, soybeans, and raw sugar (FAOSTAT, 2015). In 2012 Brazil ranked 5th in the world in export value of agricultural products with $30.5 billion, behind the USA, the Netherlands, France, and Germany (FAOSTAT, 2015). Sugarcane is by far the most produced feedstock, it outnumbers the number two feedstock, corn, by a factor ten (Bron =- IBGE). Agricultural production mostly takes place in the southeast and south of Brazil.

**Forestry sector in Brazil**

The total area occupied by planted tree forests in Brazil in 2012 was 7.39 million ha, of which 6.87 million ha eucalyptus and pine (IBÁ, 2014a). 32% of the forest area is owned by and destined for the pulp and paper industry, 26% owned by independent producers (mostly for lumber), 15% owned by and destined for steelworks and charcoal production, and the remainder is accounted for by wood panel producers, institutional investors and others (IBÁ, 2014b).
Just like agricultural production planted forests are concentrated in the southeast and south of Brazil. The states with the largest area of forest plantations are Minas Gerais.

Forestry residues production is considered to be 7% of the bark, 10% of sawdust and 28% of the cuts. The residues produced vary along the supply chain of the wood industry depending on whether wood is from native forest or plantations. In natural plantations the production in the field is higher than in plantations. Nevertheless, in the supply chain from plantations the total of residues is about 70-90%. From natural forests the generation of residues in the supply chain is about 60%, this is less because of the lack of proper management and irregularities of the plants (Bortolin et al, 2012).

The residues of the forestry industry have different uses that include the production of small furniture, uses in farms (fences), boxes for fruit transport, energy and compost. Cerqueira et al. (2012) cautioned that the amount produced could have negative environmental impacts and suggested the sector will benefit from better management. Table 4 shows the production of residues and pellets in Brazil in 2014.

Table 5 - Production of residues and pellets in Brazil in 2014 (SNIF, 2015)

| Product | unit | Amount | Value in $USD |
|---|---|---|---|
| **Wood pellets and other** | T | 6,993 | 3,459,840 |
| **Wood residues** | m3 | 654 | 108,258 |
| **Total** | | 7647 | 3,568,098 |

**Certification**

In June 2007 the São Paulo Governor and Secretaries of Agriculture and the Environment signed with UNICA the Agro-Environmental Protocol to promote sustainable environmental practices in sugarcane production and processing in the state. Bonsucro and the Roundtable for Sustainable Biomaterial (which only certifies one company: Amyris) are other leading certification schemes used in Brazil.

Certification is used in Brazil, with the FSC (Forest Stewardship Council Internacional/Brasil) and PEFC (Program for the Endorsement of Forest Certification Schemes) used more commonly. Certification started in Brazil in 1994 with FSC first area certified in 1995. The other used certification system is CERFLOR since 2002 (Programa Brasileiro de Certificação Florestal) recognised and approved by PEFC (SNIF, 205). There are around 15 main certifiers in Brazil.

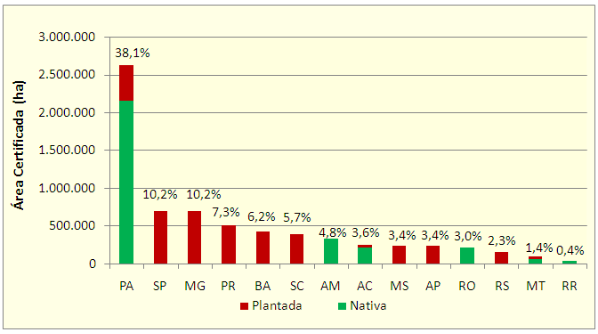


Figure 6 - Area certified under FSC by type of forest and state

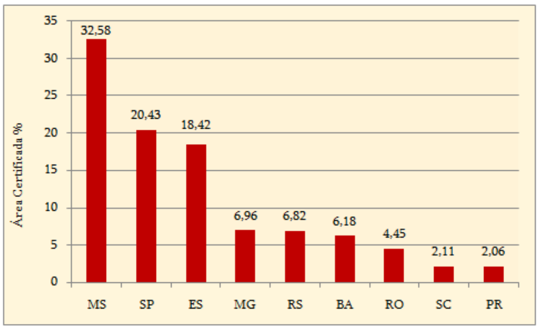


Figure 7 - Area by CERFLOR total certified area by state

Until the end of 2012 there were 919 chain of custody certifications by FSC of wood products and 93 combined certifications of forest management and chain of custody by FSC which made an average of 7.2 million hectares of forest (3.9 M hectares of plantations, 3 M hectares of native forests and 300 thousand hectares of mixed forest management (SNIF, 2015). Until 2012, CERFLOR certified a total 1,463,308.35 hectares of forests, from which 65,078.37 ha de were native and 1,398,229.98 ha were plantations (SNIF, 2015). Other certification systems for other commodities exist such as BONSUCRO (sugar cane), ICCT, RTRS (soy), among others.

# 4. Methodological application into the Brazil case study

The general Biotrade2020+ methodology (see figure 9) was adapted to suit the Brazil case study. These changes mostly affect the calculation of the technical potential. It was considered unfeasible to include the entire country, considering the size of Brazil and the fact that transporting biomass pellets over such a great distance is unrealistic. Furthermore it was recognized that some states in Brazil should be included entirely because they are part of protected or high-biodiversity areas such as the Amazon. Furthermore agricultural production is highly concentrated in Brazil, therefore some states have very little potential to offer. With these considerations in mind, the first step of this research was to make a selection of the different states in Brazil to include in the analysis.

Another, smaller, change is the inclusion of feedstocks. Instead of considering the top 5 feedstocks in terms of production, production statistics were used to estimate the potential residue production for each resource. The feedstocks that could add a significant potential to the potential were included.

The third, and major, change was that the market potential was not calculated. Instead of calculating the limitations of mobilizing biomass and establishing markets, this was combined by calculating the potential to pelletize biomass, based on pellet plant capacity. The available pelletization capacity was recognized as a major limitation from the beginning of the analysis. Mobilization of biomass and a market for lignocellulosic biomass carriers are factors already included in the attractiveness of investing in new pellet plants.

The different methodological steps are explained in more detail below.

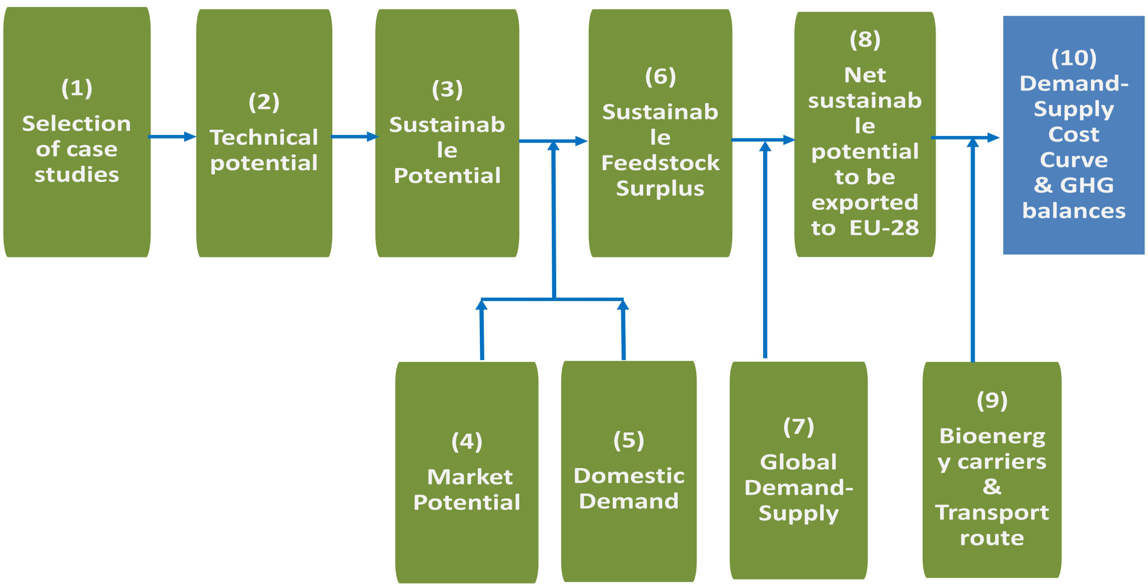


Figure 8 - General Biotrade2020+ methodology

## 4.1 Technical potential

### 4.1.1 Determination of national biomass production and consumption

Before being able to calculate the net surplus potential of lignocellulosic biomass residues in Brazil it was necessary, due to time constraints, to narrow down the focus on a selection of feedstocks. This was done in order to use the available time in the most efficient way, by focusing on the regions and feedstocks with the biggest residue potential. The Brazilian biomass production and consumption volumes were used to identify the biomass types most interesting for further study and the regions which produce large quantities of biomass with favourable conditions for export (infrastructure, logistics quality and distance to ports).

A selection of most promising agricultural and forestry feedstocks was made based on agricultural and forestry production statistics of Brazil. The feedstocks are chosen based on production volume, the RPR, and the suitability of the residue product to be transformed into wood pellets (technology development).

### 4.1.2 Selection of most promising states in Brazil

Biomass market flows were assessed on state level using IBGE data. A table with the main characteristics for region selection was made using the work of Batidzirai, Smeets, and Faaij (2012) (table 5).

Table 6 - Selection criteria for potential biomass production regions (adapted from Batidzirai et al. (2012)

| Criteria | Biomass productivity | Logistics | Sustainability | Production cost |
|---|---|---|---|---|
| **Indicators** | Feedstock production volumes, spatial distribution | Presence and quality of infrastructure, distance to export harbours, pre-treatment facilities | Biodiversity, protected areas | Harvesting costs, transport costs, storage and handling costs, pellet production costs, harbour cost |

A large number of states could be disregarded beforehand due to being part of the biodiversity rich Amazonas or Pantanal, their unfavourable geographical location (resulting in too high transportation costs) and/or low fertility and thus low biomass production volumes. Therefore, the states or regions were identified where the majority of biomass is produced, the infrastructure (road/rail transportation, shipping routes) is easily accessible, and logistics are competitive.

### 4.1.3 Estimation of the technical biomass residue potential

Biomass resources exist in many different types, ranging from primary, secondary, to tertiary residues from agricultural crops and forestry. All these types of biomass have different yields, energetic content and other biophysical characteristics. Examples of biomass resources are given in table 6.

Table 7 - Agricultural and forestry residue types (adapted from Perlack et al. (2005))

| Agricultural resources | |
|---|---|
| **Primary** | Crop residues from major crops – corn stover, small grain straw, and others<br>Grains (corn and soybeans) used for ethanol, biodiesel, and bio products<br>Perennial grasses<br>Perennial woody crops |
| **Secondary** | Animal manures<br>Food/feed processing residues |
| **Tertiary** | Municipal solid waste and post-consumer residues and landfill gases |
| Forest resources | |
| **Primary** | Logging residues from conventional harvest operations and residues from forest management and land clearing operations<br>Removal of excess biomass (fuel treatments) from |
| **Secondary** | Primary wood processing mill residues<br>Secondary wood processing mill residues<br>Pulping liquors (black liquor) |
| **Tertiary** | Urban wood residues – construction and demolition debris, tree trimmings, packaging wastes and consumer durables |

In this study only primary agricultural residues and primary and secondary forestry residues were considered. Pulping liquor is a secondary forestry residue, but since it is a liquid and not lignocellulosic, it is not taken into account in this research. Tertiary residues are highly dispersed in smaller volumes and difficult to recover (Coelho & Escobar, 2013). Therefore it has been decided to focus on the biggest and easiest to recover residue streams.

### *4.1.4 Agricultural residues*

Feedstock production volumes were collected on municipality level and aggregated on micro-region level. RPR values were applied to production volumes of agricultural feedstocks to calculate the residue production on micro-region level. If applicable, generated residues were divided in types. For example, sugarcane residues were divided into tops/straw and bagasse. LHV values were used to determine the energetic potential of the produced residues.

Bhattacharya, Pham, Shrestha, and Vu (1993); ; Nogueira et al. (2000) and Forster-Carneiro et al. (2013) provided information on the RPR's of several agricultural feedstocks. Koopmans and Koppejan (1997) have performed a meta-study for the FAO on 12 studies on RPR values of agricultural feedstocks. They present their findings as ranges of RPR's. The RPR's are compared between the different studies and the most commonly used value per feedstock was chosen to perform the calculations with. Data on the production volumes of feedstocks was collected from FAOSTAT and IBGE.

RPR and LHV values of agricultural residues used in the calculations are shown in table 7. All LHV values are on dry weight basis (0% moisture content).

**Table 8 - RPR and LHV values of agricultural residues**

| Feedstock | RPR | LHV (MJ/kg) |
|---|---|---|
| Sugarcane tops/straw | 0.34[2] | 17.38[3] |
| Sugarcane bagasse | 0.30[2] | 17.71[4] |
| Soybean straw | 1.40[2] | 12.38[5] |
| Corn stalk | 0.78[6] | 17.45[4] |
| Corn cob | 0.22[6] | 16.28[5] |
| Corn husk | 0.20[6] | 12.00[5] |
| Cassava straw | 0.80[2] | 17.50[5] |
| Rice straw | 1.48[2] | 16.02[5] |
| Rice husk | 0.22[2] | 14.17[7] |
| Coffee husk | 0.21[2] | 17.71[3] |
| Orange peel | 0.50[8] | 17.11[9] |

### *4.1.5 Forestry residues*

The same method to calculate the technical potential of agricultural residues was applied to calculate the technical potential of forestry residues. Forestry residues were divided in three categories (see figure 10): waste in the field (small branches, leaves etc.), waste from paper and cellulose production (bark, chips, parings), and waste from wood processing in the lumber and furniture industry (bark, sawdust, chips, shavings).

Since the RPR values of paper and cellulose production and processing in the literature refer to a percentage residue of roundwood, the RPR's were converted to percentage of residue of planted forest. Roundwood are logs after they are being cut from the forest planation. 15% of the planted forest volume is residue, thus roundwood represents 85% of the initial volume. The RPR of roundwood for processing (sawmills and furniture industry is 0.45. Relative to the initial planted forest volume this is 0.45/(1/0.85) = 0.3825 or 38.25%. 2.22 t oven-dry wood results into 1 t oven-dry pulp. Every produced ton of oven-dry pulp results in 0.305 t wood waste. This represents 13.75% of the initial wood input. Relative to planted forest volume this is 0.1375/(1/0.85) = 0.117 or 11.7%. This

[2] Nogueira, Lora, Trossero, and Frisk (2000)
[3] Neto (2005)
[4] Miles et al. (1995)
[5] Bhattacharya et al. (1993)
[6] Ferreira-Leitão et al. (2010)
[7] Coelho et al. (2012)
[8] Forster-Carneiro et al. (2013)
[9] Aguiar, Márquez-Montesinos, Gonzalo, Sánchez, and Arauzo (2008)

value is similar to a RPR of 9.44% (relative to planted forest volume) derived from Klabin (2011), although this only refers to bark waste, which is 67% of the total wood waste production during the paper and cellulose production process.

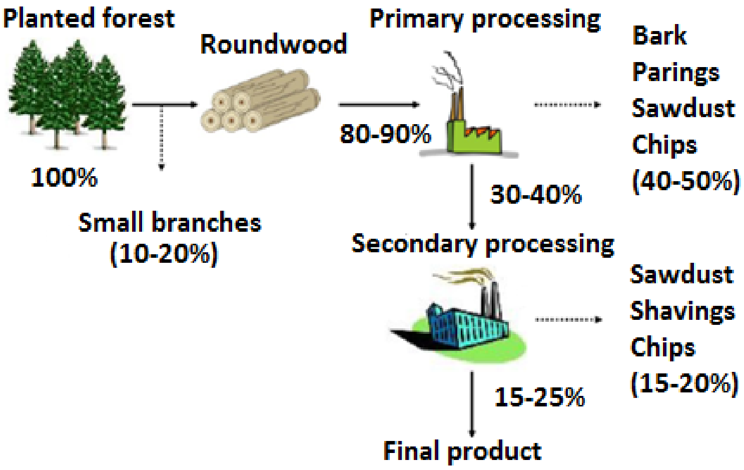


Figure 9 - Residue production in various stages of planted forest wood processing (STCP, 2011)

Coelho & Escobar (2013) and STCP (2011) provided the RPR for field residues, he average of 15% was taken from the range 10-20%. Wood input per oven-dry t produced pulp was derived from Briggs (1994), and the generated volume of wood waste types per produced t oven-dry pulp from Gavrilescu (2004). Data on production volumes of forestry plantations was collected from FAOSTAT, IBGE, IBÁ and ABIB.

RPR and LHV values of forestry residues used in the calculations are shown in table 8. All LHV values are on dry weight basis (0% moisture content).

