Master
thesis

AVAILABILITY OF SUSTAINABLE LIGNOCELLULOSIC BIOMASS RESIDUES IN BRAZIL FOR EXPORT TO THE EU

Assessment of the net sustainable surplus potential of lignocellulosic biomass residues in the south- and southeast of Brazil for export to the European Union. In 2012, 2020, and 2030, and for different scenarios

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Abbreviations and units

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	
EU RED	

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

Executive summary

In the light of the renewable energy targets set by the European Commission, potential sourcing regions for lignocellulosic biomass are reviewed by the BioTrade2020+ consortium. The aim of this research is to calculate the net sustainable surplus potential of lignocellulosic biomass residues in Brazil for export to the EU. Technical, sustainable, and net surplus potentials are calculated, local demand for residues is assessed, pre-treatment facilities, logistics and infrastructure are investigated, and biomass supply chain costs are calculated. This research attempts to give an insight in the current situation, and outlooks for 2020 and 2030 under a business as usual and an optimistic scenario. Data was collected during an internship in Campinas, São Paulo state and from desk research.

The agricultural and planted forestry sector in the south- and southeast of Brazil produce an enormous amount of lignocellulosic biomass residues. Three stages of residue potentials were calculated: the technical potential, the sustainable potential, and the net surplus potential. The technical potential of agricultural residues from sugarcane, soybean, corn, cassava, rice, coffee, and oranges amounted to 216 MTdm (3556 PJ) in 2012, with São Paulo accounting for 47%. Sugarcane trash and bagasse make up 57% of the total technical potential. The technical potential of forestry residues is 16 MTdm (295 PJ). This is significantly lower than the technical potential of agricultural residues, due to the fact only forest plantations are considered, which amount to 6.9 Mha. The majority of the technical potential of field residues, sugarcane-, soybean-, corn-, cassava-, and rice straw has to be left on the field for providing irreplaceable environmental services. Retaining about 70% of the agricultural field residues protects the soil from erosion, nutrient depletion and soil organic carbon loss. For forest plantation residues about 50% of the residues need to be left on the field. The sustainable potential of agricultural residues is 130 MTdm (2229 PJ). The sustainable potential of agricultural residues is 14 MTdm (249 PJ). The majority of forest residues are not generated in the field, but in the processing industry, and these residues have a sustainable recovery rate of 100%.

Local demand of residues for cattle feed, fuel, energy, and other purposes have priority over exporting residues to the EU. The local market should not be disrupted. The largest volume of agricultural residue, bagasse, is for 90% used for electricity generation at the sugarcane mill. Cassava, coffee, and orange peels are fully allocated on the domestic market and are not available for export to the EU. The local demand drastically decreases the net surplus potential, the technical potential minus the volume of residues that has to be left on the field minus the local use of residues. The combined net surplus potential of agricultural and forestry residues in 2012 are 856 PJ (see table 1).

The net surplus potential is also calculated for 2020 and 2030 and a business as usual and optimistic scenario. The business as usual (BAU) scenario assumes feedstock production growth rates and local demand for residues in line with historical trends. This implicates a larger volume of residues generated but also an increase of local utilization of biomass residues. The optimistic scenario assumes increase of feedstock production at a faster pace and lower local utilization rates compared to the BAU scenario. In the BAU scenario the total net surplus potential increases to 884 PJ in 2020 and then decreases to 765 PJ in 2030. This is caused by the fact that 100% of the sugarcane bagasse is expected to be used for co-firing and 50% of sugarcane trash for producing second generation bio-ethanol and co-firing. In the optimistic scenario the total net surplus potential increases to 1,202 PJ in

2020 and 1,684 PJ in 2030, due to increased growth rates of feedstock production and less local use of residues compared to the BAU scenario.

Table 1 Net sustainable surplus potentials of agricultural and forestry residues

Potentials (PJ)	2012	2020 BAU	2020 OPT	2030 BAU	2030 OPT
Sugarcane	515	463	666	308	851
Soybean	95	146	188	152	282
Corn	75	90	132	106	258
Rice	54	55	69	64	84
Forestry	117	131	147	135	209
Total net surplus	**856**	**884**	**1,202**	**765**	**1,684**

The biomass residues need to be lowered in moisture content and energy density to stabilize the raw material for transport to the EU. The residues are pre-treated in wood pellet factories. Currently, the production capacity of the wood pellet industry in the south- and southeast of Brazil is only 470 kt. With a capacity factor of 80% this corresponds to about 7 PJ of wood pellets. The production capacity of the Brazilian wood pellet industry is thus a limiting factor for the available amounts of biomass residue that can be exported to the EU.

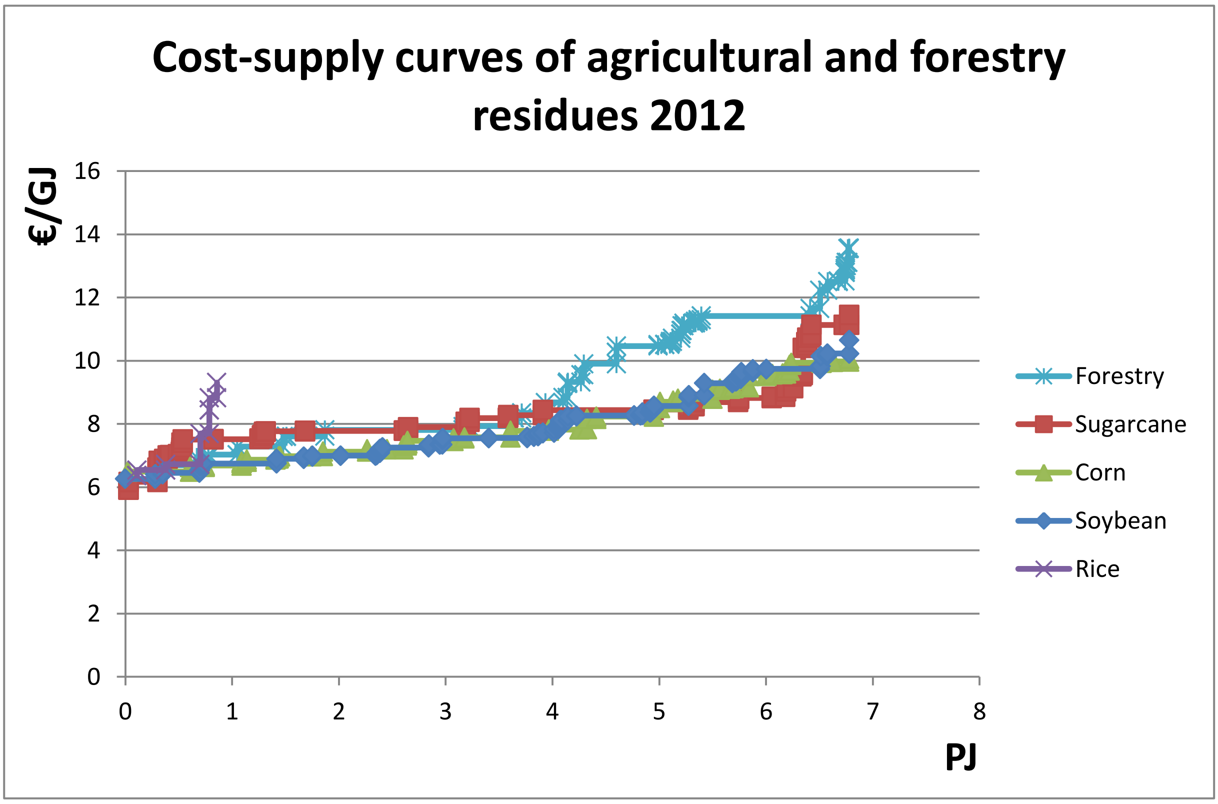

Figure 1 Cost-supply curves for agricultural and forestry residues in south- and southeast Brazil in 2012

Figure 1 shows the cost-supply curves for the five feedstocks with residues available for export to the EU. The delivery costs at the export harbour range from €5.92/GJ to €13.57/GJ. The price per delivered ton of wood pellets at the export harbour ranges from €106.56 to €244.27, which is in line with prices of €120-€160/t and €180/t of the Brazilian Biomass Industry Association and a case study in the state of São Paulo respectively.

A lot of assumptions are made regarding sustainable recovery rates, local demand for residues, the scenario’s and growth projections, and biomass supply chain costs. Further research needs to attempt to make more careful estimates that apply specifically to Brazil. Also the calculations of GHG emissions in the supply chain and calculating the cost-supply curves for biomass residue supply in 2020/2030 and for the BAU and optimistic scenario is missing in this research. They have to be performed and incorporated in the final report for the Brazil case study into the net sustainable surplus potential of lignocellulosic biomass residues for export to the EU.

BioTrade2020+

This Master's thesis is written as part of the BioTrade2020+ project. To investigate the potentials for importing biomass resources from outside the EU and to address the concerns related to biomass imports, several case studies on potential sourcing countries are conducted as part of the BioTrade2020+ project, a collaboration between several European research institutes and co-funded by the Intelligent Energy for Europe Programme of the European Commission (WIP Renewable Energies, 2014). These case studies are supporting the objectives of BioTrade2020+, such as analysing available biomass feedstock potentials, analysing local markets and domestic demand for biomass, ensuring the sustainability and efficiency of imported biomass resources and making a supply chain analysis.