Table 9 - RPR and LHV values of forestry residues

| Feedstock | RPR | LHV (Mj/kg) |
|---|---|---|
| Field residues | 0.15[10] | 19.05[11] |
| Paper and cellulose production residues | 0.117[12] | 18.18[13] |
| Sawmill and furniture industry residues | 0.3825[14] | 18.18[15] |

[10] Coelho and Escobar (2013), STCP (2011)
[11] Boundy, Diegel, Wright, and Davis (2011)
[12] Gavrilescu (2004), Briggs (1994)
[13] de Paula Protásio et al. (2013)
[14] Coelho and Escobar (2013), STCP (2011), Bortolin, Trentin, Peresin, and Schneider (2012)
[15] de Paula Protásio et al. (2013)

## 4.2 Estimation of the Sustainable Biomass Residue Potential

Sustainable sourcing of lignocellulosic biomass is considered a precondition for imported biomass to the EU, therefore several sustainability aspects are taken into consideration. Within the BIotrade2020+ project several sustainability criteria are identified to be considered for bioenergy production, this is assessed in Deliverable 2.4. The principle behind the criteria is the notion that there should be a uniform set of criteria applied to all non-food biomass feedstocks. Differences however exist between minimum requirements and advanced requirements, as well as basic and advanced levels of ambition. Table 9 shows the list of basic requirements that are applied in this case study. These requirements are closely aligned with the requirements of the RED (European Union, 2013).

**Table 10 - Basic sustainability requirements applied in Biotrade2020+ case studies**

| Criterion | Indicator |
|---|---|
| *Biodiversity* | Conservation areas and land with significant biodiversity values |
| *Climate* | Life cycle GHG emissions incl. direct LUC |
| *Employment and labor conditions* | Human and Labor Rights |
| | Occupational safety and health for workers |

Considering that the selection of Brazilian states in this case study already excludes states with high biodiversity and protected conservation areas, the biodiversity criterion is considered to be fulfilled. An analysis of life cycle GHG emissions is included in this analysis in the form of a GHG supply curve. The GHG emissions along the entire supply chain, including agricultural processes, pre-treatment and intra/inter-national transport are calculated for each region and feedstock in Brazil. By creating a GHG supply curve of the net export potential, the part of the potential that does not meet GHG reduction criteria set by the European Commission can easily be excluded.

### *4.2.1 Soil quality*

Aside from the criteria above, maintaining soil quality is considered important for the Ukraine case as well. Ukraine is characterized by very fertile soils. Maintaining the structure and texture of the soil, as well as the nutrient level, is not only crucial in ensuring long term agricultural productivity but also plays an important role in biodiversity and greenhouse gas balance. When looking at primary biomass production, several of the sustainable criteria's are affected by the amount of agricultural or forest residues that are left on the field. Agricultural residues can improve or maintain soil quality by returning to the soil the nutrients that were removed during the growth phase. A second function of residues on the field is to maintain soil structure. If soil structure is damaged, and the soil is left without protection in the form of crop residues, the soil is easily eroded away by wind or rain. This removes the fertile top layer of the soil and therefore reduces the soil quality and agricultural productivity.

Considering the limited availability of time and resources, the criterion of soil quality is included by taking into account the level of Soil Organic Carbon (SOC) as indicator. Wilhelm et al. (2004) reviewed crop and soil productivity response to corn residue removal, and found that the amount of residues left on the field to maintain organic carbon content is larger than the amount needed to prevent both wind and rain erosion. Based on this review study it is assumed that maintaining SOC levels is a larger constraint to the residue removal rate than maintaining soil structure for all the oblasts in Ukraine. Soil Organic Carbon is thus included as additional criteria in this case study:

**Table 11 - Additional sustainability requirement applied in the Brazil case study**

| **Criterion** | **Indicator** |
|---|---|
| *Soil Quality* | Soil Organic Carbon, soil structure |

The extent to which some of these sustainability constraints might hinder agricultural production depends partially on natural characteristics, such as soil type, slope, climate, biodiversity etc. On the other hand, local land management practices, such as tillage, water management, fertilizer use etc., also impact the extent to which these limitations must be applied (Batidzirai, Smeets, & Faaij, 2012). Because most of these sustainability constraints have to be applied to a very small local scale, and depend to a large extent on local land management and agricultural practices, modelling the effect on agricultural production in countries is difficult. It is therefore recognized that modelling the sustainable potential based on certain aggregated characteristics will result in an approximation. This should in no way form the basis for local agricultural practices; instead field or farm specific tools could be used to assess the local potential for maximum residue removal.

### *4.2.1. Sustainable removal rate*

The potential that needs to be left on the field to maintain soil quality can be quantified by using sustainable removal rates, the share of the residues that can be sustainably removed. Among the available studies into sustainable recovery factors of agricultural and forestry residues, there is still much debate. There are proponents who see residues as unused waste and strongly argue in favour of their use for biofuel production (Somerville, 2006). Others claim that crop residues provide irreplaceable environmental services (Smil, 1999) and removing them from the field aggravates risks of soil erosion, nutrient and soil organic carbon depletion, degradation of soil quality, and decreasing agronomic productivity (Lal & Pimentel, 2007). There are many authors positioned somewhere in the middle of this debate. They agree that crop residues offer the aforementioned valuable environmental services to the soil, but also argue that part of the residues can sustainably be removed without jeopardizing these services (Andrews, 2006; Cherubini & Ulgiati, 2010; Forster-Carneiro et al., 2013; Lindstrom, 1986; Nogueira et al., 2000).

Table 11 shows the SRF's of agricultural residues. The values were obtained from literature research and for sugarcane cross-checked with interviews with a farmer and a sugarcane mill employee (Usina Santa Lucia in Araras, São Paulo). The SRF's obtained from literature are derived from field experiments into the effects of residue removal on soil nutrient balance, soil erosion rates, and soil organic carbon percentages. The SRF's represent a removal rate at which the indicators are not negatively impacted. Processing residues like bagasse, crushed sugarcane, rice- and coffee husks, and orange peels, are not produced in the field and can thus be 100% sustainably utilized.

**Table 12 - SRF values of agricultural residues**

| Feedstock | SRF |
|---|---|
| Sugarcane tops/leaves | 0.50[16] |
| Sugarcane bagasse | 1[17] |
| Soybean straw | 0.25[18] |
| Corn stalk | 0.30[19] |
| Corn cob | 0.30[19] |
| Corn husk | 0.30[19] |
| Cassava straw | 0.30[19] |
| Rice straw | 0.25[18] |
| Rice husk | 1 |
| Coffee husk | 1 |
| Orange peel | 1 |

In the same way as agricultural residues, part of the forestry residues have to be left on the field to maintain nutrients, soil erosion prevention, and soil organic carbon. Field experiments determined that 50-55% of the forestry residues generated on forest plantations can be sustainably removed (AEBIOM, 2007). Eucalyptus and pine trees are often present on the same forest plantation, and thus same soil type, and planted in a mosaic pattern to optimize biodiversity and soil quality (Negredo Junior, 2015), therefore it is assumed that the same SRF's apply to eucalyptus and pine trees. Wood processing residue like sawdust, chips, and shavings are secondary residues produced at production facilities, it is assumed that these can be 100% sustainable utilized.

[16] Assumpção (2015), Ferreira-Leitão et al. (2010), UNICA (2015), Forster-Carneiro et al. (2013)
[17] Lindstrom (1986)
[18] Forster-Carneiro et al. (2013)
[19] Forster-Carneiro et al. (2013), Lindstrom (1986), Papendick and Moldenhauer (1995), Graham, Nelson, Sheehan, Perlack, and Wright (2007)

Table 13 - SRF values of forestry residues

| Feedstock | SRF |
|---|---|
| Eucalyptus field residues | 0.525[20] |
| Eucalyptus processing residues | 1 |
| Pine field residues | 0.525[20] |
| Pine processing residues | 1 |

## 4.3 Estimation of the Sustainable Biomass Residue Surplus Potential

One of the key criteria set by BioTrade2020+ for assessing export potentials in sourcing countries outside the EU is giving priority to local demand for biomass residues. Biomass production and consumption is affected by local competition and demand drivers and related factors such as population size, GDP, policies in energy and environment, and climate change scenarios. All these factors have an impact on the availability of biomass residues in Brazil and thus on the biomass residues surplus available for export to the EU. Social, political and economic factors as well as the productivity of agriculture and forestry sectors have been identified to determine in what way the availability of biomass residues is being limited. The current uses of agricultural and forestry residues, for example for fodder, electricity (cogeneration), the domestic wood pellet market, pulp and paper, and wood panels were quantified. Consumption volumes of agricultural and biomass residues have been presented in tables for every industry and domestic application separately. Industrial- and domestic consumption volumes were estimated using national-, federal- and industry statistics and FAOSTAT and IBGE databases. When data was not available through these sources, external reports and interviews with local stakeholders were used.

[20] AEBIOM (2007)

## 4.4 Estimation of the Net Export Potential

Agricultural and forestry residues gathered on the field, can be characterized by low energy densities; the relatively high moisture content further reduces the heating value of biomass feedstocks. Furthermore most biomass is highly heterogeneous and therefore poorly suited for direct use as fuel. These drawbacks of biomass compared to fossil fuels apply particularly to agricultural crops and to a lesser extent to forest biomass. The low energy density of raw biomass limits the marketability. In order to cost effectively transport biomass over larger distances, the energy density must be improved. Another factor that impacts the storage and transport of biomass is the presence of natural pathogens in biomass, this makes storing raw biomass a health risk. Other risks exist, such as self-heating and dust explosions, pre-treatment can help minimize or solve these risks.

Pre-treatment of biomass helps to improve the energy content, homogenize the feedstocks and reduce above mentioned risks. Pre-treatment includes several processes, such as drying, size reduction through milling, grinding and pulverization and subsequent treatment methods including torrefraction, pyrolysis and pelletization. In this research only pelletization will be considered as pre-treatment technology considering that torrefaction and pyrolysis are still in a state of development, and not ready for use on the mass market.

### *4.4.1 Capacity Pellet plants*

Considering that it is not feasible to export untreated lignocellulosic biomass to the EU, the available pellet producing capacity is considered a limitation for the net export potential. Pelletization is currently mainly applied for woody residues, agricultural residues are mostly just dried and baled and used locally. It is however possibly to use pelletization technology also on agricultural residues or on mixtures of agricultural and forestry residues (Nunes, Matias, & Catalão, 2014).

The current potential is calculated based on capacity in existing plants. Existing installed capacity is taken from the Bioenergy International Inventory. The capacity in the case study regions is currently 630 kton. A capacity factor of 80% was used to calculate the actual pellet producing capacity. This is considered optimistic since in reality pellet plants often run at lower capacity because of supply limitations (Wood Pellet Association of Canada, n.d.)

The existence of long term contracts or price-based competition is left out of consideration for simplicity reasons. A raw material (15% moisture content, Batidzirai (2013)) conversion factor to wood pellets (10% moisture, Bradley et al. (2013)) of 1.07 is used for agricultural residues, and 1.2 for forestry residues. This is to account for material losses in the pellet production process (Batidzirai, 2013).

## 4.5 Biomass Transport Logistics, Supply Chain Costs and Cost-Supply Curves

By taking into account the sustainability restrictions and subtracting the domestic demand of lignocellulosic biomass, the net available export potential is calculated, the next step is calculating the cost of exporting these pellets to the EU.

To assess whether the imported biomass pellets from Ukraine could compete with alternative energy carriers in the EU, the various costs in the supply chain were calculated. Costs can be divided in feedstock costs, transport costs, handling costs and pre-treatment costs. All these costs contribute to the market price of biomass residue energy carriers, for example wood pellets. Costs and the market price determine, among others, whether consumers in the EU are willing to import biomass residues and/or their derivatives and whether producers are willing to export them. Data on costs are derived from databases, literature and from interviews with local experts.

To estimate the cost of lignocellulosic pellet production the following cost components are included:

$$C_D = C_P + C_{Pt} + C_{Tdf} + C_{Tdp} + C_{Ti} + C_H$$

Where:

$C_D$ = Total production cost of biomass residues

$C_P$ = Cost of production of feedstock

$C_{Tdf}$ = Cost of domestic transport from field to pre-treatment facility

$C_{Tdp}$ = Cost of domestic transport from pre-treatment facility to export location

$C_{Ti}$ = Cost of international transport from facilities to the EU

$C_{Pt}$ = Cost of pre-treatment

$C_H$ = Cost of handling

Handling cost include cost components such as loading and unloading of pellets, storage of pellets, harbour fees etc. These costs will be aggregated into one total cost for the handling of pellets.

In order to be able to compare the cost over the different case studies, the cost calculations are harmonized. Pre-treatment cost estimations are taken from Ehrig et al. (n.d.). This study assesses economics and price risks in pellet supply chains including pelletization and transport from Western Canada, Western Australia and Northwest Russia to the European market (Ehrig et al., n.d.). Cost assumptions are taken from market data, meaning costs are requested from bioenergy traders and experts, and costs are considered from an end-user perspective and are therefore suitable to use in this project. Costs are calculated for two different scales, a medium-scale pellet production plant of 40,000 ton/year and a large-scale pellet plant producing 120,000 ton/year. Another option that is added based on the work of Ehrig et al. (bron) is pellet production with the use of part of the biomass feedstock for heat production to deliver the required heat for drying purposes.

In addition to the cost components from Ehrig et al. (n.d.), cost of consumables are included based on Pirraglia et al. (Pirraglia, Gonzalez, & Saloni, 2010). This study explicitly includes the cost of parts and replacements, as well as marketing and sales fees. These components seem to be overlooked often, and are added to the cost calculation in this study for the sake of completeness.

Whereas the cost of pellet production are harmonized over the different case studies, some cost factors are adapted to represent country specific cost, such as labor cost or cost of electricity. Certain feedstock characteristics, such as moisture content and calorific value are also adapted where necessary to represent differences between feedstocks. The input values used to calculate the cost of biomass pellet supply to the EU are given in Appendix A.

### 4.5.1 Cost of transport

Although there is a developed railroad network in the southeast of Brazil, many stations are abandoned and rail density is not high. Brazilian transport is heavily dependent on road transport, also for long distances (Missagia, 2011). A questionnaire sent to all 18 pellet producers in south- and southeast Brazil, filled in by four of them, revealed that the primary material, agricultural or forestry residues, as well as the final product, pellets, are transported only by truck. The poor accessibility, quality, and distance to loading stations are the main arguments against using train transport. For this reason, only truck transport is taken into consideration for transporting residues from the field to the pre-treatment facility and wood pellets from the pre-treatment facility to the export harbour.

The export harbours in the study area were selected based on port facilities, such as being able to handle containers, presence of heavy duty lifting cranes, and shipping volume capacity (World Port Source, 2016). The straight line distance between the regions and the export harbours was calculated through ArcGIS, from the geographical centres of regions to the harbours. A tortuosity factor was used for the conversion of a straight line to road distance. The tortuosity factor was derived from a study of Sultana and Kumar (2014) where they calculated the theoretical tortuosity factor (1.27), the tortuosity factors of twelve sites in Alberta, Canada (ranging from 1.28 to 1.42), and cited six studies with of which the average value was 1.34 (Leduc, Schmid, Obersteiner, & Riahi, 2009; Perlack & Turhollow, 2002; Sarkar & Kumar, 2010; Sultana, Kumar, & Harfield, 2010; Wright & Brown, 2007; Zhang, Johnson, & Sutherland, 2011). In this analysis a value of 1.35 was used.

The cost of delivering feedstocks from the fields to the pellet mills is taken as constant for all Oblasts.

The assumption is made that biomass is sourced within a 50 km radius; therefore the cost of transporting biomass to the pellet plant is taken as 50 km for all states. The transport of the states to an export port is calculated by taking the distance of the different counties within states to the different ports in Brazil. The average of all the counties is taken and the port that is located the nearest on average is selected.

Cost of transport of biomass from the ports in Brazil to ports in the Netherlands is calculated through a web-based sea freight calculator (Sea Freight Calculator, n.d.). To calculate the cost difference between the Netherlands and Austria and Italy, results from the BIT-UU model are used (Hoefnagels, Resch, Junginger, & Faaij, 2014). The BIT-UU model is a GIS-based biomass transport model with an intermodal network structure of road, rail, inland waterways, short sea shipping in Europe and ocean shipping. The model combines linear optimization of the allocation between supply and demand nodes with global input data on cost for transport of solid biomass. The BIT-UU model can optimize supply chains for least cost or GHG emissions. In this case, results from a cost-optimization are used as transport costs. Calculations of the transport cost from the US to the aforementioned three countries are used to understand the difference in cost between the Netherlands, Austria and Italy, resulting from additional road, rail and inland waterway transport required to the latter two countries.