Utrecht University is a member of Work Package 3 (Wp3). Wp3 *"…studies the demand and market of lignocellulosic biomass at a number of international sourcing regions by investigating the domestic uses of biomass resources, analysing the market segment and studying the biomass supply chain. Global lignocellulosic biomass trade, production and consumption volumes of biomass at selected sourcing regions are explored to understand local markets and demand for biomass"* (Mai-Moulin & Junginger, 2014). Lotte Visser will complement this research with assessing the potential supply of dedicated energy crops. Time constraints made it not possible to calculate the cost-supply curves for the 2020 optimistic scenario, and the 2030 BAU and optimistic scenario's, also GHG emissions in the biomass supply chain are not calculated in this research. These calculations will be done by BioTrade2020+ partners and implemented in the final Brazil country report.

1. Introduction

1.1 Scientific background and societal relevance

The world population more than doubled in the period between 1965 and 2010 from 3.29 billion to 6.92 billion and is estimated to grow with 21.6% to 8.42 billion people in 2030 (FAOSTAT, 2015). Population growth is historically linked to economic growth. Economic growth, in turn, is linked to increased consumption of energy to serve productive processes. Consequently, our society requires an increased amount of energy in the next decades to meet our basic human needs (IPCC, 2011). Global total primary energy supply (TPES) grew from 6,100 million tonne oil equivalent (Mtoe) in 1973 to 13,400 Mtoe in 2012. In 2012, 81.7% of TPES came from fossil fuel sources (oil, natural gas and coal) (IEA/OECD, 2014). Fossil fuels are the most polluting forms of energy supply in terms of greenhouse gas (GHG) emissions: 56.6% of all GHG emissions come from burning oil, natural gas and coal (IPCC, 2011). GHG emissions are the cause of anthropocentric global warming, which is the main driver of climate change (IPCC, 2007).

Besides the harmful effects on Earth's climate there are several other reasons why energy supply needs to shift from being dominated by fossil fuels to a more sustainable energy system. Two terms are important in this aspect: renewable energy and sustainable energy. However there is overlap between the definitions, they are not the same. The International Energy Agency (2015a) defines renewable energy as "Energy derived from natural processes (e.g. sunlight and wind) that are replenished at a faster rate than they are consumed. Solar, wind, geothermal, hydro, and some forms of biomass are common sources of renewable energy". Renewable energy is a comprehensive technical definition. The definition of sustainable energy is a bit more complex, and, as Prandecki (2014) points out, there is no clear definition. When we use the definition of sustainable development from the 1987 Brundtland Report of the World Commission on Environment and Development (Brundtland et al., 1987) and apply it on sustainable energy we can define it as any type of energy source that meets our needs and can be used far into the future without harming the needs of future generations. The definition of energy sustainability of the World Energy Council includes three core dimensions: energy security, social equity, and environmental impact mitigation (World Energy Council, 2015). In his book Sustainable Economy: Economic Theory and Practice of Sustainable Development Rogall (2009) describes sustainable energy in three dimensions: ecological, economic and socio-cultural. This is a division also used by Hammond and Jones (2011). The precise content of these dimensions may differ between the authors, but in general they agree on the three main pillars of which sustainable energy should consist. Due to its complexity sustainable energy is a relative concept, a set of ideas to which future energy supply should be designed accordingly to and try to meet them as much as possible.

Fossil fuels are not renewable, therefore they will be depleted at some point in the future, and thus an alternative source of energy is needed. Biomass is an alternative that has the potential to foster the transition to future sustainable energy systems, especially because it can serve as a direct substitute for oil and coal in many applications (Agar & Wihersaari, 2012; Fischer et al., 2010; IPCC, 2011; van Stralen, Uslu, Dalla Longa, & Panoutsou, 2013). According to the International Energy Agency (IEA) the contribution of biomass to the total world's energy supply is reaching 18% in 2050 (under the Blue Map Scenario) (IEA/OECD, 2010).

1.2 Problem definition

The European Commission (EC) stated that biomass has great potential to play an important role in realizing the 2020 climate change and energy targets (EC, 2014). The 2020 targets are: 20% reduction of GHG emissions compared to 1990, 20% share of renewable energy in final energy consumption, and increasing the energy efficiency by 20% (EC, 2011). New targets are set for 2030 and include a 27% share of renewable energy and 40% energy consumption reduction. In 2012, 64% of all the renewable energy consumption of member states came from biomass (IEE, 2014). The EC envisions an increase of final energy supply from biomass from 850 terawatt-hours (TWh) in 2007 to 1,650 TWh in 2020. Following the EU Renewable Energy Directive (EU RED) commissioned in 2009 EU Member States are required to have a share of at least 20% energy from renewable sources in their gross final energy consumption by 2020. Furthermore, at least 10% of the final energy consumption for transportation purposes must come from renewable energy sources (EC, 2009). Each member state has already developed a national renewable energy action plan, including national targets for the use of renewable energy.

In 2012, the total EU biomass supply for electricity, heating, and cooling amounted to 103.3 Mtoe, of which 95.7 Mtoe was domestically produced. Biomass supply is projected to grow to 132 Mtoe in 2020. Forest biomass represents 74.4% of the total biomass supply (71 Mtoe) in 2012. Although the share is decreasing to 55.7% in 2020, the absolute amount is expected to grow to 73.6 Mtoe. Agricultural biomass supply for energy is projected to grow from 13.2 Mtoe in 2012 to 41.7 Mtoe in 2020 (EC, 2014). However, it is not likely that all this biomass can be produced domestically in the EU.

Even at an aggressive mobilization rate of domestic biomass sources, imports of extra-EU biomass are likely to be needed in the short-term future. For 2020, a gap of 15% in the primary bioenergy supply is foreseen, corresponding to 21.4 Mtoe. This will largely be met by imports of woodchips and densified biomass, such as wood pellets (EC, 2014). The EU, especially the northwest, simply has not the advantages of larger land availability and favourable climate conditions like south-eastern USA, Brazil, western Africa, and Southeast Asia. Agricultural industries are far bigger in these regions, with the exception of western Africa, compared to the EU. In 2013, the top 8 crop commodities summed up to 1251 MT in South-America, 674 MT in North-America, 654 MT in southeast Asia, and 493 MT in the EU (FAOSTAT, 2015). Out of these regions, the EU also had the lowest growth percentage of production, yields, and harvested area in the 2000-2013 period (FAOSTAT, 2015). In 2014, Asia was world's biggest share of roundwood production with 30.6%, followed by the Americas (28.4%), Africa (19.6%), and the Europe (19.4%) (FAOSTAT, 2015).

Importing biomass from outside the EU can cause issues with sustainability (mainly in the sourcing countries), cost competitiveness, more complicated logistical infrastructure, and competition for food, feed and other uses (EC, 2014). Therefore, it is necessary to carefully examine biomass potentials under sustainability constraints. A lot of research on the use of biomass residues for energy and heating purposes has already been done, among them specific studies on the Brazilian case as well (Coelho, Monteiro, Karniol, & Ghilardi, 2012; Ferreira-Leitão et al., 2010; Forster-Carneiro, Berni, Dorileo, & Rostagno, 2013; Missagia, 2011; Portugal-Pereira, Soria, Rathmann, Schaeffer, & Szklo, 2015). However, no study has assessed the whole biomass residue supply chain, including: the availability of lignocellulosic biomass residues, applying sustainability constraints to the harvestable residue potential, giving priority to local demand of biomass residues for food, energy, and other uses, investigating the existing domestic biomass pre-treatment facilities and transport logistics and costs, as well as GHG emissions in the whole supply chain. This research attempts to fill in the blank spots in previous studies in one comprehensive study. Brazil was chosen as a case study because of its vast size of the country, geographic location in the tropics with favourable climatic conditions for high biomass yields, and high agricultural and forestry production volumes. This makes Brazil a promising candidate to provide large volumes of biomass residues to the EU.

1.3 Research aim and scope

The aim of this thesis research is to calculate the net potential volume of sustainable lignocellulosic biomass residues from agriculture and forestry in Brazil for export to the EU. Only lignocellulosic agricultural and forestry residues are considered; other biomass residues such as liquids and municipal and urban waste are not taken into account, because these are produced by different feedstocks, different production systems and are thus separate waste streams. Lignocellulosic biomass also occurs in larger volumes (Coelho & Escobar, 2013) and has suitable characteristics to be processed into wood- or torrefied pellets. Besides the criterion of being lignocellulosic, only residues are considered; dedicated energy crops are not. To calculate the energy potentials of energy crops, the land availability in Brazil has to be investigated, ideally including direct and indirect land use change effects. This is done by other BioTrade2020+ project partners. Focusing only on the lignocellulosic residues produced by agriculture and forestry makes it possible, considering the time available, to conduct a transparent and thorough, in-depth research.

In this research, ‘sustainable’, in relation to using lignocellulosic biomass residues for pellet production, is considered as not causing negative environmental effects, for example nutrient depletion in the soils, and erosion. Besides sustainability, local demand for feed, energy, and other sustainable uses, like using rice and coffee husks for chicken bedding and processing saw dust into wood panels, is given priority. It is important not to disturb the local market by exporting biomass residues that already have a sustainable use in Brazil itself. Other aspects are also taken into account, such as the current Brazilian wood pellet market, costs, and transport logistics. The current pellet production capacity directly limits the volume of surplus residues (sustainable potential minus local demand) that can be processed into pellets for export to the EU. Costs and transport logistics limit the economic viability of using biomass residues for pellet production.

For this Master’s thesis, only the logistics design and costs inside Brazil were assessed, the calculations of intercontinental transport cost will be carried out by BioTrade2020+ project partners using the BIT-UU model. This model calculates the least-cost route in Brazil, from the farm to the export terminal. Hoefnagels et al. (2014) have linked the BIT-UU with the Biomass Logistics Model (BLM) and extended it with intercontinental transport routes.

The calculations will be done for the current situation, 2020, and 2030, as well as for a business as usual and an optimistic scenario. The focus was laid on the feedstocks with the highest production volume in Brazil, the most productive states in terms of agriculture and forestry, and states close to export harbours.

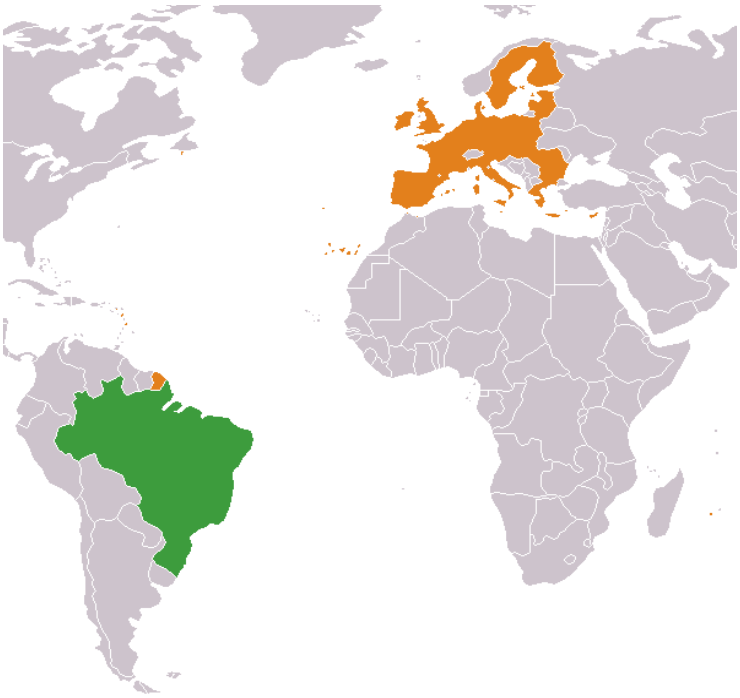

Figure 2 Geographical locations of Brazil (green) and the European Union (orange) (Wikimedia Commons, 2010)

1.4 Research questions

The main research question of this Master's thesis was:

> **What is the net sustainable lignocellulosic biomass residues potential in selected regions of Brazil available for export to the European Union, in 2012, 2020 and 2030, and for different scenario's?**

To support answering the main research question, a research framework (figure 3 in the methodology section) and a set of sub-questions were developed. The number before each sub-questions relate to the corresponding research steps in the framework.

Step	**Research questions**
1	What states in Brazil have the favourable combination of high productivity of agricultural and forestry feedstocks and proximity to export harbours?
2+3	What are the technical and sustainable production potentials of lignocellulosic biomass residues in Brazil? In 2012, 2020, and 2030, and in a BAU and optimistic scenario?
4	What is the domestic demand of lignocellulosic biomass residues, including uses such as food, feed and energy? In 2012, 2020, and 2030, and in a BAU and optimistic scenario?
	How does the Brazilian wood pellet industry look like and what are the future outlooks?
6	How does the international biomass residues supply and demand market look like and what are the future outlooks?
8	What are the costs in the biomass supply chain?
	What are the supply costs of lignocellulosic biomass residues at the current production capacity of the Brazilian wood pellet industry be delivered?

2. Methodology

Together with the BioTrade2020+ project partners, Utrecht University has developed a methodology to determine the net sustainable potential of lignocellulosic biomass resources in various regions of the world for export to the EU. The methodology is divided into four separate aims:

1.1 A methodology to develop global scenario's for trade of lignocellulosic biomass for energy and other purposes up until 2030

1.2 A methodology to assess competing demand for lignocellulosic biomass

1.3 A step-wise methodology how to determine the amount of net available sustainable biomass for export in a given country/case study

2 A methodology to optimise the supply chain of biomass from sourcing regions to the EU

Aims 1.2 and 1.3 have been used as a blueprint for the methodology of this Master's thesis research. The research steps were adopted and specified for the case study of Brazil. Aims 1.1 and 2 do not apply to the case study of Brazil specifically, and are thus not within the scope of this research. Other BioTrade2020+ partners will conduct the research for these aims.

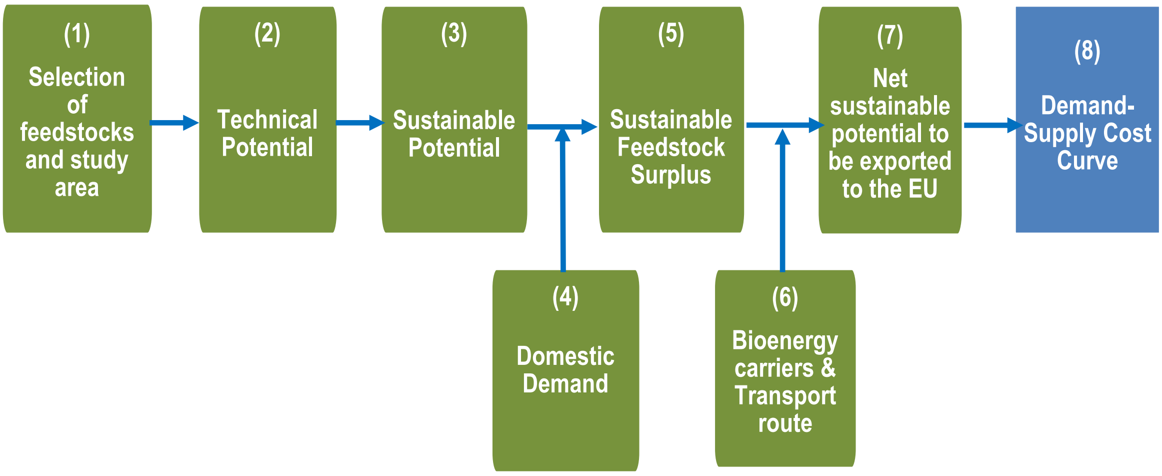

Figure 3 Assessment of sustainable lignocellulosic biomass value chains (adapted and modified from Mai-Moulin & Junginger (2014))

The framework is slightly different compared to the general framework developed for the country case studies. During the research it has been found more logical to change the order of some research steps, or to conduct some sub-steps under different main research steps. For example, the first step in the BioTrade2020+ methodology was to determine the country case studies, while in this Master's thesis research Brazil is already selected as case study. Step 1 is changed into determining on which feedstocks and states of Brazil to focus. The market potential is split into available surplus residues in Brazil and available wood pellet production capacity. These two aspects are investigated under step 4 and step 6. Step 6 and 7 are switched in order, since the available conversion technologies for biomass residues and transport logistics are a limiting factor on the net sustainable residues export potential, and thus have to be considered first. Step 5 and 7 are evaluations of the outcomes of step 4 and step 6, respectively. That is the reason there are no separate research questions for these steps. By modifying the general research framework into a specific framework for the Brazil case study and incorporating new insights from doing the research the results can be presented in a more logical and comprehensive way.

In order to collect necessary field data, an internship was conducted at the Energy Department of the Mechanical Engineering faculty of the University of Campinas (UNICAMP). Campinas is situated in the State of São Paulo, Brazil, and was the base from where the research for the Brazil case study was performed.

2.1 Estimation of Domestic Technical Biomass Production Potential

2.1.1 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 and not to put too much effort in investigating tiny, insignificant potentials or regions too far from export harbours. 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: seven agricultural feedstocks and two forestry feedstocks (see table 2). The feedstocks are chosen based on production volume (using a RPR it is a direct proxy for the volume residues produced from that particular feedstock) and the suitability of the residue product to be transformed into wood pellets (technology development). For these feedstocks the residue types and associated technical, sustainable and net surplus potentials were calculated for 2012, 2020 and 2030, and for the BAU and optimistic scenario (which are described in section 2.7).

Table 2 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)	Production (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		

FAOSTAT provided information about production and consumption of biomass in Brazil, for both agricultural- and forestry feedstocks. If the required data was not available through FAOSTAT, external sources were consulted like the ABIB, IBÁ or IBGE.