## 4.7 Scenario Approach

All research questions will be assessed with a scenario and future outlook approach. One of the key aims of the BioTrade2020+ project is to investigate the future market and opportunities for sustainable lignocellulosic biomass feedstocks. This development is heavily dependent on technology, economy, and policies on e.g. climate, energy, agriculture and business. To be able to anticipate the possible trends and changes of costs and quantities of biomass trade and reflect market developments two scenarios were created for 2020 and 2030.

### *4.7.1 Business as usual scenario*

#### Agricultural and forestry feedstock production

Agricultural- and forestry production and consumption is considered to evolve at current pace, yield increases follow historic trends and current and proposed policies on, for example, agriculture and forestry, energy, infrastructure, and climate are considered. In the Brazilian agricultural outlook for 2020 (FIESP / ICONE, 2012) projections for a range of feedstocks on planted area, yield, and production volume are made on country level. According to the authors the projections indicate that the agri-business will follow the observed historical growth rates. For the BAU scenario the average annual growth rates for planted area and yields were calculated over the 1990-2012 period (the longest historical data set available on state level). Extrapolations from 2012 until 2030 were made with these growth rates. The agricultural yield is considered to be limited by the current yields in the US (Balasubramanian, Bell, & Sombilla, n.d.; Food and Agriculture Organization of the United Nations, 2013; United States Department of Agriculture, 2014) (bronnen van verschillende yields). Yields in the US are the highest in the world for many crops (Syngenta, 2014), and have been more or less stable for years.

Data on state level was obtained from the 'Banco de Dados Agregados' (Database of Aggregated Data) of IBGE. Within states, the average annual growth rates were considered to be equal in all micro-regions. Multiplying the projected yields in 2020 and 2030 with the projected planted area gave the production volumes of agricultural feedstocks and round wood for paper and cellulose, and for other purposes. Planted area is also projected according to historical rates. However, the total agricultural area is considered to be limited by the maximum area that is technically available for agriculture, as calculated with the PLUC model according to Verstegen et al. (2015). This means that in some states, such as Paraná, the total agricultural area remains the same, since any increase would exceed the suitable land availability.
From this step onwards, residue generation and the different potentials were calculated in the same way as has been explained for the current situation earlier in this chapter.

#### Local demand for feed, energy, and other uses

Competing demand for agricultural and forestry residues for feed, energy, and other uses is assumed to follow the historical trends (see table 13). This means that bagasse, increasingly utilized in the last decade and currently for 90% co-fired, will not be available anymore in 2020 and 2030. Even though the production of sugarcane is considered to increase, the domestic utilization of bagasse is considered to at least match this growth rate. Sugarcane tops and straw are investigated for production of second generation bio-ethanol, of which the first plants have started production in Brazil. However, the technology still has to mature and for 2020 no widespread application is foreseen. From 2021 onwards second generation bio-ethanol is expected to be economically viable (Valor Econômico, 2015). Some sugarcane mills are going to incorporate sugarcane straw in the firing of bagasse to produce additional electricity (Assumpção, 2015). In 2030 it is assumed 50% of tops and straw is used for second generation ethanol and co-firing.

**Table 14 - Local demand for agricultural residues in 2020/2030 and in BAU/High Export**

| Feedstock | Type of residue | 2020 BAU | 2020 Optimistic | 2030 BAU | 2030 Optimistic |
|---|---|---|---|---|---|
| Sugarcane | Bagasse | 100% | 90% | 100% | 90% |
| | Tops/straw | 0% | 0% | 50% | 25% |
| Soybeans | Straw | 10% | 0% | 30% | 0% |
| Corn | Stover | 60% | 50% | 60% | 30% |
| Rice | Straw | 0% | 0% | 0% | 0% |
| | Husk | 85% | 67% | 100% | 67% |

Soybean straw is an excellent source of cattle feed with a high nutritional value (Da Silva & Chandel, 2014). Currently it is not utilized in Brazil, but considering the large expansion of soybean cultivation and the big cattle industry in Brazil, with the largest commercial herd in the world (FAOSTAT, 2015), it is assumed to be utilized for 10% in 2020 and 30% in 2030. Corn stover is traditionally widely used as a source of cattle feed, despite its low nutritional value (Da Silva & Chandel, 2014). It is assumed to remain the same utilization rate as in the current situation: 60%. Rice straw is assumed to remain unused for 2020 and 2030. Rice is largely produced in specific locations in Santa Catarina and Rio Grande do Sul, states where no large cattle industry is and no straw demand for fodder (Millen, Pacheco, Meyer, Rodrigues, & De Beni Arrigoni, 2011). For electricity generation and drying rice husks are used on a large scale, they are easier accessible (rice is de-husked at the mill, no extra transport needed). For 2020 husks are assumed to be increasingly used at the rice mill (50%) and at the same rate as in 2012 for chicken bedding (35%). In 2030 60% of rice husks are expected to be utilized at the mill, and 35% for chicken bedding, totalling 100%.

**Table 15 - Local demand for forestry residues in 2020/2030 and in BAU/optimistic scenario**

| Feedstock | Type of residue | 2020 BAU | 2020 Optimistic | 2030 BAU | 2030 Optimistic |
|---|---|---|---|---|---|
| Eucalyptus & pine | Field | 0/5/10/15% | 0/5% | 0/25/40% | 0/10/15/25% |
| | Paper and cellulose production | 75% | 70% | 85% | 70% |
| | Lumber processing | 75% | 70% | 85% | 70% |

Eucalyptus residues are not economically harvestable and thus 100% left in the field (Negredo Junior, 2015), also for the 2020 and 2030 BAU scenario (see table 14). Pine residues however, generate more residues compared to eucalyptus and are economically harvestable, although this currently happens on a very small scale (only paper and cellulose producer Klabin does it)(Negredo Junior, 2015). Bahia, Espírito Santo, and Minas Gerais have a share of less than 3.5% pine in their planted forests, and thus it is assumed there is no local demand in 2020 and 2030. São Paulo has about 12% pine plantations and field residue harvesting is estimated at 5% in 2020 and 15% in 2030. Rio Grande do Sul has 37% pine plantations and estimated field residue harvesting is 10% in 2020 and 25% in 2030. Paraná and Santa Catarina both have more than 75% pine plantations and the field residue utilization rate is estimated at 15% in 2020 and 40% in 2030. Brazilian paper and cellulose producing giants Klabin (2015) and Fibria (2013) both aim to increase their re-use of generated residues in the future. Paper and cellulose production residues and lumber production residues are assumed to follow historical trends and increase from 70% utilization in 2012 to 75% in 2020 and 85% in 2030.

#### *Wood pellet production capacity*

The Business As Usual growth rate of pellet plant capacity in Brazil over the past years is unknown. In the Business As Usual scenario the assumption is made that the pellet plant capacity will increase according to the estimated expansion of world pellet capacity, which is 14.1% per year between 2015 and 2023 according to a report published by Transparency Market Research (KMEC Engineering, n.d.). It is assumed that this growth rate will continue until 2030, by lack of estimates about this period.

The currently existing pellet plant capacity is suitable for forestry biomass pellets, in order to convert agricultural residues in to pellets, new dedicated pellet plants need to be built. Agricultural pellets have some drawbacks compared to forest pellets, such as lower energy content and higher sulfur, nitrogin and clorine content (Visaspace, 2011). It is assumed that until 2020 any pellet plant capacity is for use with woody biomass only. In 2030, 30% of the additional capacity will be for agricultural biomass and 70% for woody biomass.

### *4.7.2 Optimistic scenario*

#### Agricultural and forestry feedstock production

In the optimistic scenario it is assumed that planted area and yields of agricultural crops and forestry increase faster compared to the BAU scenario. This could be realized by converting pastures into cropland at a higher rate, improved farming practices, technological developments, and/or more stringent policies on, for example, agriculture and forestry, energy, infrastructure, and climate. Outlooks from the Brazilian institutions FIESP, ICONE, the Ministry of Agriculture, Livestock, and Supply and the Presidential Secretariat of Strategic Affairs (FIESP, 2014; Lima et al., 2012; Ministério da Agricultura, 2014; F. C. Neto, Prado, & Pereira, 2014) give projections for the 2012-2022 period, the higher growth estimates of this outlook are linked to the BAU extrapolations.

#### Local demand for feed, energy, and other uses

In the optimistic scenario, local demand for agricultural and forestry is considered lower than in the BAU scenario. In this way, more residues are available for pellet production for export to the EU. The optimistic utilization rates are listed in table 13 for agricultural residues and in table 14 for forestry residues. Sugarcane bagasse is assumed to continue at the same rate as in the current situation: 90%

in 2020 and 2030. Sugarcane straw utilization for second generation bio-ethanol and co-firing is assumed to develop at a slower rate compared to the BAU: 0% in 2020 and 25% in 2030. This might seem counter-intuitive; it must be kept in mind that in this case study the optimistic scenario reflects a scenario which is optimistic for the export of residues. Therefore this scenario represents lower domestic utilization of residues. Soybean straw is assumed to remain unused in 2020 and 2030. Corn stover is expected to slowly be replaced by other cattle feed sources with higher nutritional values, such as citrus pellets. In 2020 50% is utilized and in 2030 30%. Rice straw remained unused in the 2020 BAU scenario, and thus in the optimistic scenario as well. Rice husk demand for chicken bedding is assumed to decrease, since rice production is estimated to grow faster in the period until 2030 compared to the chicken industry (FAOSTAT, 2015). However, it is uncertain if rice husks are the only source of chicken bedding for chicken farmers. Therefore, a decrease of utilization is considered in the optimistic scenario, and not in the BAU scenario.
Similar to agricultural residues, the optimistic scenario expects less demand for forestry residues, in order to have a larger availability for pellet production for export to the EU. As explained in the BAU scenario, Bahia, Minas Gerais, and Espírito Santo have no field residue utilization, this remains the same in the 2020 and 2030 optimistic scenario. In 2020 São Paulo also has 0% utilization, due to the low share of pine plantations, and 10% in 2030. Paraná and Santa Catarina have an estimated rate of 5% in 2020 and 25% in 2030. For Rio Grande do Sul this is 5% in 2020 and 15% in 2030.

### Wood pellet production capacity

In order to estimate possible optimistic development of pellet plant capacity in Brazil, the situations is compared to that in the South-East of the US. The pellet market in this region is the most developed in the world and has experienced an impressive increase in the last decade (Southern Environmental Law Center, 2015). These optimistic assumptions are used in the High Export scenario. Mimicking the US growth rate is considered realistic considering it is based on actual realized growth rates, but optimistic considering the more favorable conditions in the US compared to Brazil in terms of investment attractiveness. In order to compare the two countries, the current capacity is compared. The capacity in Brazil is almost similar to the capacity in the US in 2007. Between 2007 and 2015, the capacity in the US grew steadily, with an average growth rate of 27.4% per year (Southern Environmental Law Center, 2015).

In the High Export scenario the capacity is assumed to grow with the same growth rate in the US between 2007 and 2015, it is assumed that capacity will grow linearly with 27.4% a year. In the Business As Usual scenario it is assumed that pellet plant productivity will grow linearly according to the estimated expansion of world pellet capacity, which is 14.1% per year. Aside from the existing pellet plant capacity, the assumption is made that pellet plant capacity will be evenly spread over the different states in the case-study region.

Just as with the BAU scenario it is assumed that until 2020 any pellet plant capacity is for use with woody biomass only. In 2030, 30% of the additional capacity will be for agricultural biomass and 70% for woody biomass.

Next to the sharper increase in production capacity, also the infrastructure connecting pellet plants with ports will increase in the High Export scenario. The quality and development of infrastructure, especially railroad transport is assumed to improve drastically. More regions will be connected to fast and cheap transport options, and truck transport is not the only transport mode anymore. In 2030 in the High Export scenario rail transport is assumed to account for 50% of the transport of pellets from plants to ports. It is assumed that train transport is 30% cheaper than truck transport (The Brazil Business, 2012).

# 5. Results

## 5.1 Selection of Focus Region and Feedstocks

### *5.1.1 Agricultural production*

Table 15 below shows the agricultural and forestry production in 2012 of the largest feedstocks. Combined with the residue to product ratios that were showed earlier, the largest feedstocks in terms of residue production are selected.

**Table 16 - Agricultural and forestry sector Brazil 2012, highlighted in green the feedstocks chosen to investigate in this research (IBGE, 2012; IBÁ, 2014; Couto, Nicholas, & Wright, 2011; Escobar, 2014; FAO, 1999; Ryan, 2008)**

| Agricultural feedstocks | Planted area ($ha*10^3$) | Yield average (t/ha) | Productio n (kt) | Forestry feedstocks | Planted area ($ha*10^3$) | Yield average (t/ha) | Production (kt) |
|---|---|---|---|---|---|---|---|
| Sugarcane | 9,752 | 74 | 721,077 | Eucalyptus | 5,304 | 19.05 | 101,041 |
| Corn | 15,065 | 5 | 71,073 | Pine | 1,563 | 20.88 | 32,635 |
| Soybean | 25,091 | 3 | 65,849 | Rubber tree | 169 | - | - |
| Cassava | 1,758 | 14 | 23,045 | Acacia | 148 | - | - |
| Oranges | 763 | 25 | 18,013 | Parica | 87 | - | - |
| Rice | 2,443 | 5 | 11,550 | | | | |
| Banana | 490 | 14 | 6,902 | | | | |
| Cotton | 1,420 | 4 | 4,969 | | | | |
| Wheat | 1,942 | 2 | 4,418 | | | | |
| Tomato | 65 | 61 | 3,874 | | | | |
| Potato | 136 | 27 | 3,732 | | | | |
| Coffee | 2,123 | 1 | 3,038 | | | | |
| Beans | 3,183 | 1 | 2,795 | | | | |
| Watermelon | 97 | 22 | 2,080 | | | | |
| Sorghum | 728 | 3 | 2,017 | | | | |
| Coconut | 260 | 8 | 1,954 | | | | |

Agricultural production is highly concentrated in in Brazil, as can be seen in the figure below (figure 11). The ten states with an agricultural share higher than 2% are considered to meet the criteria of significant agricultural production

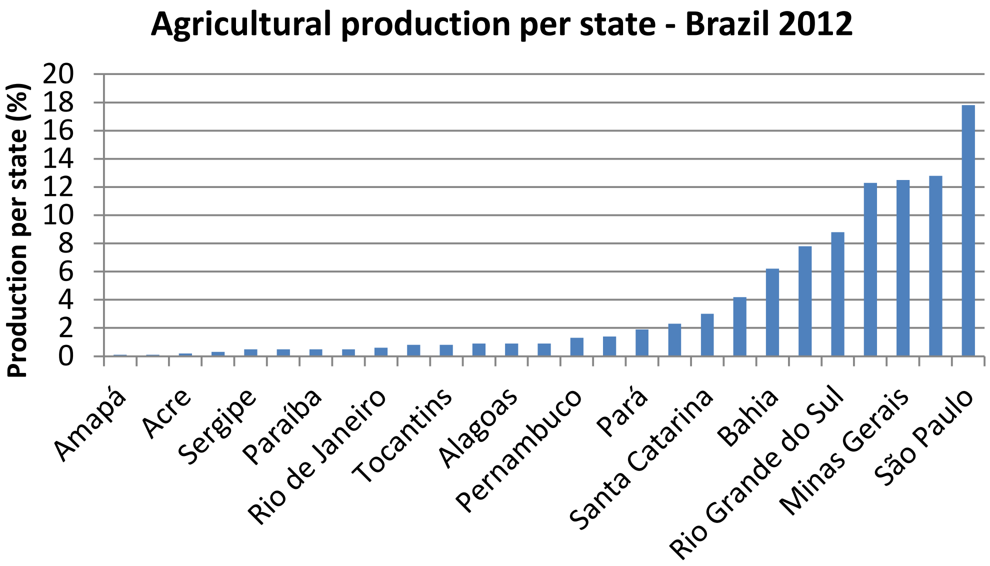


Figure 10 - Agricultural production per state (IBGE, 2012)

Considering the next criteria, presence and quality of infrastructure and distance to export harbours, three states are excluded: Goiás, Mato Grosso and Mato Grosso do Sul. From the easternmost area of Goiás to the nearest export port (as reached by truck), the distance exceeds 750 km, from the easternmost area of Grosso do Sul this exceeds 700 km and Mato Grosso is located even more inland. These distances are considered too large to allow for cost effective transport of residues or pellets towards the export ports.

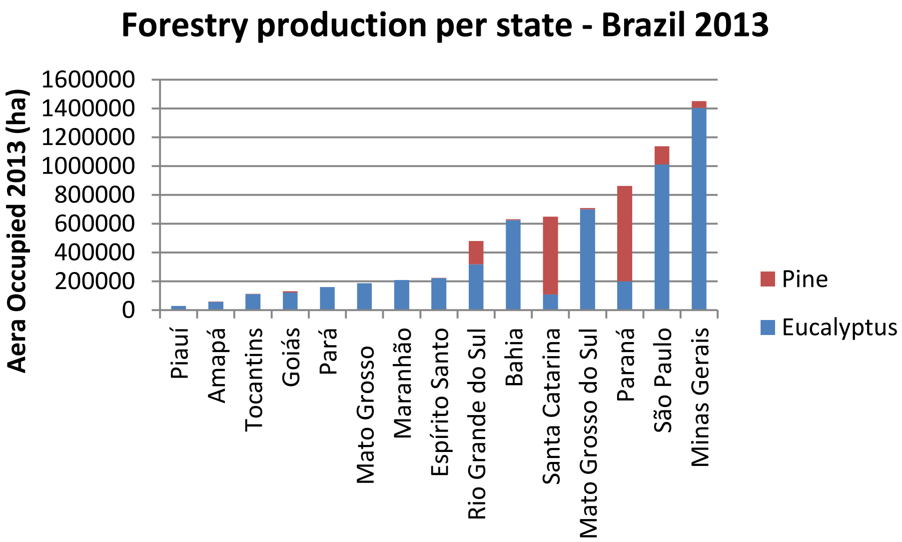


Figure 11 - Forest plantation area occupied 2013 (IBÁ, 2014a)

### *5.1.2 Sustainability*

The expansion of agricultural practices, while at the same time preserving natural resources, is a concern to the Brazilian Government. In 2009 an initiative was launched by the government to restrict the expansion of sugarcane production to “areas that are agronomically, climatically and environmentally suitable” ((Brazilian Government, n.d.; SugarCane, 2016). The three rules as established in this initiative are: No expansion of sugarcane in sensitive ecosystems, no clearance of native plants and the identification of suitable areas (SugarCane, 2016). The below figure (Figure 13) shows the suitable areas for sugarcane production, as well as the sensitive ecosystems that should be protected against increased production of sugarcane. This zoning approach is assumed to apply to all forms of agricultural practices, and therefore the identified protected areas should be excluded from the case study selection. As can be seen, none of the remaining Brazilian states include areas that fall within the sensitive ecosystems area, therefore all remaining states are considered to meet this criterion.

Figure 12 - Suitable areas for sugarcane expansion (SugarCane, 2016)

### *5.1.3 Production cost*
Since the collected data about the production cost is based on national averages, there is no basis to exclude states based on production cost of biomass pellets.

### *5.1.4 Selected states*
Based on the four selection criteria included, seven states were selected and included in the analysis: Espírito Santo, Santa Catarina, Bahia, Rio Grande do Sul, Paraná, Minas Gerais and São Paulo.

Table 17 – Evaluation of Brazilian states based on four selection criteria

| Criteria | Production | Logistics | Sustainability | Production cost |
|---|---|---|---|---|
| Espírito Santo | ✓ | ✓ | ✓ | ✓ |
| Santa Catarina | ✓ | ✓ | ✓ | ✓ |
| Mato Grosso do Sul | ✓ | | | |
| Bahia | ✓ | ✓ | ✓ | ✓ |
| Goiás | ✓ | | | |
| Rio Grande do Sul | ✓ | ✓ | ✓ | ✓ |
| Paraná | ✓ | ✓ | ✓ | ✓ |
| Minas Gerais | ✓ | ✓ | ✓ | ✓ |
| Mato Grosso | ✓ | | | |
| São Paulo | ✓ | ✓ | ✓ | ✓ |

The agricultural production of the included states represents about 70% of the total agricultural production in Brazil. Production mainly takes place in São Paulo, and to lesser extent Minas Gerais and Paraná.

Table 18 - Agricultural feedstock production in selected Brazilian states 2012 (IBGE, 2012)

| Agricultural feedstocks (kt) | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul | % total Brazil |
|---|---|---|---|---|---|---|---|---|
| Sugarcane | 6,894 | 4,651 | 70,521 | 406,153 | 47,941 | 499 | 982 | 74.6% |
| Soybean | 3,213 | 0 | 3,073 | 1,567 | 10,938 | 1,080 | 5,945 | 36.4% |
| Corn | 1,883 | 77 | 7,625 | 4,479 | 16,555 | 2,870 | 3,155 | 55.6% |
| Cassava | 2,201 | 207 | 824 | 1,355 | 3,869 | 530 | 1,191 | 44.2% |
| Rice | 24 | 3 | 62 | 121 | 178 | 1,097 | 7,692 | 79.5% |
| Coffee | 142 | 772 | 1,594 | 275 | 105 | 0 | 0 | 95.1% |
| Oranges | 1,037 | 16 | 865 | 13,366 | 913 | 63 | 362 | 92.3% |
| **Total** | **15,394** | **5,726** | **84,565** | **427,322** | **80,499** | **6,139** | **19,327** | **69.9%** |

### *5.1.5 Forestry production*

Forestry production seems to be concentrated in the same states as agricultural production, as can be seen in figure 14 below which shows the location of planted forest clusters and lumber producers. These are considered important since only planted forest clusters will be included for the harvest of field residues, and lumber producers are an important source of process residues.

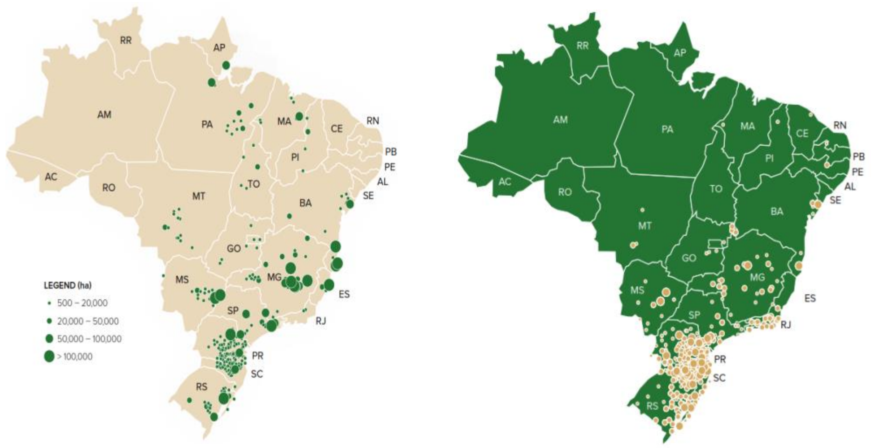


Figure 13 - Planted forest clusters (left) and lumber producers (right) (IBÁ, 2014a)

Table 18 differentiates for each pre-selected state the area of eucalyptus and pine plantations, roundwood production for either paper and pulp or other purposes (mostly lumber), and firewood and charcoal production. In most states the area of eucalyptus plantation is bigger than the area of pine location. The states Paraná and Santa Catarina area exceptions, the fact that the majority of pine production and of lumber producers are located in these states indicates that pine is the main source of lumber. Eucalyptus wood on the other hand is the main source of paper and cellulose production.

In Minas Gerais, the state with the largest planted area of eucalyptus and pine combined, the amount of charcoal produced stands out in comparison with the other states. Charcoal is an important source of thermal energy for the pig iron industry, and Minas Gerais produces 60% of the pig iron produced in Brazil (Nogueira, Teixeira, & Uhlig, 2009). Hence, large amounts of planted forest wood in Minas Gerais are converted into charcoal.

Table 19 - Forest plantation production statistics (IBÁ, 2014a; IBGE, 2015b) – converted to planted volume using a ratio 375 $kg/m^2$ (Pereira et al., 2012).

| **Forestry products** | **Bahia** | **Espírito Santo** | **Minas Gerais** | **São Paulo** | **Paraná** | **Santa Catarina** | **Rio Grande do Sul** | **Total** |
|---|---|---|---|---|---|---|---|---|
| Eucalyptus (ha) | 605,464 | 203,349 | 1,438,971 | 1,041,695 | 197,835 | 106,588 | 284,701 | 3,878,603 |
| Pine (ha) | 11,230 | 2,546 | 52,710 | 144,802 | 619,731 | 539,377 | 164,832 | 1,525,228 |
| Roundwood ($m^3*10^3$) | 15,021 | 5,351 | 13,990 | 31,068 | 29,054 | 19,488 | 7,928 | 121,900 |
| *For paper & cellulose* | 14,692 | 5,066 | 5,884 | 19,167 | 9,862 | 9,839 | 2,652 | 67,162 |
| *For other purposes* | 329 | 285 | 8,106 | 11,901 | 19,192 | 9,649 | 5,276 | 54,738 |
| Firewood ($m^3*10^3$) | 1,026 | 187 | 7,034 | 7,060 | 13,924 | 8,322 | 14,510 | 52,036 |
| Charcoal ($m^3*10^3$) | 416 | 88 | 11,891 | 211 | 76 | 24 | 133 | 12,829 |

It has to be noted that there is a discrepancy between the planted forest area in 2012 and the produced volumes of Roundwood, firewood, and charcoal in 2012. Because of the rotation period of 7 years for eucalyptus and 15-16 years for pine, there is a delay in the effect of an increase in the planted area on the production volume of wood. This discrepancy is especially noticeable for Minas Gerais and São Paulo, where the largest expansion of eucalyptus plantations has taken place in the last six years. The area of pine plantations has been stable or slightly declining in all the states (IBÁ, 2014a).

#### *5.1.5 Infrastructure*

This region in the southeast and south, where agricultural and forestry production is concentrated, is also characterised by a concentration of population and financial resources. This is also the region of Brazil with the most advanced and well developed road networks. Every selected state, except the landlocked Minas Gerais, has direct sea access and is equipped with at least one large international export harbour: the port of Salvador (Bahia), Rio de Janeiro (Rio de Janeiro), Vitória (Espírito Santo), Santos (São Paulo), Paranaguá (Paraná), Itajaí (Santa Catarina), and Rio Grande (Rio Grande do Sul) (World Port Service, 2015).

Wood pellet manufacturers are mainly located in São Paulo and Paraná, close to the source of raw biomass used for the pellets, which is for most factories pine residues (ABIPEL, 2015b).

The combination of criteria such as agricultural and forestry production volumes, presence and quality of road-, and port infrastructure indicates that this cluster of states in southeast and south Brazil has the highest potential of supplying large volumes of sustainable lignocellulosic biomass residues to the EU. Therefore the seven states Bahia, Espírito Santo, Minas Gerais, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul are selected as case study region.

## 5.2 Technical Potential of Lignocellulosic Biomass Residues

#### *5.2.1 Agricultural residues*

The seven selected feedstocks produced a total technical potential of 216 MT agricultural residues (3556 PJ) in 2012, São Paulo accounting for 47% of the production with 102 MT. 91% of the total residue production in São Paulo comes from sugarcane bagasse and tops/straw. Other states have more balanced production levels. Paraná (44 MT, 21%) produces most of it residues from corn, soybeans, and sugarcane. Minas Gerais (29 MT, 13%) mainly produces from sugarcane and corn. Rio Grande do Sul (23 MT, 11%) from rice and soybeans. Bahia, Santa Catarina, and Espírito Santo have less significant levels of residue production. Table 19 shows residue production volumes per state per feedstock and per residue type, as well as the total energetic potential of residues in each state.

Table 20 - Technical potential agricultural residues 2012 (dry matter)

| Feedstock | Type of residue | RPR | LHV (MJ/kg) | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|---|---|
| Sugarcane | Bagasse | 0.30 | 17.71 | 1.03 | 0.70 | 10.58 | 60.92 | 7.19 | 0.07 | 0.15 |
| | Tops/straw | 0.34 | 17.38 | 0.55 | 0.37 | 5.61 | 32.31 | 3.81 | 0.04 | 0.08 |
| Soybeans | Straw | 1.40 | 12.38 | 3.82 | 0.00 | 3.66 | 1.86 | 13.02 | 1.28 | 7.07 |
| Corn | Stalk | 0.78 | 17.45 | 1.25 | 0.05 | 5.06 | 2.97 | 10.98 | 1.90 | 2.09 |
| | Cob | 0.22 | 16.28 | 0.38 | 0.02 | 1.55 | 0.91 | 3.37 | 0.58 | 0.64 |
| | Husk | 0.20 | 12.00 | 0.33 | 0.01 | 1.36 | 0.80 | 2.94 | 0.51 | 0.56 |
| Cassava | Straw | 0.80 | 17.50 | 1.59 | 0.15 | 0.60 | 0.98 | 2.80 | 0.38 | 0.86 |
| Rice | Straw | 1.48 | 16.02 | 0.03 | 0.00 | 0.08 | 0.16 | 0.23 | 1.42 | 9.94 |
| | Husk | 0.22 | 14.17 | 0.01 | 0.00 | 0.01 | 0.03 | 0.04 | 0.24 | 1.65 |
| Coffee | Husk | 0.21 | 17.71 | 0.03 | 0.15 | 0.30 | 0.05 | 0.02 | 0.00 | 0.00 |
| Oranges | Peel | 0.50 | 17.11 | 0.09 | 0.00 | 0.08 | 1.20 | 0.08 | 0.01 | 0.03 |
| | | | **Total Mt** | **9.12** | **1.45** | **28.88** | **102.19** | **44.48** | **6.44** | **23.08** |
| | | | **Potential PJ** | **138** | **25** | **478** | **1781** | **691** | **100** | **343** |

Sugarcane residues make up 57% (123 MT) of the total residue production, of which São Paulo has the biggest share with 76% (93 MT). The second largest volume of residues is produced by corn stalks, cobs, and husks (18%), followed by soybean straw (14%). The other feedstock residues only make up 11% of the technical potential (see figure 15). 46% of the residues (99 MT) is not a field residue, but a processing residue: sugarcane bagasse is the product of sugarcane crushing in a sugarcane mill (see figure 16), corn cob and husk are removed at the corn processing plant, and the same applies to rice husk and coffee husk.

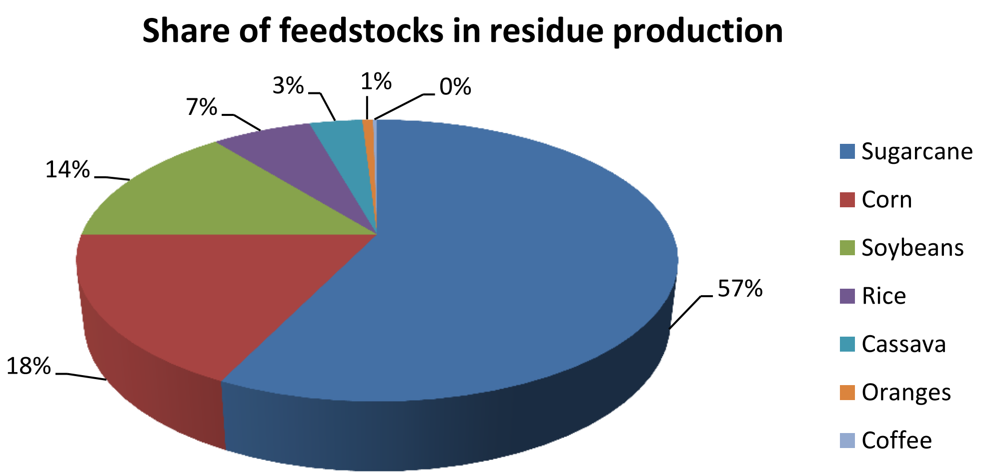


Figure 14 - Share of feedstocks in technical potentials agricultural residues production

Figure 17 zooms in to a more detailed administrative level, the micro-region level (a collection of municipalities), makes clear that within states there is a distinct spatial pattern of residue production. In every state, except Espírito Santo, the production of agricultural residues is concentrated in the west, furthest away from the Atlantic Ocean. An explanation could be that inland there is more land available for agriculture, since the largest built agglomerations are located near the coast. Another could be the better climate and weather conditions, and soil fertility. Most of the high residue volume producing micro-regions have sugarcane as their number one cultivated feedstock.

São Paulo and Paraná, the states with the highest production volume, have a well-developed railroad network connecting the hinterland with the big cities and international harbours. Pellet factories do concentrate in São Paulo and Paraná, but do not seem to be located specifically in or near micro-region with large production volumes of agricultural residues. This can be explained by the fact the vast majority of existing pellet producing factories use pine residues as raw material and thus not agricultural residues. Pellet factories are, however, specifically located at or near railroad lines.