2.1.2 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 2). Research steps 2.1.1, 2.1.3 and 2.4 contributed data on the main criteria:

- Agricultural and forestry production volumes and residue-to-product ratio's
- Land quality / Production cost of biomass
- Geographical location and proximity to infrastructure (road-, rail- and maritime transport)
- Logistics infrastructure quality and costs

Table 3 Selection criteria for potential biomass production regions (adapted from Batidzirai et al. (2012))

Biomass productivity	Sustainability	Production cost	Logistics
Feedstock production volumes, spatial distribution, local demand	Nutrient preservation, soil erosion protection, maintaining 2% soil organic carbon	Harvesting costs, transport costs, storage and handling costs, pellet production costs, harbour cots	Presence and quality of infrastructure, distance to export harbours, pre-treatment facilities

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 (see table 3). 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 relatively close to sea ports, and logistics are competitive.

2.1.3 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 4.

Table 4 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 - Grains (corn and soybeans) used for ethanol, biodiesel, and bio products - Perennial grasses - Perennial woody crops
Secondary	- Animal manures - 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 - Removal of excess biomass (fuel treatments) from
Secondary	- Primary wood processing mill residues - Secondary wood processing mill residues - 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.

Technical potential is defined following E Smeets and Faaij (2007) and Batidzirai et al. (2012):

- The technical potential of biomass residues is defined as the fraction of the theoretical potential that is available under current technological possibilities and spatial restrictions due to transport distance and other land uses

2.1.3.1 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. The spatial distribution of the technical potential of agricultural residues was visualized with a map created with ArcGIS software, a geographical information system. In this map also information on the location export harbours and pellet factories is shown. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario.

The technical potential of agricultural residues was calculated with the equation:

$$AR = \sum_{i} (FP_i \times RPR_i)$$

Where:

AR	Technical biomass potential of primary agricultural residues (t/yr)
FP_i	Agricultural feedstock production (t/yr)
RPR_i	Residue-to-product ratio

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 5. All LHV values are on dry weight basis (0% moisture content).

Table 5 RPR and LHV values of agricultural residues

Feedstock	RPR	LHV (Mj/kg)
Sugarcane tops/straw	0.34[1]	17.38[5]
Sugarcane bagasse	0.30[1]	17.71[6]
Soybean straw	1.40[1]	12.38[3]
Corn stalk	0.78[2]	17.45[6]
Corn cob	0.22[2]	16.28[3]
Corn husk	0.20[2]	12.00[3]
Cassava straw	0.80[1]	17.50[3]
Rice straw	1.48[1]	16.02[3]
Rice husk	0.22[1]	14.17[7]
Coffee husk	0.21[1]	17.71[5]
Orange peel	0.50[4]	17.11[8]

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

2.1.3.2 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 3): 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). Similar to agricultural residues, a map was created with ArcGIS to visualise the spatial distribution of the technical potential of forestry residues. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario.

The technical potential of forestry residues was calculated with the equation:

$$FR = \sum_i (WP_i \times RPR_i)$$

Where:

FR	Technical biomass potential of primary and secondary forestry residues (t/yr)
WP_i	Wood production from eucalyptus and pine plantations (t/yr)
RPR_i	Residue-to-product ratio

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 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 4 illustrates the breakdown of residue production in the three stages of wood processing of planted forest.

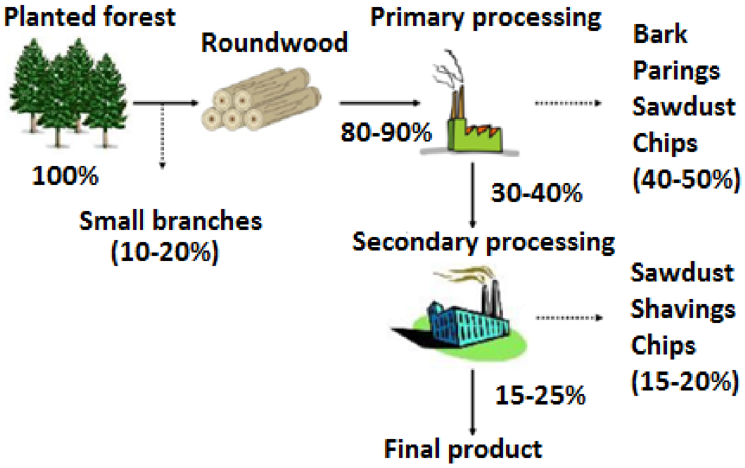

Figure 4 Residue production in various stages of planted forest wood processing (made according to STCP, 2011)

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 6. All LHV values are on dry weight basis (0% moisture content).

Table 6 RPR and LHV values of forestry residues

Feedstock	RPR	LHV (Mj/kg)
Field residues	0.15[1,2]	19.05[6]
Paper and cellulose production residues	0.117[3,4,]	18.18[7]
Sawmill and furniture industry residues	0.3825[1,2,5]	18.18[7]

[1] Coelho and Escobar (2013)
[2] STCP (2011)
[3] Gavrilescu (2004)
[4] Briggs (1994)
[5] Bortolin, Trentin, Peresin, and Schneider (2012)
[6] Boundy, Diegel, Wright, and Davis (2011)
[7] de Paula Protásio et al. (2013)

2.2 Estimation of the Sustainable Biomass Residue Potential

The sustainable potential was defined as the fraction of the technical potential that is available under sustainability criteria consideration (Batidzirai et al., 2012). 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). Lal & Pimentel (2007) question whether or not residues should be used for energy production, instead of carbon sequestration and soil quality improvement. *"Should the answer to this question be determined by short-term economic or the long-term sustainability of natural resources?"* On the other hand there are many authors who are 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).

The sustainability criteria and indicators used in this research to calculate the sustainable potentials of agricultural and forestry residues in Brazil are listed in tables 7 and 8. In the literature, nutrient preservation, soil erosion prevention and maintaining soil organic carbon appeared to be the most important factors to account for when removing residues from the field. For forestry residues conservation areas are also a criteria, meaning only residues from forest plantation are investigated and not from native and preserved forests. However, a few criteria are not taken into account, due to being out of scope for this research: direct and indirect land use change, supply chain GHG emissions. These criteria are certainly of importance, and will be implemented in research from other project partners.

Table 7 Sustainability criteria for agricultural residues

Criterion	Indicator
Soil quality	Erosion Soil organic carbon Soil nutrient balance

Table 8 Sustainability criteria for forest plantation residues

Criterion	Indicator
Biodiversity	Conservation areas
Soil quality	Erosion Soil organic carbon Soil nutrient balance

2.2.1 Agricultural residues

A sustainable recovery factor (SRF) was applied to the technical potential of agricultural residues. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario. The sustainable potential of agricultural residues was calculated with the equation:

$$SAR = \sum_{i} (AR_i \times SRF_i)$$

Where:

SAR	Sustainable biomass potential of primary agricultural residues (t/yr)
AR_i	Technical biomass potential of primary agricultural residues (t/yr)
SRF_i	Sustainable recovery factor, the percentage of agricultural residues that can be sustainably removed

Table 9 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). Farmers or organizations from other crops were very hard to get in contact with during the fieldwork in Brazil, but there were accurate SRF's available in literature from various sources. 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. While it is true that SRF's depend on local conditions, soil type, and field inclination (Andrews, 2006) assumptions have to be made to generalize SRF's for all the researched states. 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. When multiple sources are noted after a SRF it means all these sources reported the same SRF.

Table 9 SRF values of agricultural residues

Feedstock	SRF
Sugarcane tops/leaves	0.50[1,2,3,4]
Sugarcane bagasse	1[5]
Soybean straw	0.25[4]
Corn stalk	0.30[4,6,7,8]
Corn cob	0.30[4,6,7,8]
Corn husk	0.30[4,6,7,8]
Cassava straw	0.30[4,6,7]
Rice straw	0.25[4]
Rice husk	1[5]
Coffee husk	1[5]
Orange peel	1[5]

[1] Assumpção (2015)
[2] Ferreira-Leitão et al. (2010)
[3] UNICA (2015)
[4] Forster-Carneiro et al. (2013)
[5] Not produced in field, processing residue
[6] Lindstrom (1986)
[7] Papendick and Moldenhauer (1995)
[8] Graham, Nelson, Sheehan, Perlack, and Wright (2007)

2.2.2 Forestry residues

A sustainable recovery factor (SRF) was applied to the technical potential of forestry residues. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario. The sustainable potential of agricultural residues was calculated with the equation:

$$SFR = \sum_i (FR_i \times SRF_i)$$

Where:

SFR	Sustainable biomass potential of primary and secondary forestry residues (t/yr)
FR_i	Technical biomass potential of primary and secondary forestry residues (t/yr)
SRF_i	Sustainable recovery factor, the percentage of forestry residues that can be sustainably removed

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 not produced on the field, thus it is assumed they can be 100% sustainably utilized.

Table 10 SRF values of forestry residues

Feedstock	**SRF**
Eucalyptus field residues	0.525[1]
Eucalyptus processing	1[2]
Pine field residues	0.525[1]
Pine processing residues	1[2]

[1] AEBIOM (2007)

[2] Not produced in field, processing residue

2.3 Domestic Demand for Biomass for Energy, Feed, and Other Uses

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. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario.