Figure 15 - Sugarcane bagasse stored at the Santa Lucia mill in Araras, São Paulo

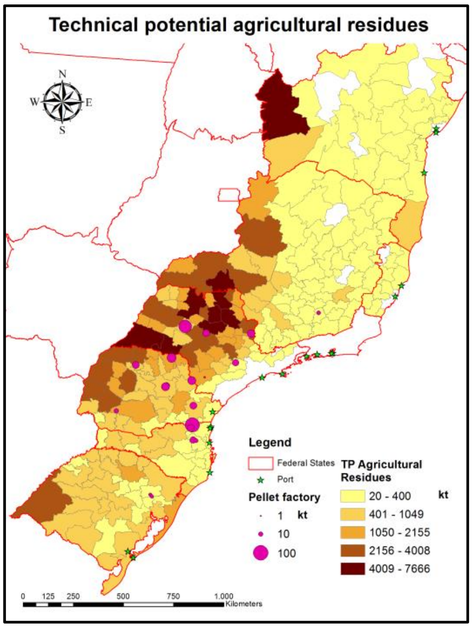


Figure 16 - Spatial explicit map of technical potential of agricultural residues

### *5.2.2 Forestry residues*

The seven selected feedstocks produced a total technical potential of 16 MT forestry residues (295 PJ) in 2012, with Paraná (4.76 MT), São Paulo (3.47 MT), and Santa Catarina (2.99 MT) as the main contributors (see table 20). Compared to agricultural residue production, this is a factor 13.5 and 12 less in terms of volume and energetic content respectively. 83% of the residues are processing residues; they are generated in the paper and cellulose industry and lumber production (sawmills, wood panel and furniture manufacturers). These residues consist of sawdust, bark, chips, knots, and shavings. Only 17% are field residues on pine and eucalyptus plantations, consisting of bark, tops, needles, and small branches.

**Table 21 - Technical potential forestry residues (dry matter)**

| Feedstock | Type of residue | RPR | LHV (MJ/kg) | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|---|---|
| Eucalyptus & Pine | Field | 0.15 | 19.05 | 0.63 | 0.22 | 0.59 | 1.26 | 1.42 | 1.00 | 0.36 |
| | Paper & cellulose | 0.117 | 18.18 | 0.58 | 0.20 | 0.23 | 0.73 | 0.45 | 0.47 | 0.11 |
| | Processing | 0.382 | 18.18 | 0.04 | 0.04 | 1.05 | 1.49 | 2.88 | 1.51 | 0.73 |
| | | | **Total Mt** | **1.25** | **0.46** | **1.87** | **3.47** | **4.76** | **2.99** | **1.20** |
| | | | **Potential PJ** | **23** | **8** | **34** | **63** | **89** | **56** | **22** |

Note that the RPR of field residues is applied to the volume of roundwood production for paper and cellulose, and to the volume of roundwood for processing purposes. The RPR for paper and cellulose only applies to the volume of roundwood production for paper and cellulose, and the RPR for processing only to the volume of roundwood production for processing purposes.

Pine and eucalyptus plantations are much less common in most micro-region than most types of agricultural feedstocks. This results in a more sparsely distribution of forestry residue production (see figure 14). As opposed to agricultural residues, forestry residues are mostly generated in the centre of states (Minas Gerais, São Paulo, Paraná, and Santa Catarina) or in the east at the coast (Bahia, Espírito Santo, and Rio Grande do Sul). The majority of pellet factories are situated within or next to a micro-region with large production volumes of forestry residues, which coincides with the fact that pine residues are the main source of raw material of wood pellet manufacturers in Brazil. Some factories with small pellet production capacities seem to be located in a micro-region without forestry residue production, but this is because micro-regions with a lower residue production than 20 kt are left out of this map to create a more distinct overview where large volumes of residues are located.

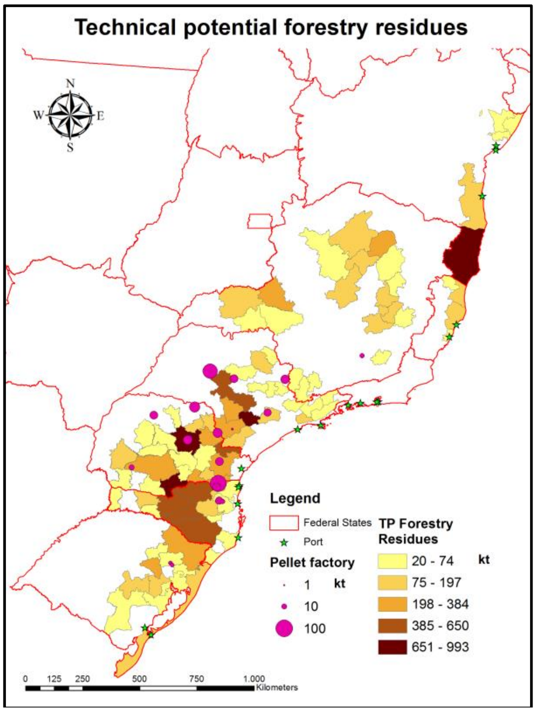


Figure 17 - Spatial explicit map of technical potential of forestry residues

## 5.3 Sustainable potential of Lignocellulosic Biomass Residues

### *5.3.1 Agricultural residues*

Growing crops on a field withdraws valuable nutrients and organic matter from the soil that are used by the crop to grow. These nutrients are often complemented with fertilizer, either natural or artificial. Without re-applying nutrients and organic matter to the soil after each harvest the nutrient stocks in soils will decline. This has a negative impact on agricultural yields and thus production volumes (Cherubini & Ulgiati, 2010; Lindstrom, 1986). When so many nutrients and organic matter are taken away from the soil, so that the biological threshold for biomass recovery is surpassed, the field could even become degraded (Nogueira et al., 2000). Therefore, it is necessary to leave part of the generated agricultural residues on the field after harvest (see Figure 19). This organic material decays over time and gives back nutrients to the soil. If residues are completely removed off the field after harvest nutrients need to be re-stocked by fertilizer (Andrews, 2006), which is often expensive. Leaving residues on the field also protects the soil from water and wind erosion, a problem that especially occurs on fields with an inclination. Increased soil erosion and runoff decreases nutrients and organic matter in the soil. This protection provided by residues cannot be replaced by using additional fertilizer, since fertilizer a retaining characteristic, it does not have much volume compared to residues and is quickly taken up by the soil, whereas residues lie on top of the soil and slowly decay. Residues covering the field can also reduce evaporation from the surface, conserving moisture and increasing the resilience against droughts (Andrews, 2006; Lindstrom, 1986), which occur often in the researched area in Brazil. A positive effect of residue removal is the killing of deleterious bacteria, protecting the crops from pests (Assumpção, 2015; Mandal et al., 2004).

**Figure 18 - Piled and dried sugarcane tops and straw left in field for nutrients, organic matter, and soil erosion protection. Araras, São Paolo**

Thus, residues cannot be completely removed from the field, because they offer irreplaceable environmental services. However, part of the residues can sustainably be removed (see Table 21). The total sustainable potential of agricultural residues declines from 216 MT (technical potential) to 130 MT (2229 PJ), meaning that 86 MT residues have to be left on the field. The share of sugarcane residues increases to 78%, because the single largest residue type in terms of production volume, bagasse, can be fully recovered due to it being a process residue. The other sugarcane residue, tops and straw produced in the field, have a relatively high SRF (40%) compared to the other crops. Sugarcane has large yields/ha compared to crops such as soybeans and corn: an average in the seven investigated states of 77.8 t/ha, 2.2 t/ha, and 5.2 t/ha respectively. This means a higher residue yield/ha and a relatively lower volume of residues that have to be left on the field for especially soil erosion protection. Residue cover for soil erosion protection is dependent on soil cover percentage. A larger residue yield means relatively less residues needed to cover the surface, and thus a larger sustainable recovery factor. São Paulo remains the largest producer with 81 MT (62%), followed by Paraná (19 MT, 14%) and Minas Gerais (17MT, 13%).

Table 22 - Sustainable potential agricultural residues (dry matter)

| Feedstock | Type of residue | SRF | LHV (MJ/kg) | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|---|---|
| Sugarcane | Bagasse | 1 | 17.71 | 1.03 | 0.70 | 10.58 | 60.92 | 7.19 | 0.07 | 0.15 |
| | Tops/straw | 0.40 | 17.38 | 0.27 | 0.19 | 2.81 | 16.16 | 1.91 | 0.02 | 0.04 |
| Soybeans | Straw | 0.25 | 12.38 | 0.96 | 0.00 | 0.91 | 0.47 | 3.25 | 0.32 | 1.77 |
| Corn | Stalk | 0.30 | 17.45 | 0.37 | 0.02 | 1.52 | 0.89 | 3.29 | 0.57 | 0.63 |
| | Cob | 0.30 | 16.28 | 0.11 | 0.00 | 0.47 | 0.27 | 1.01 | 0.18 | 0.19 |
| | Husk | 0.30 | 12.00 | 0.10 | 0.00 | 0.41 | 0.24 | 0.88 | 0.15 | 0.17 |
| Cassava | Straw | 0.30 | 17.50 | 0.48 | 0.04 | 0.18 | 0.29 | 0.84 | 0.11 | 0.26 |
| Rice | Straw | 0.25 | 16.02 | 0.01 | 0.00 | 0.02 | 0.04 | 0.06 | 0.35 | 2.48 |
| | Husk | 1 | 14.17 | 0.01 | 0.00 | 0.01 | 0.03 | 0.04 | 0.24 | 1.65 |
| Coffee | Husk | 1 | 17.71 | 0.03 | 0.15 | 0.30 | 0.05 | 0.02 | 0.00 | 0.00 |
| Oranges | Peel | 1 | 17.11 | 0.09 | 0.00 | 0.08 | 1.20 | 0.08 | 0.01 | 0.03 |
| | | | **Total Mt** | **3.34** | **1.10** | **17.28** | **80.56** | **18.58** | **2.03** | **7.37** |
| | | | **Potential PJ** | **53** | **19** | **297** | **1416** | **303** | **31** | **110** |

### *5.3.2 Forestry residues*

For forestry residues the same arguments apply to leave part of the residues in the field after harvest. According to Negredo Junior (2015) from Klabin, the biggest paper and cellulose producer and exporter of Brazil, most small scale eucalyptus and pine plantation holders leave 100% of the residues in the field. Partly because of the aforementioned sustainability reasons, but also because harvesting the residues is not economically interesting. Klabin does harvest part of the field residues, 40 t/ha, although they could not give a percentage of residues that is left on the field. The European Biomass Association (AEBIOM, 2007) calculated that 52.5% of the forest plantation field residues can sustainably be removed. Residues generated during paper and cellulose production and processing of roundwood can completely be sustainably utilized?

The forestry residues only decline from 16 MT technical potential to 14 MT (249 PJ) sustainable potential. Only field residues cannot be fully harvested and they are also the smallest type of residue generated. The proportions of residue production per state remain the same: Paraná produces 4 MT (30%), São Paulo 3 MT (22%), Santa Catarina 2.5 MT (18%), followed by the other states with smaller volumes (see table 22).

**Table 23 - Sustainable potential forestry residues (dry matter)**

| Feedstock | Type of residue | SRF | LHV (MJ/kg) | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|---|---|
| Eucalyptus & Pine | Field | 0.525 | 19.05 | 0.36 | 0.13 | 0.34 | 0.73 | 0.82 | 0.56 | 0.21 |
| | Paper & cellulose | 1 | 18.18 | 0.58 | 0.20 | 0.23 | 0.73 | 0.45 | 0.46 | 0.11 |
| | Processing | 1 | 18.18 | 0.04 | 0.04 | 1.05 | 1.49 | 2.88 | 1.47 | 0.73 |
| | | | **Total Mt** | **0.98** | **0.37** | **1.62** | **2.94** | **4.15** | **2.48** | **1.05** |
| | | | **Potential PJ** | **18** | **7** | **29** | **53** | **77** | **46** | **19** |

Figure 19 - Top left to bottom left: Field after wood harvest, piled up forestry residues, residues left in the field, chipping of field residues, Telêmarco Borba, Paraná

## 5.4 Local demand for Energy, Feed, and Other Uses

Various types of agricultural and forestry residues already have a local use in Brazil. If this is a sustainable use it is not desirable to take the residues off the Brazilian market and export them to the EU. Therefore, in the Biotrade2020+ methodology, priority to local demand of residues for energy, feed, and other uses is given. Subtracting the sustainable potential with the local demand will result in the net sustainable residue surplus potential.

### *5.4.1 Agricultural residues*

Table 23 lists all the various local uses of agricultural residue types in Brazil, as obtained from literature study and interviews. The majority of the residues have, completely or partially, a sustainable use in Brazil. Agricultural residues are not a source of human food, so using them for pellet production does not interfere directly with human food supply and security (Smeets et al., 2004). Indirectly it could interfere, since agricultural residues like corn stover and cassava straw are used for cattle feed, which is a source of food for humans. However, it is assumed there are enough alternatives for cattle feed, and thus human food security is not jeopardized.

**Table 24 - Domestic demand of agricultural residues in 2012**

| Feedstock | Type of residue | Fuel and energy | Cattle feed | Other uses | Total |
|---|---|---|---|---|---|
| Sugarcane | Bagasse | 90% is co-fired in boilers at sugarcane mill[1,2,3,4] | No use | No use | 90% |
| | Tops/straw | No use | No use | No use | 0% |
| Soybeans | Straw | No use | No use | No use | 0% |
| Corn | Stover | No use | 60%[5] | No use | 60% |
| Cassava | Straw | No use | 90%[3] | 10% for starch and substrate for microbial processes[3] | 100% |
| Rice | Straw | No use | No use | No use | 0% |
| | Husk | 40% used for steam and drying at rice plant[6] | No use | 35% sold to chicken farms for bedding[4] | 75% |
| Coffee | Husk | 6.25% used for drying and roasting at coffee plant[4] | No use | 93.5% sold at no cost to chicken farms for | 100% |
| Oranges | Peel | No use | 93% used for citrus pulp pellets[3,7] | 7% for pulp, oil, and essences[3,7] | 100% |

1 Usina Santa Lucia (2015)
2 EPE/MME (2014)
3 Ferreira-Leitão et al. (2010)
4 Missagia (2011)
5 Da Silva and Chandel (2014)
6 Mayer, Salbego, de Almeida, and Hoffmann (2015)
7 Citrosuco (2015)

The largest source of sustainable residue, sugarcane bagasse, is for approximately 90% fired in steam boilers to provide electricity to sugarcane mills (EPE/EME, 2014; Ferreira-Leitão et al., 2010; Missagia, 2011; Usina Santa Lucia, 2015). Almost all sugarcane mills are self-sufficient in their electricity needs by co-firing their crushed sugarcane stalks leftovers. Any excess of electricity produces is sold to the power grid. Most recent numbers of 2012 say that bioelectricity from bagasse provides 3% of Brazil's energy needs, this is expected to reach 18% in 2020 (bagasse and straw) (UNICA, 2013). On the one hand this growth is due to the increase of sugarcane production, and thus increase of bagasse production, and on the other hand bagasse firing is becoming a more common practice. Sugarcane mills are on a large scale building new and/or extra steam boilers to increase bagasse firing from 90% to 100% . Sugarcane straw used to be burned on the field to get rid of the huge amounts of waste produced. In recent years, federal governments, São Paulo being the first, have put a ban on this practice because of the damage being done to the environment and nearby villagers (respiratory diseases) (SugarCane, n.d.). Now, sugarcane straw is piled up and laid in between every few rows of sugarcane stalks (see figure 19) for nutrients, soil organic matter and erosion prevention. However, partial straw removal from the field begins to gain ground. The untapped energy potential is recognized, one third of the energy content of sugarcane is in the straw (UNICA, 2013), and the removed straw is starting to be co-fired with bagasse on a small scale. On larger scale straw is starting to be used for second generation ethanol production

**Figure 20 - Left: steam boiler for firing  bagasse, Right: stored leftover bagasse from previous season. Araras, São Paulo**

Soybean straw appears not to be currently used for feed, energy, or other uses, despite the fact it has a high nutritional value and is suitable for roughage for cattle (Heuzé, Tran, Hassoun, & Lebas, 2015). An interview with Suani Teixeira Coelho (2015) revealed that soybean straw is currently not utilized in Brazil, other than leaving them in the field for nutrients and erosion protection.
The majority of corn stalks, cob, and husk, or corn stover, is used as animal feed for dairy cattle, although it has a low nutritional value (Da Silva & Chandel, 2014). It is assumed the residue use for cattle feed is 60%. Other purposes could be fuel, bio based building materials, and chemicals (Da Silva & Chandel, 2014), but there are no reports of this use of corn residues on a commercial scale in Brazil.
Cassava residues are on a large scale applied in the chemical industry due to the high starch content. No residues are available for wood pellet production (Coelho, 2015; Ferreira-Leitão et al., 2010)

Rice residues are for 15-20% used for drying the rice and a total of 40% is used for drying, cogeneration to produce electricity at rice mills, and other processes (Mayer et al., 2015). 35% is sold to chicken farms for bedding (Missagia, 2011), leaving an availability of 25%.
According to a case study of Missagia (2011) in Minas Gerais 0.25 t of coffee husks are used for drying 4 t coffee, corresponding to 6.25% of the total volume of coffee residues. The remaining part is given at no cost, except transport costs, to chicken farms for bedding. Afterwards, the chicken farmer returns the husks, including chicken manure, back to the coffee farmer, who uses it has biological fertilizer.
93% of orange peels are processed into citrus pellets, a supplement to animal feed. The remaining 7% is used to make pulp, oil, citrus terpene, and essences (Citrosuco, 2015; Ferreira-Leitão et al., 2010).