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.

2.4 Global Biomass Demand and Supply

The global market for the demand and supply of biomass and bioenergy has grown rapidly in the past few years, and RES programs like the EU RED are very likely to contribute towards further and faster growth. Biomass trade flows towards the EU were investigated to establish the position of the EU in the global demand, and supply market for biomass and bioenergy at current situation, 2020 and 2030.

External resources and data like the IEA World Energy Outlook for Renewable Energy and the IEA Energy Technology Perspectives 2050 report were reviewed to estimate global biomass demand, supply and trade for various timeframes and scenarios. Due to time constraints these estimations could not be validated with modelling future biomass demand and supply for different scenarios in models. However, this will be done in further research of BioTrade2020+ project partners.

2.5 Estimation of the Net Sustainable Biomass Residue Surplus Potential to be Exported to the European Union

The technical potential of lignocellulosic biomass residues in the selected states of Brazil, the sustainable potential, and the domestic demand and consumption of biomass residues, is all the input needed to calculate the net sustainable biomass surplus potential to be exported to the EU. This research step was done for 2012, 2020 and 2030, and for the BAU and optimistic scenario. The net surplus potential was calculated with the data input of the results of sections 2.1-2.3 and using the following equation:

$$NR = \sum_{i,k} (SAR_i - UA_i) + (SFR_k - UF_k)$$

Where:

NR	Net sustainable biomass residue surplus potential (tons/yr)
SAR_i	Sustainable biomass potential of primary agricultural residues (tons/yr)
SFR_k	Sustainable biomass potential of primary and secondary forestry residues (tons/yr)
UA_i	Demand for agricultural residues for other applications (tons/yr)
UF_k	Demand for forestry residues for other applications (tons/yr)

2.6 Biomass Transport Logistics, Supply Chain Costs and Cost-Supply Curves

The next step was to take into account the supply chain of agricultural and forestry residues, from the field till the export harbour. Logistics infrastructure, road transport, and trade facilitation were considered. To assess whether the imported biomass residues from Brazil 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 whether consumers in the EU are willing to import Brazilian biomass residues and/or their derivatives and if Brazilian producers are willing to export them rather than selling them on the Brazilian market or assigning any other purpose to the residues.

2.6.1 Biomass logistics design

To determine the lowest domestic supply chain costs the optimal transport routes of the biomass residues from the sourcing region to the export harbour were calculated. Although there is a developed railroad network in the southeast of Brazil (see figure 8), 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 coordinates of all existing and producing pellet factories in the study area were put in ArcGIS, as well as coordinates of 18 export harbours. The harbours were selected on the basis of port facilities, such as being able to handle containers, presence of heavy duty lifting cranes, and shipping volume capacity. ArcGIS was used for determining the geographical centre points of micro-regions. The obtained coordinates were exported to Excel and using the Haversine equation the straight line distance between the geographical centre points, pellet factories, and export harbours were calculated. A tortuosity factor was used for the conversion of a straight line to road distance. The created matrix with distances between micro-regions and pellet factories, and pellet factories and export harbours served as input data for calculating the cost-supply curves (see section 2.6).

Information on the location, production capacity and primary material use of Brazilian pellet factories was obtained from the Brazilian Pellet Industry Association (ABIPEL), while World Port Service was consulted for an overview and characteristics of Brazilian export harbours. 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). For calculation purposes a value of 1.35 was used.

2.6.2 Assessment of biomass residues supply chain costs

To estimate the cost of biomass production of the selected biomass feedstocks in Brazil the cost balance equation was used:

$$C_D = C_P + C_{Pt} + C_{Td} + C_H$$

Where:

C_D	Total production cost of biomass residues (€/t)
C_P	Harvesting costs (€/t)
C_{Pt}	Cost of pre-treatment (€/t)
C_{Td}	Cost of domestic transport from field to pellet factory and from pellet factory to export harbour(€/t/km)
C_H	Harbour costs (€/t)

Table 11 gives an overview of all the costs in the supply chain of lignocellulosic agricultural and forestry residues. Moisture contents of the feedstocks considered are: 15% for straw bales (sugarcane, soybean, corn, rice)(Filho, 2005; McKendry, 2002) and rice husks (Belonio, 2005), 50% for bagasse (Missagia, 2011; Usina Santa Lucia, 2015), 30% for forestry field residues (Negredo Junior, 2015; Van Loo & Koppejan, 2008), and 50% for paper and cellulose production residues and lumber processing residues (chips, sawdust, shavings)(Van Loo & Koppejan, 2008).

Table 11 Biomass residue supply chain costs

Feedstock	Harvesting (€/t)	Transport (€/km/t)	Pre-treatment (€/t)	Transport pellet (€/km/t)	Profit EBITDA (€/t)	Harbour costs (€/t)
Sugarcane tops/straw	9.42[1]	0.09[1]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Sugarcane bagasse	4.42[2]	0.38[2]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Soybean straw	16.33[3,5,6]	0.09[1]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Corn stover	19.98[3,5,6]	0.09[1]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Rice straw	17.43[4,5]	0.09[1]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Rice husks	0	1.475[2]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Forest field residue	11.72[7]	0.28[7]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Paper & cellulose residue	29.34[8]	0.28[7]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]
Lumber processing residue	29.34[8]	0.28[7]	50.17[9]	0.10[8,10]	27.27[9]	7.26[9]

[1] Filho (2005). Field experiments in São Paulo. Trash collecting in field, baling, loading and unloading, trailer towing, and bale transport on the field.

[2] Missagia (2011). Bagasse: feedstock price when bought from a sugarcane mill, 30% moisture content. Transport cost of 20 Brazilian Real per ton for 30 km, converted to €/km. Rice husk: given to

chicken farmer, who only pays transport costs of 100 Brazilian Real per ton for 30 km, converted to €/km. The high cost of rice husk transport can be explained by the very low density of about 90 kg/m^3 (Belonio, 2005)

[3] Kludze et al. (2013). Corn stover needs to be chopped before it can be baled. Cost of stover chopping is added to harvest costs of reference 4,5, and 6.

[4] Kadam, Forrest, and Jacobson (2000). Field experiments in the US. Reports just like reference 5 rice straw harvesting costs of around US$ 20. Includes: collection, baling, loading and unloading, and transport on the field.

[5] Delivand, Barz, and Gheewala (2011). Field experiments in Thailand. Includes: collection, baling, loading and unloading, and transport on the field. Rice straw harvesting costs of around US$ 20, an average of reference 4 and 5 is taken.

[6] Sultana and Kumar (2011). Reports similar straw baling costs of €8,60/t as references 5 and 6.

[7] Negredo Junior (2015). Visit to Klabin forest plantation in Telêmaco Borba, Paraná.

[8] Rasga (2013). Raw material price when bought from a sawmill, based on a density of 350 kg/m^3 and 50% moisture content.

[9] BBER (2015b). Brazilian biomass industry association. Pre-treatment: pellet production cost including storage, operation cost of pellet mill, energy, labour, and amortization. Profit EBITDA: profit of pellet manufacturer before interest, taxes, depreciation, and amortization. Harbour costs: fixed transport costs and harbour fees and taxes.

[10] Questionnaire held among Brazilian pellet manufacturers, respondents were: Ecoxpellets, Araupel, TCF Pellets, and Chamape. Reported transport costs range between €0,083 – 0,103 /t/km. Rasga (2013) notes €0,104/t/km. An average of €0,096/t/km at 10% moisture content is used.

2.6.3 Developing demand-supply cost curves

Existing pellet factories were matched with the nearest micro-regions, as calculated in section 2.6.2, and the pellet production capacity was filled with the net sustainable residue surplus potentials, as calculated in section 2.5. A capacity factor of 80% was used, derived from the pellet industry in the USA (unpublished work by Hoefnagels). The USA is the largest supplier of wood pellets to the EU (Pöyry, 2011), and with the growing EU demand it is assumed the Brazilian pellet factories can operate at the same capacity factor as the USA. 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). When the nearest micro-region cannot supply the complete volume of residues to fill the production capacity of a factory, the second nearest micro-region is linked, and so forth. When multiple micro-regions supply one pellet factory, their respective shares in the raw material supply are calculated and applied to the total transport costs of raw material from the field to the mill. Since in that case the raw material is transported over different distances, and the biomass is delivered at different costs in the factory, also the final biomass supply from one factory is delivered at different costs at the export harbour.

Data input was supplied by research steps 2.5, 2.6.1, and 2.6.2. The cost-supply curves were calculated for all the feedstocks with available net surplus residues in 2012 and for the 2020 BAU scenario for sugarcane- and forestry residues. Time constraints made it not possible to conduct the calculations for the other feedstocks for 2020 BAU, 2020 optimistic, 2030 BAU, and 2030 optimistic.

2.7 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.

2.7.1 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. 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. 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 12). 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. 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 12 Local demand for agricultural residues in 2020/2030 and in BAU/optimistic scenario

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 13 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 13). 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

For 2020, pellet production capacity is assumed to consist of existing and currently planned new factories. For 2030 this capacity is expected to grow with a capacity growth rate derived from the development of the pellet market in the USA. This is currently the largest international pellet industry. In 2020 the Brazilian installed wood pellet production capacity is about 3.8 MT (existing plus planned), estimations in unpublished work from Hoefnagels show that a production of 3.7 MT wood pellets in the USA in 2014 can grow to about 12 MT in 2024, a ten year time span. This growth rate is adapted and applied to the Brazilian pellet industry, resulting in an estimated production capacity of 12 MT in 2030. New factories have a production capacity of 250 kt pellets per year, the optimal pellet factory size as calculated by Batidzirai (2013) are placed in micro-regions that are located close to export harbours and produce enough residues to supply the needed raw material input.

2.7.2 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 and the 2014-2024 period. Outlooks for the 2012-2022 period give higher estimates compared to outlooks for 2014-2024. This could be explained by the extreme weather conditions in south- and southeast Brazil, which affected harvests in 2012 and 2013. Assuming such bad harvesting seasons occur less frequently in the optimistic scenario the higher growth estimates of the 2012-2022 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 7 for agricultural residues and in table 8 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. 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

New pellet plants are expected to be built in micro-regions in a similar way described in the BAU scenario. Existing and planned factories, which are operational in 2020, will increase their production capacity according to the amount of residues available in the micro-region where the factory is located. On top of that, the quality and development of infrastructure, especially railroad transport, is assumed to improve drastically. More regions are connected to fast and cheap transport options, and truck transport is not the only transport mode anymore. Rail transport will be allocated for transport of pellets to the export harbour, which will lower the delivery cost of wood pellets.

3. Case Study Description

3.1 General Country Characteristics Brazil

The Federative State of Brazil is a country located in the eastern part of South-America. It is the 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). After 325 years of colonial suppression by Portugal, Brazil becomes officially independent on August 29 1825 with the Treaty of Rio de Janeiro. Dom João VI remained king of Brazil and had several successors until a military coup on November 15 1889 proclaimed the Republic of Brazil. A turbulent century with several presidents interspersed with military juntas came to an end in 1988 with the formulating of the current constitution and defining Brazil as a federal republic (3rd edition of the Constitution of the Federative Republic of Brazil, 2010).

3.1.1 Demography, geography and climate

Brazil is divided into 26 Federal Units or states (figure 5), 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).

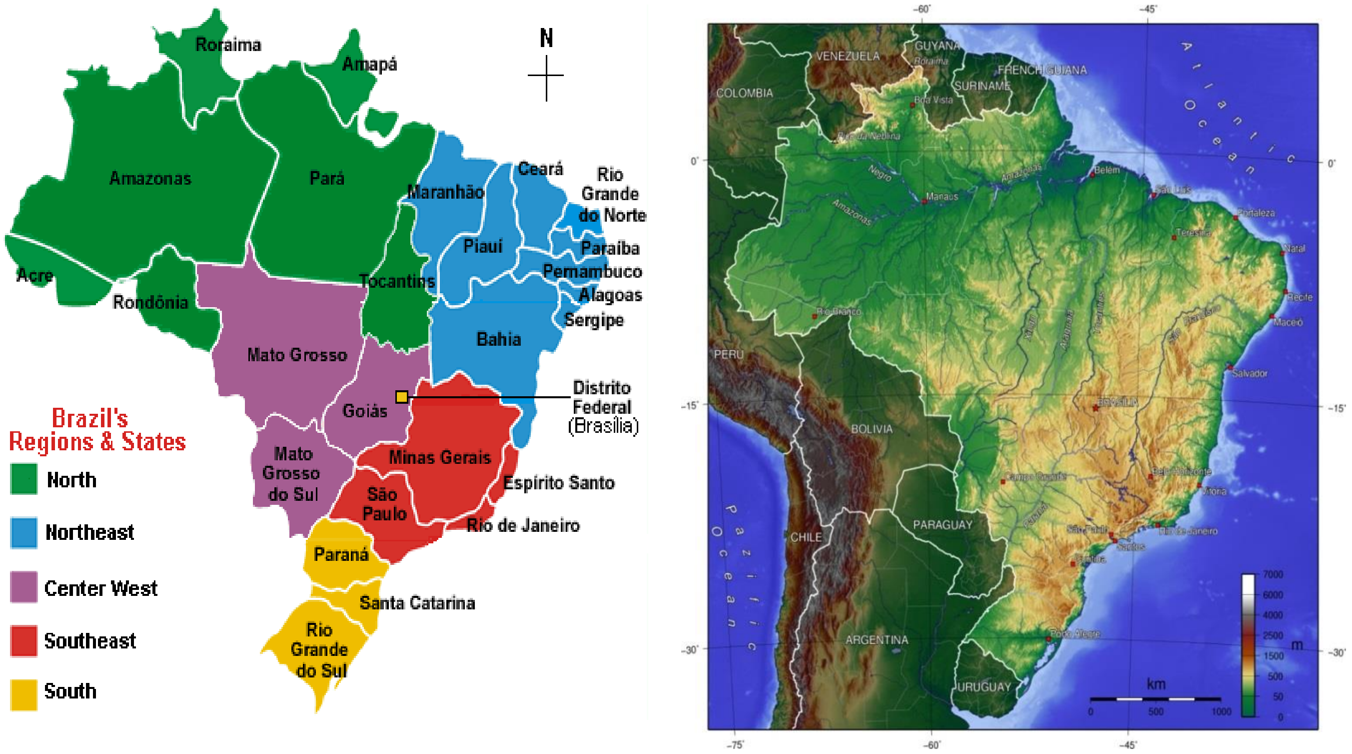

Figure 6 Left: administrative division of Brazil/ Right: Topographical map of Brazil

Stretching 4,395 km between roughly 5^{o} North and 34^{o} South, and 4,319 km between roughly 34^{o} West and 74^{0} West, 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, the 2nd largest area after Russia (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). Most of the north, centre-west and the north-east coast of Brazil have a tropical climate, with a gradual decrease in the frequency and volume of precipitation from north-west to south-east direction. Semi-arid dry zones occur in the north-east and a sub-tropical climate is prevalent in the south and south-east (Alvares et al., 2013). As opposed to the Andes countries in the west of South-America, Brazil's geological formation is very old. As a result, tens of millions of years of erosion has shaped the country's landscape. While the highest mountain of Brazil (2,994 m above sea level) is located close to the Venezuelan border, the principal mountain ranges are located in the south-east with elevations averaging around 2,000 m (see figure 6). However, only 0.5% of Brazil lies above 1,200 m. Other large geomorphological sections are the Central Highlands (averaging about 1,000 m) and the Amazon Basin (averaging around 200 m) (Hudson, 1998).

One of the greatest features of the Brazilian landscape is the extensive river systems slicing through the country. Eight major draining basins all end up in the Atlantic ocean, with the largest two, the Amazon Basin and the Tocantins-Araguaia Basin, accounting for more than half of the country's total drainage area. 20% of the world's water supplied to oceans by rivers originates from the Amazon Basin (Hudson, 1998).

3.1.2 Land use in Brazil

Figure 9 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 (see table 14). 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).

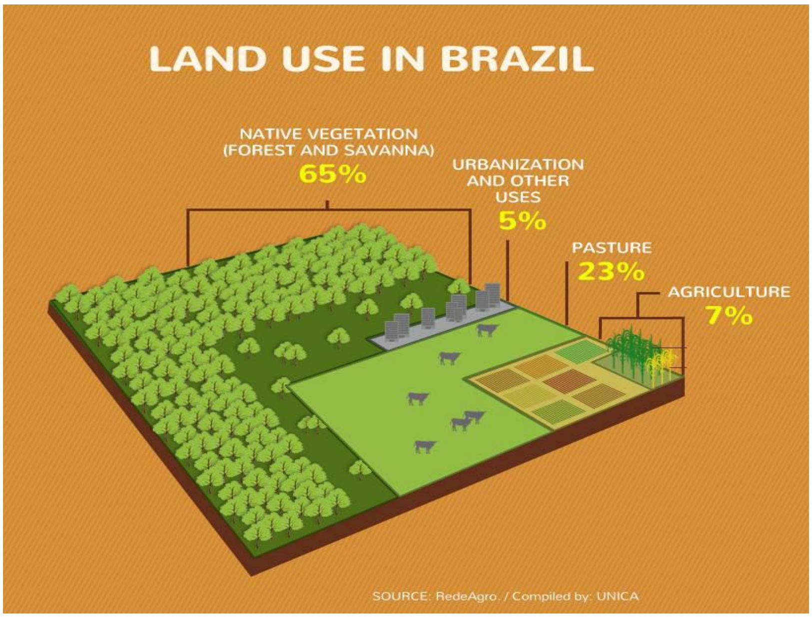

Figure 7 Land use in Brazil (RedeAgro/UNICA, 2015)

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.