### *5.4.2 Forestry residues*

Table 24 lists the local demand for forestry residues. Forest plantation field residues are currently almost completely left on the field. During the visit to their forestry unit in Telêmaco Borba, Paraná, Klabin reported that part of the pine field residues are harvested and chipped to be fired in steam boilers. However, they are the only plantation holders doing that (Negredo Junior, 2015), and since Klabin's 149,000 ha of pine plantations (Klabin, 2015) only make up 2% of the total forest planation area in the seven researched states, it is neglected. These residues are thus available for wood pellet production. Eucalyptus forests produce less residues and are 100% left on the field, because it is not economically to harvest and process the part that can sustainably be removed, 52.5% (AEBIOM, 2007; Fibria, 2013; Negredo Junior, 2015). Missagia (2011) also describes forest plantation field residues to be *"(…) a free commodity"*.
Residues generated in the paper and cellulose production industry are widely used for providing energy to the mills. Around 70% of the residues are incinerated in boilers to produce steam, which in turn generates electricity. The other 30% is discarded into landfills, and are thus available for wood pellet production (Fibria, 2013; Klabin, 2012).

Table 25 - Domestic demand of forestry residues

| Feedstock | Type of residue | Fuel and energy | Cattle feed | Other uses | Total |
|---|---|---|---|---|---|
| Eucalyptus & Pine | Field | No use[1,2] | No use[1,2] | No use[1,2] | 0% |
| | Paper & cellulose | 70% co-firing[3,4] | No use | No use | 70% |
| | Processing | No use | No use | 70% for plywood, chicken bedding, and wood briquettes[1,5] | 70% |

[1] Missagia (2011)
[2] Negredo Junior (2015)
[3] Klabin (2012)
[4] Fibria (2013)
[5] de Cerqueira, Vieira, Barberena, Melo, and de Freitas (2012)

Case studies in the states of Bahia (de Cerqueira et al., 2012), and Minas Gerais and Espírito Santo (Missagia, 2011) have shown that processing residues from sawmills and furniture production are for about 70% re-used to produce small wooden objects, plywood, chicken bedding, and wood briquettes. Ferreira-Leitão et al. (2010) also lists these uses of residues, with the addition of the possibility to produce bioethanol from forestry residues, however this has not been applied on a commercial scale in Brazil yet.

## 5.5 Global Biomass Demand and Supply

According to Haberl et al. (2010), bio-energy consumption globally amounts to approximately 50 EJ, about 10% of global TPES in 2011. A wide variety of studies into future technical potentials of bio-energy show a large range between 30 to over 1000 EJ/yr in 2050. This discrepancy in estimations is mainly caused by different assumptions regarding land availability, feedstock yields, and recovery factors. The same authors estimate the global technical primary bio-energy potential to range between 160 and 270 EJ/yr in 2050.

Agricultural feedstock and forestry residues could provide a large amount of that bio-energy potential. In 2050, the technical primary potential of agricultural residues is 49 EJ/yr (Haberl et al., 2010; based on unpublished work of Bhattacharya) and that of forestry residues 27 EY/yr (Haberl et al., 2010; calculated based on Anttila, Karjalainen, & Asikainen, 2009). No specific estimates are given for Brazil, but for Latin America & the Caribbean they do; this region could provide 11 EJ/yr of feedstock residues and 3 EJ/yr of forestry residues. Combined, it is the world region with the largest potential of bio-energy supply. Taking into account the size and the agricultural and forestry production volumes of Brazil, it is assumed that Brazil will account for a large share of this potential.

Agricultural and forestry residues are among the raw materials suitable to be used to produce wood pellets. The global production of wood pellets has risen to 23.6 MT in 2013, an increase of 13% compared to 2012 volumes. The average calorific value of wood pellets is around 18 MJ/kg. 23.6 MT wood pellets equals 0.42 EJ, and thus wood pellets make up less than 1% of the global bio-energy consumption. In the 2003-2013 period the production increased more than five-fold. Almost 50% of the production is accounted for by the EU, followed by North-America with 33% (see figure 22). Smaller players on the market are China and Russia with a combined share of about 13% (REN21, 2014). This indicates that South-America, and especially Brazil with large volume of biomass residue production, currently does not have a significant share in the global wood pellet production. Bio-energy production in Brazil is mainly focused on the production of bioethanol and biodiesel. However, according to Pöyry (2011), South-America, with Brazil as the largest contributor, has the potential to quickly become an important producer of wood pellets in the short-term future. The production volume is estimated to be 3 MT in 2015 and 4.4 MT in 2020. Compared to a production volume of 0.1 MT in 2010 only China is predicted to have a faster growth (0.6, 3 and 10 MT in 2010, 2015 and 2020 respectively). Despite having a large technical potential of residues, the lack (or cancelling) of investments, and competition with other cheap exporters (e.g. Canada and the USA) impose the biggest constraints for the development of the Brazilian wood pellet industry.

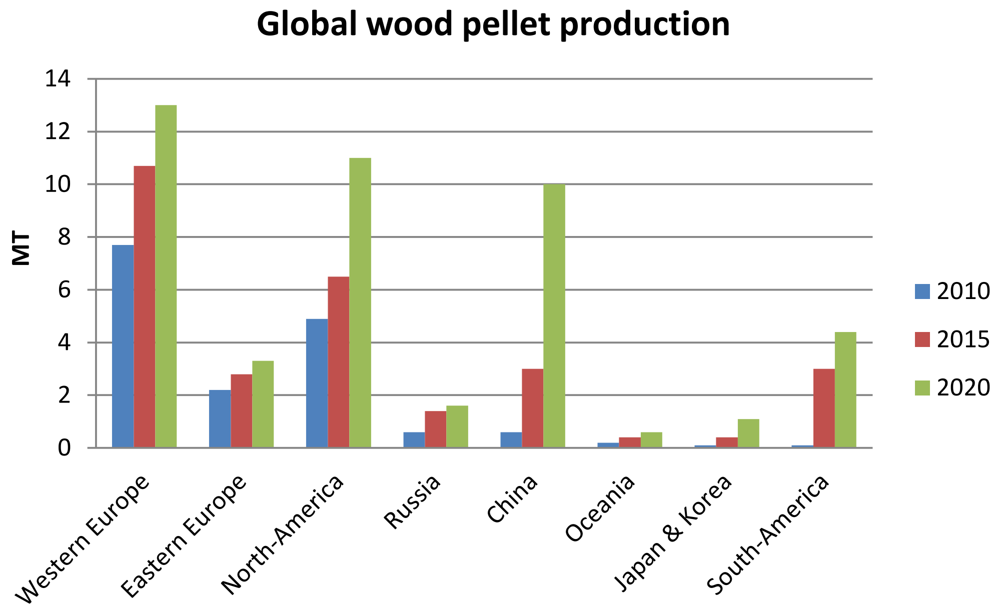


**Figure 21 - Global wood pellet production 2010, 2015 and 2020 (adapted from Poÿry (n.d.))**

Looking at the consumption and trade flows of wood pellets there is a clear trend visible: the EU consumes by far the largest volume (see figure 23), 10.8 MT in 2011 (Pöyry, 2011) and 15 MT in 2013 (REN21, 2014), and the largest import flow comes with bulk ships from North-America to the EU. Within the EU there is an internal trade flow from the Baltic countries and Finland towards Sweden, Denmark, Belgium, the Netherlands and the UK (Alakangas et al., 2012). As of 2011, there was no trade flow yet from South-America to the EU or any other continent. Logical, since there was barely any production of wood pellets. However, as mentioned earlier, the wood pellet market in South-America, especially Brazil, is growing rapidly. Trade flows between Brazil and the EU are emerging and Brazil seems to become an important supplier of wood pellets to the EU (ABIPEL, 2015a; Cocchi et al., 2011; Haberl et al., 2010; Lamers et al., 2014; Pöyry, 2011, 2012, 2013).

There are several studies estimating the EU wood pellet consumption in the short-term future. Besides Pöyry (2011), estimating a consumption of 24.6 MT wood pellets, AEBIOM (2008) estimates 60-80 MT, and REN21 50-80 MT. Other estimates range between 30-55 MT (ENVIVA, Hawkins Wright, and McKinsey, 2013). To fill the estimated gap between production and consumption, the supply gap, of solid biomass 55-85 MT wood pellets would be required. Although a realistic import volume in 2020 is estimated to be 11 MT (Pöyry, 2012). A quick scan performed by Junginger et al. (2012) indicates that Bahia, Minas Gerais, and Rio Grande do Sul, Brazilian states that are part of the research scope of this thesis, could potentially supply 22 MT of wood pellets to the EU in 2030. This would be a share of about 25% of the total available wood pellet supply from outside the EU.

Every reviewed study highlights the high uncertainty in supply development and price formation in the world wood pellet market. This uncertainty causes the 2020/2030 production and consumption volume estimates to have such a big bandwidth. Despite the uncertainty in the volume of wood pellet trade flows by 2020/2030, the notion is clear that the EU is unable to produce enough to meet their demands. This gap needs to be filled with imports from outside the EU. Wood pellet imports could provide an important share of this gap, with Brazil as a promising supply agent from 2020 and onwards.

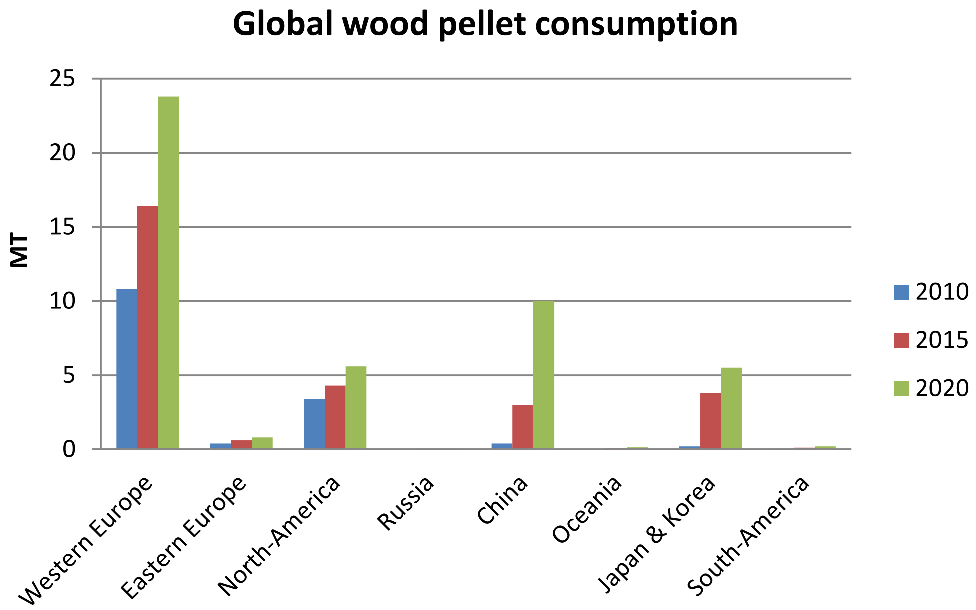


Figure 22 - Global wood pellet consumption (adapted from Pöyry (n.d.))

## 5.6 Net Sustainable surplus potential Lignocellulosic Biomass Residues – Current situation

### *5.6.1 Agricultural residues*

The net sustainable surplus potential of agricultural is listed in Table 25 and amounts to a total of 627 PJ, this 31.0% of the sustainable potential and 19.4% of the technical potential.

Table 26 - Net sustainable surplus potential agricultural residues – current situation (PJ)

| Feedstock | Type of residue | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|
| Sugarcane | Bagasse | 1.7 | 1.2 | 17.1 | 101.3 | 11.9 | 0.1 | 0.2 |
| | Tops/straw | 3.6 | 2.4 | 36.9 | 210.9 | 24.8 | 0.3 | 0.5 |
| Soybeans | Straw | 11.1 | 0.0 | 10.6 | 5.4 | 37.6 | 3.7 | 21.0 |
| Corn | Stalk | 3.6 | 0.1 | 10.2 | 5.8 | 21.6 | 3.8 | 4.5 |
| | Cob | 1.0 | 0.0 | 2.9 | 1.7 | 6.2 | 1.1 | 1.3 |
| | Husk | 0.7 | 0.0 | 1.9 | 1.1 | 4.0 | 0.7 | 0.8 |
| Cassava | Straw | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rice | Straw | 0.1 | 0.0 | 0.3 | 0.6 | 0.9 | 5.3 | 37.3 |
| | Husk | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.8 | 5.5 |
| Coffee | Husk | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oranges | Peel | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **Total PJ** | **21.7** | **3.7** | **80.6** | **326.8** | **107.1** | **15.8** | **71.3** |

Whereas in the sustainable potential sugarcane bagasse was by far the biggest residue potential, it is now the second biggest with 134 PJ, due to the fact 90% of bagasse is used for electricity production at the sugar mill. Sugarcane straw has the largest net sustainable surplus potential with 279 PJ. São Paulo has the largest net surplus residue potential, 327 PJ, almost entirely made up of sugarcane residues. Figure 24 shows the breakdown of the technical-, sustainable-, and net surplus potentials per state in the current situation.

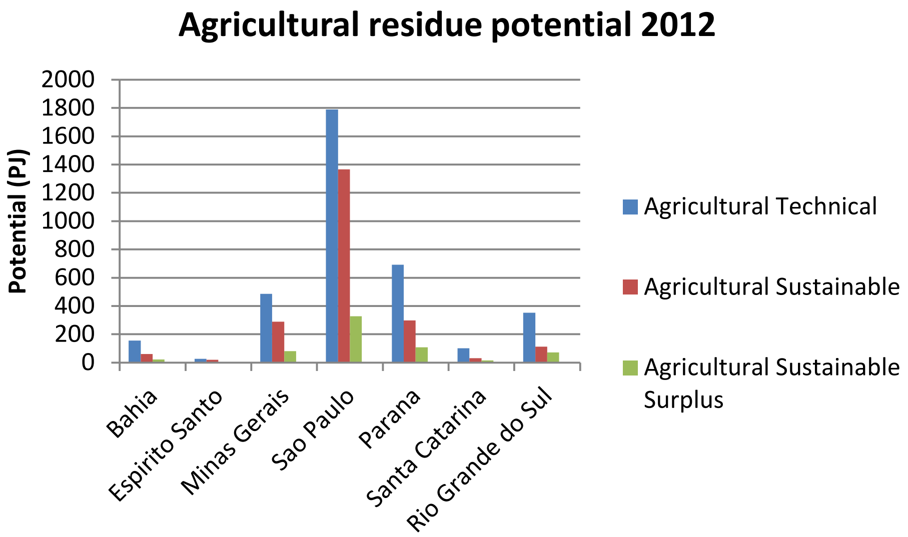


Figure 23 - Breakdown of different agricultural residue potentials for 7 selected Brazilian states (base year 2012)

Figure 25 shows the spatial distribution of the net surplus potential of agricultural residues. The concentration is in the western part of Bahia (soybean), the centre and west of São Paulo (sugarcane), the west of Paraná (soybean, sugarcane, corn), and the west of Rio Grande do Sul (rice).

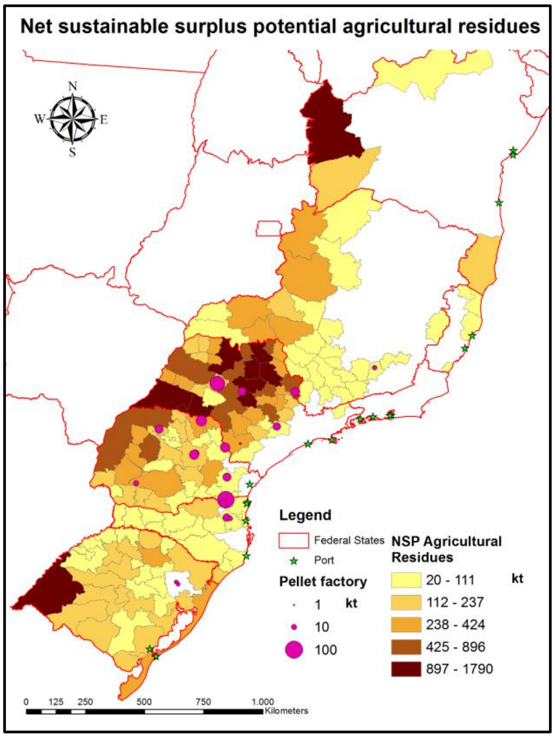


Figure 24 - Net sustainable surplus potential agricultural residues per micro-region in 2012

### *5.6.2 Forestry residues*

The net sustainable surplus potential of forestry residues amounts to 91.2 PJ, 38,6% of the sustainable potential and 32,9% of the technical potential. Field residues represent the largest part of the net surplus potential with 46 PJ, they are currently not used in Brazil, while 70% of the residues from paper and cellulose production and processing are utilized for various purposes (see table 26). Paraná, São Paulo, and Santa Catarina together generate 69% of the total volume of net surplus residues.