Table 14 Land use in Brazil in 2012 (FAOSTAT, 2015; IBA, 2014a; IBGE, 2015a; ICONE, 2012)

Land use	Ha*10^3
Total land area	851,577
Water body	15,763
Settlement/infrastructure	42,580
Forest and savanna	553,525
Native forest/savanna	546,135
Planted forest	7,390
Agriculture	59,610
Meadow/pasture	195,863

3.1.3 Social development, economy, and industry

Brazil is going through a huge economic development since the beginning of the millennium and is a member of the BRICS, 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 2,244.131 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 0.744 (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). These numbers may sound pretty bad and indicates Brazil still has a long way to go before being established as a developed, in all aspects of society, industrialised country, but every single of the aforementioned indicators has improved significantly in the past few years.

Estimates from 2013 indicate that services contributed 68.1% to the GDP, industry 26.4% and agriculture 5.5% (25% when including agribusiness). However, if we look at the value of Brazil's exports we see that agricultural products make up 36% (CIA, 2014). The main industries are automobile, petrochemicals, machinery, electronics, cement, textiles, food and beverages, mining and aircraft, while the main agricultural products are soybeans, coffee, beef, citrus, sugarcane, rice, corn and cocoa. Table 15 depicts the trade balance, the shares in imports and exports of the different commodities, and their destinations and origin in 2013. 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). Table 15 clearly shows the importance of exports of agricultural and forestry products like soybeans, sugar and ethanol, and pulp and paper. The existing trade infrastructure gives opportunity to the trade of lignocellulosic biomass products to the EU.

Table 15 Trade balance of Brazil (MDIC, 2013)

Main exported products and its shares	Main imported products and its shares
Ores – 14.5%	Oil and fuels – 19.1%
Transport materials – 13.0%	Mechanic equipment – 14.9%
Soybeans and products – 12.8%	Electric/electronic equipment – 11.8%
Oil and fuel – 9.2%	Vehicles and parts – 9.4%
Meats– 6.7%	Chemicals – 5.5%
Chemicals – 6.0%	Fertilizers – 3.7%
Sugar and ethanol – 5.7%	Plastics – 3.7%
Metallurgic products – 5.5%	Iron, steel and its products – 3.3%
Machines and equipment – 3.7%	Pharmaceuticals – 3.1%
Pulp and paper – 3.0%	Optical and precision equipment – 3.0%

Major export destinations and its shares	Main supplier countries and its shares
China – 19.0%	China – 15.6%
United States – 10.3%	United States – 15.1%
Argentina – 8.1%	Argentina – 6.9%
The Netherlands – 7.2%	Germany – 6.3%
Japan – 3.3%	Nigeria – 4.0%

3.2 Energy and Electricity Sector

3.2.1 Energy and resources

Brazil has a large variety of natural resources, including bauxite, gold, iron ore, manganese, nickel, phosphates, platinum, tin, clay, uranium and petroleum. In 2013 the reserves (measured and estimated) of petroleum, natural gas and coal amounted to 4,798,620 thousand m3, 839,482,000 m3, and 32,285,000 t, respectively (EPE, 2014). To put this into an international perspective: Brazil is the world's 12th largest oil producer, with 3.05% of the global market share (IEA, 2014). Brazil's coal and natural gas production is not of a significant share of the global market volume. In 2006 a huge oil field was found in the pre-salt layer deep under the ocean floor of the coast between the states of Santa Catarina and Espírito Santo. The state-controlled oil company Petrobras has the license to explore the pre-salt fields, and in 2014 they were producing 492,000 barrels per day, representing almost 20% of the company's total production (Petrobras, 2015). With the deep ocean drilling techniques becoming more and more economical competitive with conventional fossil fuel sources production from these fields have gained a significant share in Brazil's total petroleum and natural gas production: 15% and 14% respectively (EIA, 2015). Several new fields have been found in the pre-salt layer since its first discovery, and estimates are that the total reserves could be 50 million barrels of oil, four times as large as Brazil's current national reserves (EIA, 2015). The ultra-deepwater drilling is the topic of a strong environmental debate, but could make Brazil one the world's biggest oil producers, fostering their economic development enormously.

Despite the recent discoveries of large fossil fuel reserves Brazil is one of the only large economic and industrial powers with a very high share of renewable energy in their electricity matrix. A staggering 79.3% of the domestic electricity supply comes from renewable resources, of which hydroelectricity makes up 70.6% (see figure 8) (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). It was still the largest in 2013, but several droughts have curbed Itaipu's electricity output in 2014. 2013 production was 98.6 TWh and provided 75% of Paraguay's electricity needs and 17% of Brazil's (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. Dams to retain water in large basins can cause a large area upstream of the dam to be innundated, destroying nature, lowering biodiversity and in some causes destroy land owned and inhabited by natives. Furthermore, downstream of the dam the water supply will be susbstantially less, which can affect the needs of human water consumption and agricultural consumption. Droughts on the other hand can severely harm the plant's electrocity output, and, since Brazil is highly dependent on hydroelectricity, plunge the whole country in an energy crisis. This happened in the period 2001-2002, when for more than four months electricity supply could not be ensured. In that period, almost 90% of Brazil's installed electricity production was hydroelectric. Besides several drier years than average, transmission problems and delays in the commissioning of new generation problems contributed to the crisis (World Bank, 2007).

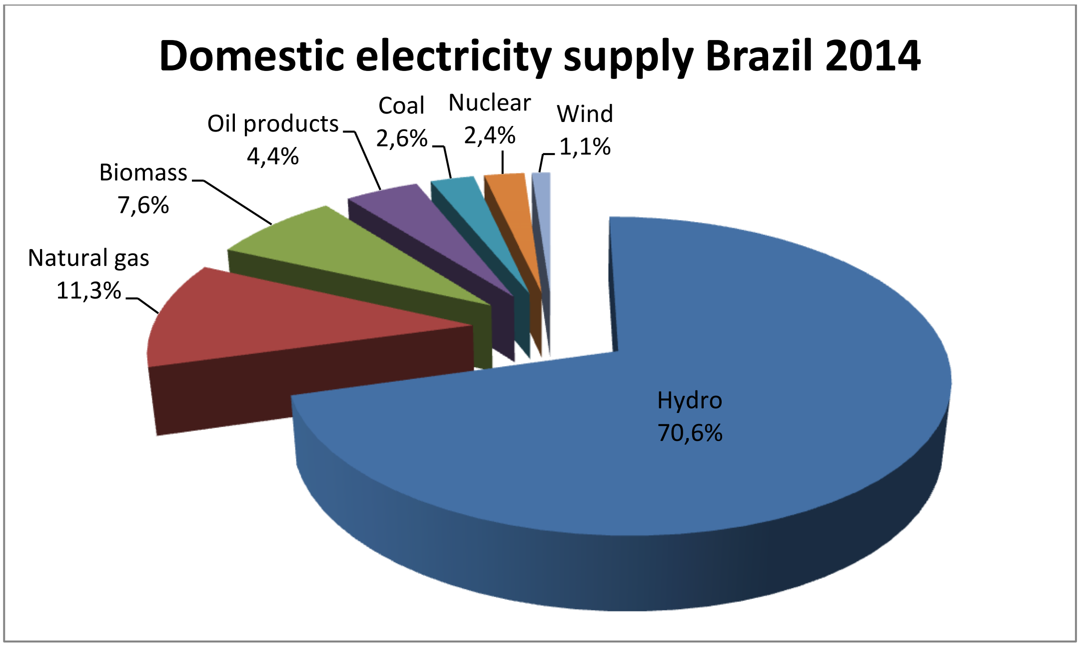

Figure 8 Domestic electricity supply by source (own work, data from: EPE, 2014)

Table 16 summarises the energy and electricity mix of Brazil in 2013. As said, 79.3% of the domestic electricity supply is provided by renewables, while it constitutes 41% of the domestic energy supply and 46.4% of the primary energy production.

Table 16 Energy and electricity mix of Brazil in 2013 (assembled with data from EPE, 2014)

Non-renewable energy	Domestic electricity supply (% of total)	Domestic energy supply (10^3 toe)	Primary energy production (10^3 toe)
Petroleum and oil	4.4%	116,500 (39.3%)	104,762 (40.6%)
Natural gas	11.3%	37,792 (12.8%)	27,969 (10.8%)
Coal and coke	2.6%	16,478 (5.6%)	3,298 (1.3%)
Nuclear	2.4%	3,896 (1.3%)	2,375 (0.9%)
Total	**20.7%**	**174,665 (59%)**	**138,404 (53.6%)**
Renewable energy			
Hydraulic	70.6%	37,054 (12.5%)	33,625 (13.0%)
Firewood and charcoal	-	24,580 (8.3%)	24,580 (9.5%)
Sugarcane products	-	47,603 (16.1%)	49,306 (19.1%)
Biomass	7.6%	(incl. in others)	(incl. in others)
Wind	1.1%	(incl. in others)	(incl. in others)
Others	-	12,313 (4.2%)	12,340 (4.8%)
Total	**79.3%**	**296,215 (41%)**	**119,852 (46.4%)**

3.2.2 Sugarcane and ethanol

A striking feature is the contribution of sugarcane products to the domestic energy supply and primary energy production: respectively 16.1% and 19.1%. Brazil has a long lasting history of ethanol fuel from sugarcane. 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). The global oil crisis, which caused prices on the world oil market to increase with 300% in just five months, triggered the end of the so called ‘Brazilian Miracle’, a period of accelerated economic growth. From 1973 to 1974 the value of Brazilian oil imports more than quadrupled from US$ 600 million to US$ 2,5 billion (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. The second global oil crisis of 1979 caused oil prices to increase with 200%, and even more in the subsequent years. In 1986, prices were on a level considered normal again. This new crisis encouraged the government to take more measures to stimulate ethanol as a fuel. 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. These measures were extremely successful: after just six years, in 1985, ethanol-fuelled cars accounted for 96% of all new cars sold. After this peak however, Brazil started to face a severe economic crisis at the end of the 1980’s. Inflation reached record heights in 1989 and the inflation control policy of the government caused the removal of ethanol incentives. Accompanied with decreasing oil prices this negatively affected the competitiveness of ethanol. Production was cut and gasoline made a comeback. 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. Between 2004 and 2009 hydrous ethanol consumption increased by 265% and in 2007 total ethanol consumption surpassed gasoline consumption in the state of São Paulo. Since 2015 regular gasoline has to be blended with at least 27% ethanol (Amato & Matoso, 2015).