Table 27 - Net sustainable surplus potential forestry residues – current situation (PJ)

| **Feedstock** | **Type of residue** | **SRF** | **LHV (MJ/kg)** | Bahia | Espírito Santo | Minas Gerais | São Paulo | Paraná | Santa Catarina | Rio Grande do Sul |
|---|---|---|---|---|---|---|---|---|---|---|
| Eucalyptus & Pine | Field | 0.525 | 19.05 | 5.7 | 2.0 | 5.4 | 7.4 | 13.0 | 9.1 | 3.2 |
| | Paper & cellulose | 1 | 18.18 | 2.6 | 0.9 | 1.0 | 1.4 | 2.0 | 2.1 | 0.5 |
| | Processing | 1 | 18.18 | 0.2 | 0.2 | 4.7 | 6.7 | 12.9 | 6.8 | 3.2 |
| | | | **Potential PJ** | **8.5** | **3.1** | **11.1** | **15.5** | **27.9** | **18.0** | **7.0** |

Figure 26 shows the breakdown of the technical-, sustainable-, and net surplus potentials per state. The distribution over the states is more equal compared to the net surplus of agricultural residues, since there is not one significantly dominant residue type in one state, like sugarcane residues are in São Paulo for agricultural residues.

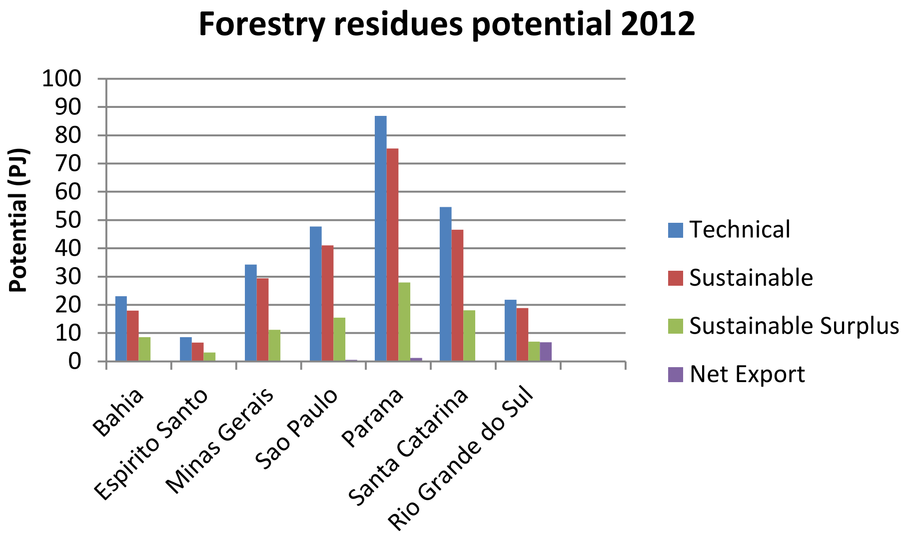


Figure 25 - Breakdown of different forestry residue potentials for 7 selected Brazilian states (base year 2012)

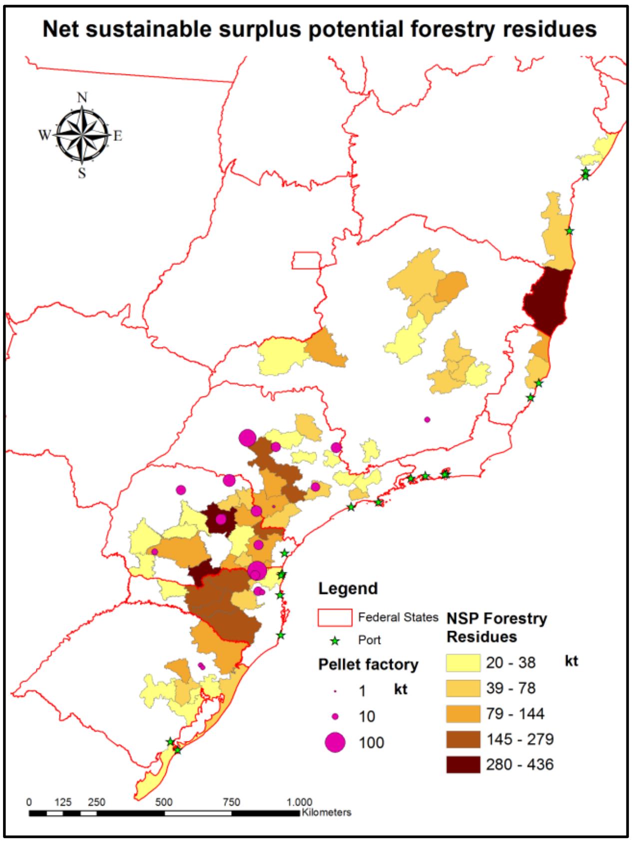


Figure 26 – Net sustainable surplus potential forestry residues per micro-region in 2012

Figure 24 shows the spatial distribution of the net surplus potential of forestry residues. Forestry residues are much more fragmented and concentrated in smaller areas compared to agricultural residues. The net surplus potential is located mainly in the centre-east of São Paulo, Paraná and Santa Catarina.

## 6.1 Net sustainable surplus potential agricultural residues in 2020/2030 and BAU/optimistic scenario

The 2020 BAU scenario net surplus potential of agricultural residues is slightly lower compared to 2012 (see table 29). The growth in agricultural production is limited by the availability of suitable land in São Paulo and Paraná, the states with the largest production. At the same time, local utilization of sugarcane bagasse and straw increases, resulting in lower availability of residues. The effect of local demand becomes even clearer in the BAU 2030 scenario.
In the High Export scenario the potential increases as a result of higher agricultural production in states other than Paraná and São Paolo, combined with lower local utilization compared to the BAU scenario.

Table 28 - Net surplus potential of agricultural residues for 2012/2020/2030 and the BAU and High Export scenarios

| Potentials (PJ) | 2012 | 2020 BAU | 2020 OPT | 2030 BAU | 2030 OPT |
|---|---|---|---|---|---|
| Sugarcane bagasse | 134.1 | 0 | 171.3 | 0 | 201.3 |
| Sugarcane tops/straw | 279.3 | 348.7 | 356.6 | 200.7 | 314.4 |
| Soybean straw | 89.4 | 107.9 | 126.3 | 101.7 | 157.5 |
| Corn stalk | 49.6 | 58.0 | 76.3 | 66.1 | 126.5 |
| Corn cob | 14.2 | 16.6 | 21.8 | 18.9 | 36.2 |
| Corn husk | 9.2 | 10.7 | 14.1 | 12.2 | 23.3 |
| Rice straw | 44.6 | 50.7 | 52.3 | 59.9 | 63.6 |
| Rice husks | 6.6 | 4.5 | 10.1 | 0 | 12.3 |
| **Total net surplus (PJ)** | **627** | **597** | **829** | **459** | **935** |

Between 2012 and the 2020 optimistic scenario the net surplus residue potential increases about 32% to 829 PJ, and between 2020 optimistic and 2030 optimistic with another 13% to 935 PJ. In the BAU scenario the potential reduces with 5% until 2020 and with another 23% between 2020 and 2030.

## 6.2 Net sustainable surplus potential forestry residues in 2020/2030 and BAU/optimistic scenario

The growth in eucalyptus and pine forest plantations results directly in increased field residues, and the growth in production of planted forest for paper and cellulose production and lumber processing also results in larger volumes of generated processing residues (see table 30). Similar as with agricultural residues the BAU scenario for local demand for residues tempers the increased net surplus of forestry residues due to increased roundwood production. Also here, the limited available agricultural areas in São Paulo and Paraná limit the potential.
Utilization rates for all residues increase, and the net surplus potential decreases to 87 PJ in the 2020 BAU scenario and 70 PJ in the 2030 BAU scenario.

Table 29 - Net surplus potential of forestry residues for 2012/2020/2030 and the BAU and High Export scenario

| Potentials (PJ) | 2012 | 2020 BAU | 2020 OPT | 2030 BAU | 2030 OPT |
|---|---|---|---|---|---|
| Field | 45.9 | 47.1 | 52.8 | 49.8 | 65.4 |
| Paper and cellulose production | 10.6 | 10.7 | 13.4 | 20.2 | 17.5 |
| Lumber processing | 34.6 | 29.2 | 35.8 | 0 | 41.5 |
| **Total net surplus** | **91.2** | **87.0** | **101.9** | **70.0** | **124.4** |

In the optimistic scenario's for 2020 and 2030 utilization rates of residues from paper and cellulose production and lumber processing remains the same compared to 2012, for field residues it increases at a slower pace compared to the BAU. Net surplus potentials increase to 102 PJ and 124 PJ in the 2020 optimistic and 2030 optimistic scenario respectively. Surprising is the large growth rate of net surplus residues from lumber processing between the 2020 optimistic scenario and the 2030 optimistic scenario. This indicates the roundwood consumption for lumber processing increases at a larger speeds compared to roundwood consumption for paper and cellulose production. Lumber processing also has a higher RPR than paper and cellulose production.

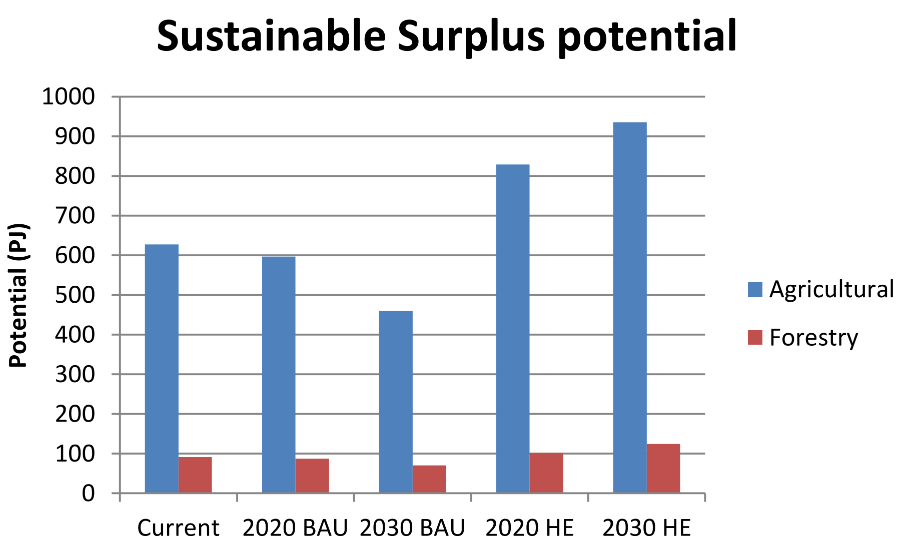


Figure 27 – Sustainable Surplus potential of agricultural and forestry residues for 2012/2020/2030 and the BAU and High Export scenarios

## 6.2 Net export potential forestry residues in 2020/2030 and BAU/optimistic scenario

The net export potential in all the scenarios is considerably lower than the sustainable surplus potential, as a result of the limited pellet plant capacity installed in Brazil. However, because of the exponential growth in capacity, with a strong growth rate of 27% in the High Export scenario, the potential in 2030 in the HE scenario is still 411 PJ.

Table 30 - Sustainable Surplus and Net Export potential of agricultural and forestry residues for 2012/2020/2030 and the BAU and High Export scenarios

| | Potentials (PJ) | 2012 | 2020 BAU | 2020 OPT | 2030 BAU | 2030 OPT |
|---|---|---|---|---|---|---|
| Sustainable Surplus | Agricultural residues | 627.0 | 597.0 | 828.7 | 459.4 | 935.1 |
| | Forest residues | 91.2 | 87.0 | 101.9 | 70.0 | 124.4 |
| Net Export | Agricultural residues | 0.0 | 0.0 | 0.0 | 15.5 | 112.3 |
| | Forest residues | 8.6 | 18.9 | 36.6 | 55.2 | 298.7 |
| | **Total net export** | **8.6** | **18.9** | **36.6** | **70.7** | **411.0** |

In the current and 2020 scenario's the pellet plant capacity limits the potential severely, to 1.2% in the current scenario, 2.8% in the 2020 BAU scenario and 3,9% in the 2020 HE scenario. In 2030 according to the BAU scenario, 13,4% of the Sustainable Surplus potential can be exported, in the 2030 HE scenario this is 38,8%.

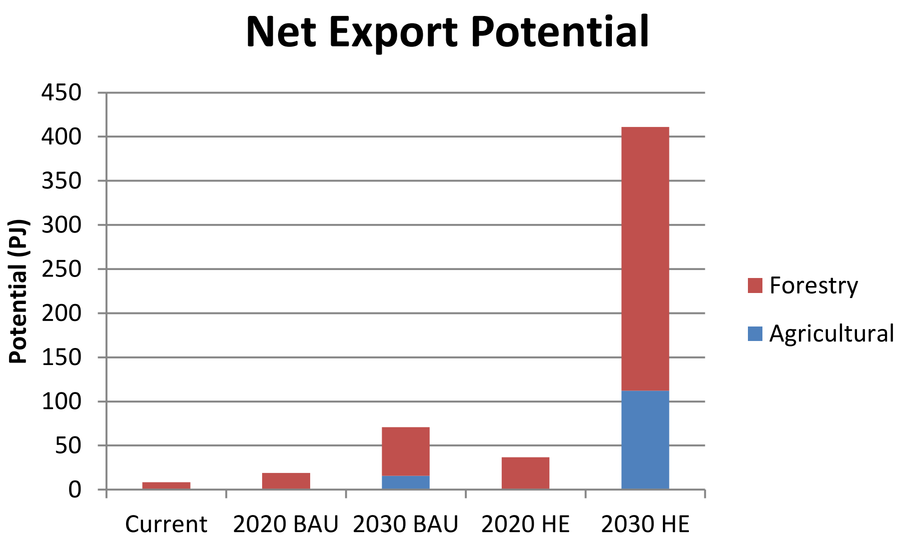


Figure 28 - Net Export Potential for 2012/2020/2030 and the BAU and High Export scenarios

## 7. Discussion

### 7.1 Cost Supply Curves

Factoring in the capacity of pellet production facilities, the net export potential is reduced to 8.6 PJ. Thus, wood pellet production capacity is in the current situation by far the main limiting factor for biomass residue export to the EU. Figure 28 shows the cost-supply curves of the current situatoin. Delivery costs range from €14.2/GJ (232 €/ton) to €15.3/GJ (251 €/ton) (figure 28). It should be noted that forest residues are more expensive than agricultural residues, the fact that in this scenario only wood pellets are produced increases the cost. Cost of transport to three different EU countries is calculated: Austria, Italy and the Netherlands. These countries serve as examples of countries that can be reached via either the North Sea or the Mediterranean Sea, as well as a landlocked country. The cheapest option from each state is then selected and used in the Cost Supply Curve calculation.

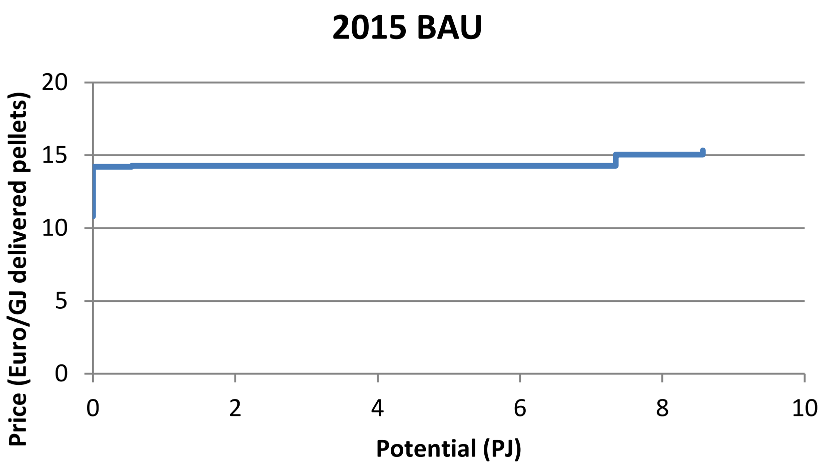


Figure 29 - Cost Supply Curve - current

These cost are higher than the range of €122-€160 euro calculated by the Brazilian Biomassa Industry Association in their Woodpellet & Briquette book (BBER, 2015b). Rasga (2013) calculated a cost of €180/t pellets from pine residues delivered at the harbour in a case study in São Paulo state.

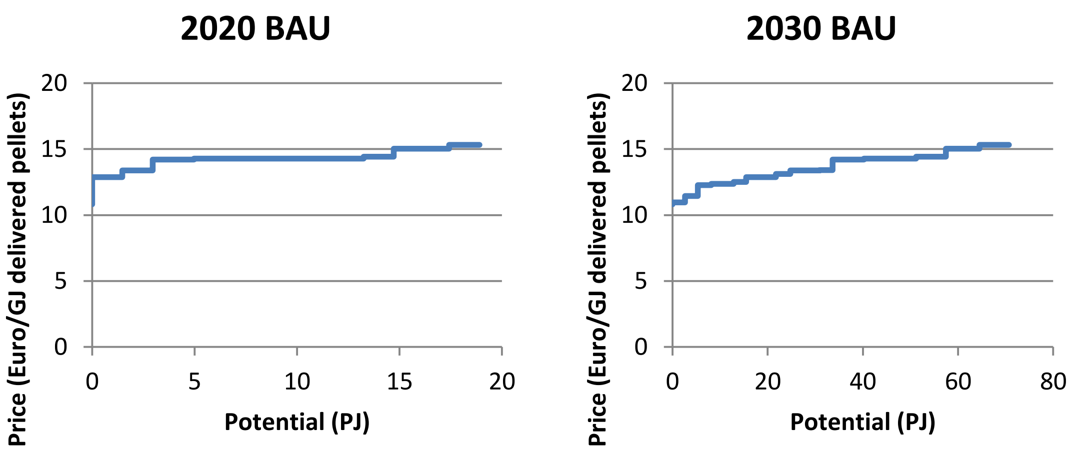


Figure 30 - Cost Supply Curve 2020 and 2030 - Business As Usual

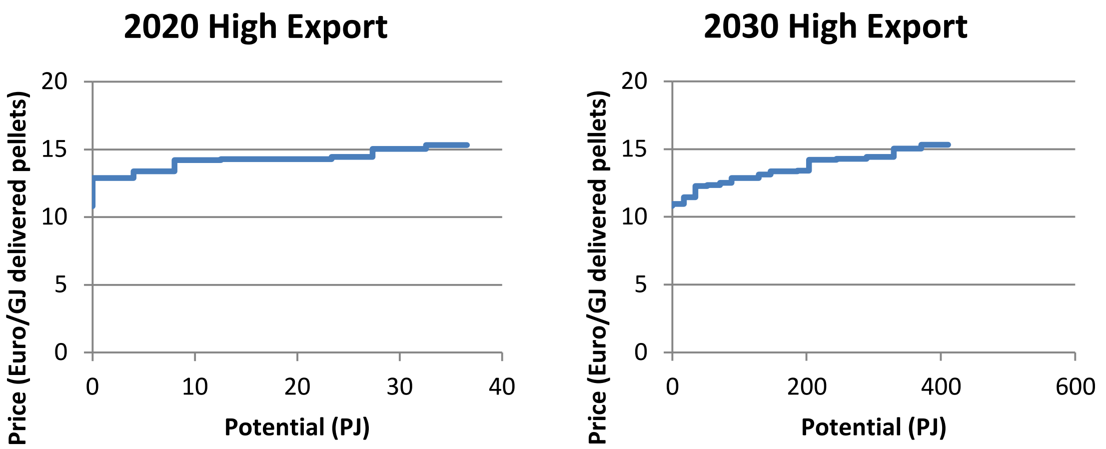


Figure 31 - Cost Supply Curve 2020 and 2030 - High Export

In the high export scenario the cost range from €10.4/GJ (177 €/ton) to €15.3/GJ (251 €/ton). The lowered prices can be explained by the cheaper agricultural residues that will become available in 2030.

Comparing these price estimates to spot prices of biomass imported into Europe shows that pellets from Brazil, if available for the calculated prices, would not be able to compete with currently imported biomass. Cif ARA spot prices between 185 $/tonne and 160 $/tonne translates to about 9.0 – 10.4 €/GJ. This however also shows that a small share of the wood pellets from Brazil could possibly be cost effective under the circumstance of rising wood pellet prices to the level of the 2014.

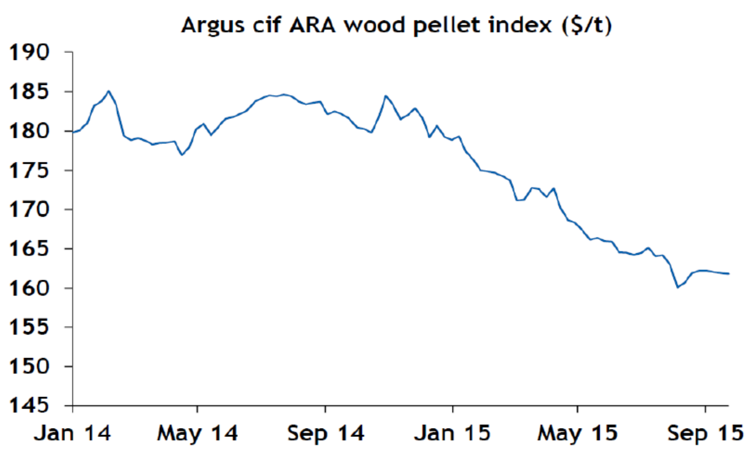


Figure 32 - Spot prices of imported wood pellets into Europe (Dell, 2015)

## 7.2 GHG emission savings

One of the sustainability criteria important for residue use for pellet production is the total (direct) greenhouse gas emissions across the supply chain. Greenhouse gas emissions are calculated based on the same characteristics of the pellet production cost.
For the sea shipping $CO_2$ emissions, the assumption is made that maritime transport takes place in large bulk vessels (14,201 tonnes), emitting 7 $gCO_2$/tonne-km (Responsible Care, ECTA, & Cefic, 2011).
The distance between Brazil and the Netherlands is calculated by using Rio de Janeiro as start point and Rotterdam as end point, this results in a distance of 5243 nautical miles, or 9710 km. The additional GHG emissions of transport to Austria and Italy relative to the Netherlands are taken from the BIT-UU model results for the US, similar to the cost calculations.

The below figure 34 shows the GHG supply Curve for Brazil in the 2020 BAU scenario. The GHG emissions do not differ between the different scenarios.

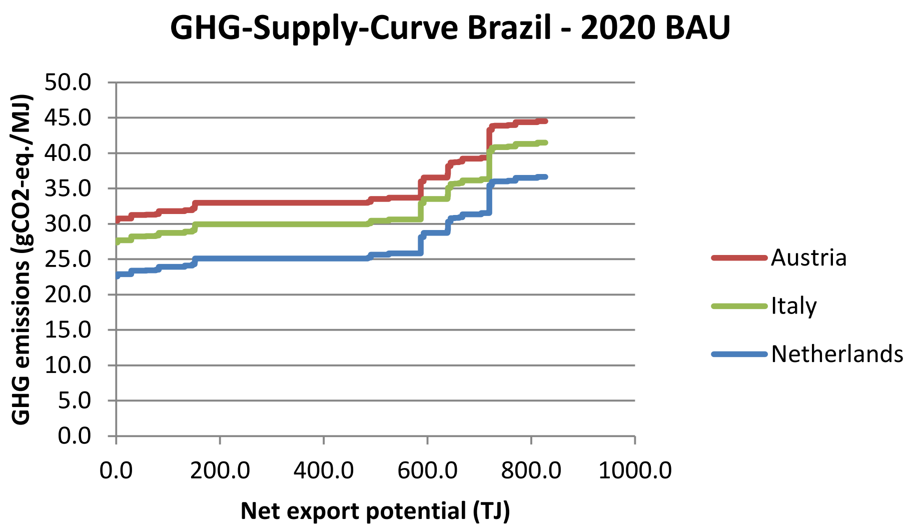


Figure 33 - GHG supply curve of pellet delivered from Brazil to Austria, Italy or the Netherlands

Table 31 - GHG emissions of pellet delivered from Brazil to Austria

| Austria | GHG emissions of feedstock supply (g CO2-eq/MJ) | GHG emission savings | |
|---|---|---|---|
| | | FT-diesel (NGCC) | Electricity generation |
| **Sugarcane** | 33.1 | 75% | 83% |
| **Soybean** | 44.2 | 66% | 78% |
| **Corn** | 39.0 | 70% | 80% |
| **Rice** | 36.5 | 72% | 82% |
| **Forest** | 31.4 | 76% | 84% |

Table 32 - GHG emissions of pellet delivered from Brazil to Italy

| Italy | GHG emissions of feedstock supply (g CO2-eq/MJ) | GHG emission savings | |
|---|---|---|---|
| | | FT-diesel (NGCC) | Electricity generation |
| **Sugarcane** | 30.1 | 77% | 85% |
| **Soybean** | 41.1 | 69% | 79% |
| **Corn** | 36.0 | 73% | 82% |
| **Rice** | 33.5 | 74% | 83% |
| **Forest** | 28.4 | 78% | 86% |

Table 33 - GHG emissions of pellet delivered from Brazil to the Netherlands

| Netherlands | GHG emissions of feedstock supply (g CO2-eq/MJ) | GHG emission savings | |
|---|---|---|---|
| | | FT-diesel (NGCC) | Electricity generation |
| **Sugarcane** | 25.2 | 81% | 87% |
| **Soybean** | 36.3 | 72% | 82% |
| **Corn** | 31.2 | 76% | 84% |
| **Rice** | 28.7 | 78% | 86% |
| **Forest** | 23.6 | 82% | 88% |

As can be seen in the above tables, the entire potential meets the EU criterion of 35% greenhouse gas savings of at least 35% in comparison to fossil fuels. This criterion will increase to 50% in 2017 and 60% in 2018, still the potential from Brazil would meet these targets(European Commission, n.d.).

The differences between the three countries are due to additional train, truck and inland waterway transport required to transport the pellets to Austria or Italy. Differences between the feedstocks are the result of different nutrient substitution requirements. The assumption is made that nitrogen, potassium and phosphorus that are withdrawn from the soils are replenished by applying fertilizers. Since the nutrient content of residues varies, the amount of fertilizer needed to replenish residue extraction also varies.

## 7.3 Uncertanties

The main limiting factor in the Brazil case study is the pre-treatment capacity. There is no reliable overview of existing pellet plants in Brazil, overviews that do exist often include plants that, upon consulting with local experts, appear to be never actually built or are taken out of operation. A better understanding of the existing pellet market as well as the possible developments in the future, including an understanding of the business climate is needed to improve the analysis of available current and future pellet production capacity.

Another factor which may have a great impact on the availability of lignocellulosic feedstocks for pellet production is the use of sugarcane tops and straw for second generation ethanol production. The potential in Brazil is almost entirely made up of sugarcane residues; the assumption to exclude a share of the residues for ethanol production therefore highly impacts the results. Moreira, Pacca and Parente (2014) analysed the future production of bio-ethanol based on cost-benefit analysis of oil production and two scenarios of ethanol production. The difference between the two scenarios in their results is a factor three. In 2070 in the High Ethanol scenario production would be 764 mln boe per day, in the Low Ethanol scenario this would be 256 mln boe. Understanding that the possible range of bio-ethanol production in Brazil is large, the uncertainty of residue use for ethanol production is also large. It must be noted that although higher production of bio-ethanol would lower the potential of solid bio-energy carriers, in the end both are renewable fuels and therefore share the same purpose.

A third issue which has not received enough attention in the current study is the conditions under which the potentials could be mobilized. Current practices of leaving residues in the field or burning the residues need to be changed in order to mobilize surplus potentials. It could be very difficult to motivate agricultural companies to change their practices regarding the use of residues, especially since the value of residues could be considered low compared to the primary product.
Furthermore, investments need to be made in infrastructure networks in order to lower the cost of transport and make export of pellets feasible. Currently only truck transport is a realistic option in Brazil, railways in Brazil are old and ill maintained making rail transport not feasible at the moment. If large scale investments succeed in improving rail infrastructure and lowering cost, a larger share of the country can produce competitive solid biofuels for export.

# 8. Conclusion

In this report the potential for net surplus sustainable lignocellulosic biomass from Brazil was analysed. Brazil offers a significant potential of agricultural and forestry residues to be used as bioenergy carriers. The large sugarcane industry produces large amounts of bagasse and straw. The use of agricultural and forestry residues for pellet production could offer a potential between 718 PJ in the current situation and 1047 PJ in the most optimistic scenario in 2030.

This study however found that the availability of pellet plants to convert residues into suitable bioenergy carriers for export is greatly limiting the potential. The current potential is reduced to only 8.6 PJ. When using a very optimistic growth rate of 27% per year, this potential might increase to 411 PJ in 2030, a more realistic growth rate of 14% would result in 70.7 PJ in 2030.

The cost of pellet production in Brazil has not been investigated into great detail, since reliable data about costs of the different components is missing. The current cost calculation leads to the conclusion that importing pellets from Brazil into Europe is not competitive at this time. However, comparing the prices to spot prices of 2014 and 2015 shows that a part of the biomass potential from Brazil could compete with the higher range of historical spot prices. Cost reductions in Brazil, mainly through improvement of rail infrastructure could result in lower cost of pellets.

This study has identified a very large potential source of lignocellulosic biomass from Brazil. Mobilizing this source would contribute to socio-economic developments in Brazil as well as strengthen the renewable energy sector both in Brazil as well as in the EU. The lignocellulosic biomass from Brazil could play an important role in meeting the EU renewable energy targets.

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# Appendix A – Input Cost Supply Curve Calculations

| | scale | medium | large | large - wood chips |
|---|---|---|---|---|
| **Plant characteristics** | | | | |
| Size | kton/yr | 40.000 | 120.000 | 120.000 |
| Pellet production rate | t/h | 5 | 15 | 15 |
| Lifetime | yrs | 17,5 | 17,5 | 17,5 |
| CCR | | 0,12 | 0,12 | 0,12 |
| **Capital cost** | | | | |
| CAPEX | M€ | 3,74 | 9,18 | 11,29 |
| operation & Maintenance cost | % percentage of total i | 1% | 1% | 1% |
| Other cost | % percentage of total i | 3% | 3% | 3% |
| **Operational details** | | | | |
| Labour requirement | FTE | 5,75 | 5,75 | 5,75 |
| | h/yr | 16790 | 16790 | 16790 |
| Energy-e | kW | 570 | 1617 | 1900 |
| | MWh/yr | 4556 | 12934 | 15200 |
| | kWh/t pellets ar | 114 | 108 | 127 |
| Energy-h | kWh/tev.w. | 1.200 | 1.000 | 1.000 |
| Boiler efficiency | | 90% | 90% | 90% |
| Consumables | € / t ad | 9 | 9 | 9 |

| | | | | | |
|---|---|---|---|---|---|
| **Variables** | **Feedstock characteristics** | | | | |
| | Cal. value | MJ / kg ar (LHV) | 6,95 | 6,95 | 6,95 |
| | Moisture content (fresh) | wt.% (w.b.) | 50% | 50% | 50% |
| | Moisture content (dry) | wt.% (w.b.) | 8,5% | 8,5% | 8,5% |
| | Cal. Value after drying | MJ / kg ar (LHV) | 16,35 | 16,35 | 16,35 |
| **Variables** | **Plant characteristics** | | | | |
| | Interest rate | | 0,10 | 0,10 | 0,10 |
| | Operating hours | h | 7000 | 7000 | 7000 |
| **Variables** | **Input costs - land factors** | | | | |
| | Electricity price | € /MWh | 121,9 | 121,9 | 121,9 |
| | Labour | € /h | 8,1 | 8,1 | 8,1 |
| | Transport cost (truck) | € /km/t | 0,09 | 0,09 | 0,09 |
| | Transport cost (train) | € /km/t | | | |
| | Harbor cost | € /t | 7,26 | 7,26 | 7,26 |
| | Profit | % | 10% | 10% | 10% |
| Agricultural residues | Pre-processing cost | € /t field site | 12,08 | 12,08 | 12,08 |
| | Transport to pellet plant | € /t ar delivered | 2,15 | 2,15 | 2,15 |
| Forest residues | Pre-processing cost | € /t field site | 20,04 | 20,04 | 20,04 |
| | Transport to pellet plant | € /t ar delivered | 4,30 | 4,30 | 4,30 |
| Energy crops | Pre-processing cost | € /t field site | 12,08 | 12,08 | 12,08 |
| | Transport to pellet plant | € /t ar delivered | 2,15 | 2,15 | 2,15 |