3.2.3 Renewable energy

Besides fostering the use of biofuels, Brazil has made considerable effort to promote alternative sources of electricity. Earlier in this chapter hydroelectricity was already discussed. 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.

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 9 shows the increase of final energy consumption from biomass resources. The majority of the increase is the result of the increase in bagasse firing.

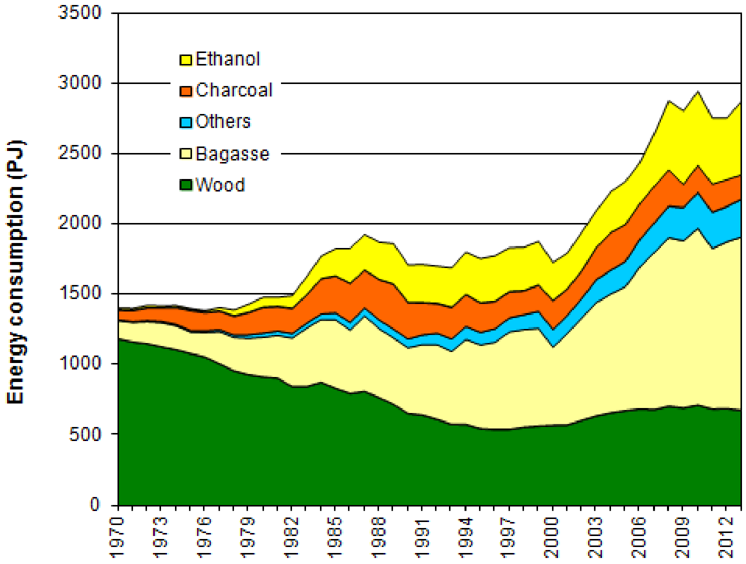

Figure 9 Final energy consumption of biomass resources (EMP/MME, 2014)

3.3 Agriculture and Forestry Sector

3.3.1 Agriculture sector in Brazil

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. Initially the focus was laid on cultivating sugarcane, but Brazil has grown to be the world's largest producer of, among others, coffee, oranges, and sugarcane. Brazil is also 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).

Table 18 lists the most produced agricultural commodities in Brazil in 2012. The production volume of a feedstock is a direct proxy for the production volume of residues. From this list the feedstocks with the largest production volume as well as with residues with suitable characteristics for pelletizing are chosen. Sugarcane is by far the most produced feedstock, it outnumbers the number two feedstock, corn, by a factor ten. Seven agricultural feedstocks have been chosen: sugarcane, corn, soybean, cassava, oranges, rice, and coffee. Rice and coffee have a relative low production volume compared to the others, but have been added due to the good suitability of their residues, straw and husks, for producing pellets. Rice also has a high RPR of 1.7 (see table 5).

Table 17 Agricultural sector Brazil 2012 (IBGE, 2012)

Agricultural feedstocks	Planted area (ha*10^3)	Yield average (t/ha)	Production (kt)
Sugarcane	9,752	74	721,077
Corn	15,065	5	71,073
Soybean	25,091	3	65,849
Cassava	1,758	14	23,045
Oranges	763	25	18,013
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

In relation to the scope of this research, identifying the potential of agricultural and forestry residues for export to the EU, it is of importance to focus on the volumes of residues easiest accessible and closest to the export harbours, in order to minimize transport costs. As explained in chapter 3, the southeast and south of Brazil are where the population and GDP income is concentrated. In these coastal states, bordering the Atlantic ocean, the biggest cities and the harbours with the highest loading and unloading capacity are located. Furthermore, fertile soils, and the sub-tropical climate with enough precipitation give better conditions for large-scale agricultural cultivation compared to northern and central Brazil. In table 18, the production volumes of the seven chosen feedstocks are listed per state. In the column on the right the production volume in these seven states is calculated as the share of the total production volume in Brazil. 70% of the total volume of the seven feedstocks is produced in the southeast and south. Rio de Janeiro is not taken into account, because the agricultural production is of a magnitude similar to Espírito Santo, which is already low compared to the other states, and the planted forest industry is negligible (see paragraph 5.1.2).

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%**

3.3.2 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 (see table 19) (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).

Table 19 Planted forest sector characteristics Brazil 2012 (calculated with data from (Couto, Nicholas, & Wright, 2011; Escobar, 2014; FAO, 1999; IBÁ, 2014a; Ryan, 2008))

Forestry feedstocks	Planted area (ha*10^3)	Yield average (t/ha)	Production (kt)
Eucalyptus	5,304	19.05	101,041
Pine	1,563	20.88	32,635
Rubber tree	169	-	-
Acacia	148	-	-
Parica	87	-	-

Just like agricultural production planted forests are concentrated in the southeast and south of Brazil, as is visualized in figure 10. The states with the largest area of forest plantations are Minas Gerais and São Paulo. Rio de Janeiro is not taken into account, because the planted forest area is less than 20,000 ha, insignificant compared to the other states.

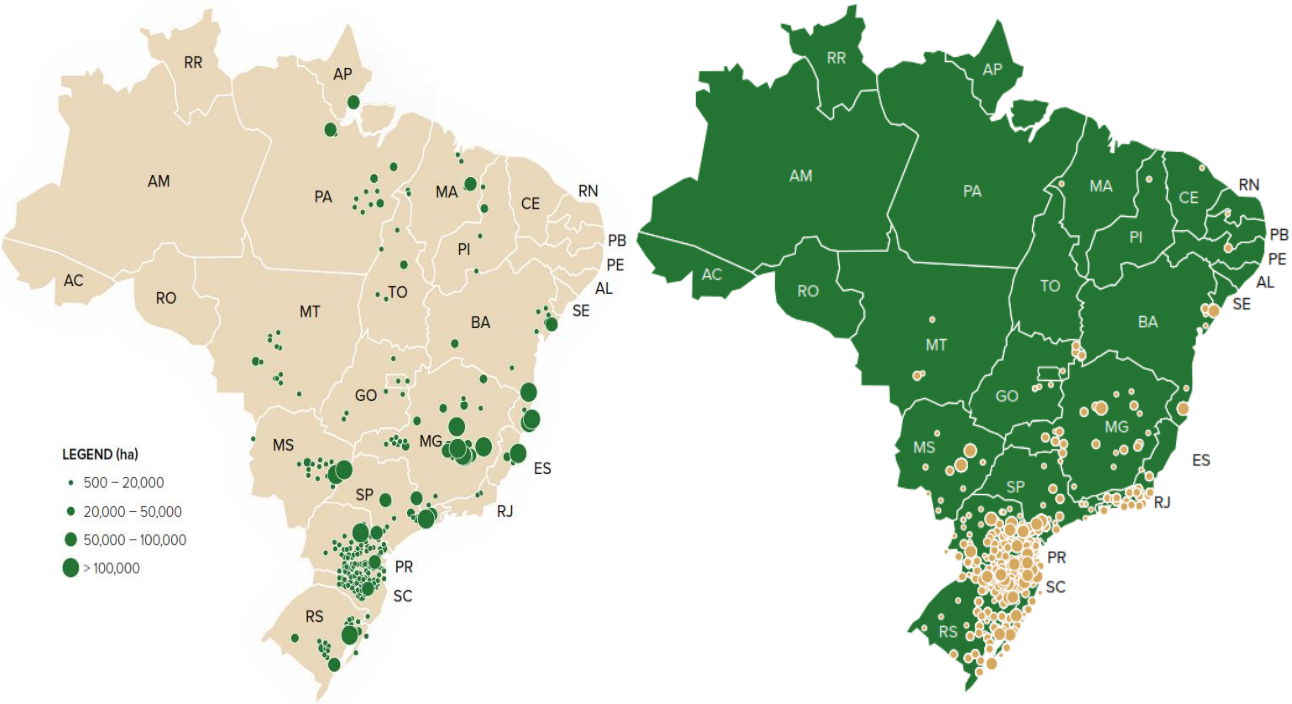

Figure 10 Left: location of the main planted forest clusters 2013 (IBÁ, 2014a). Right: Location of the main lumber producers 2013 (IBÁ, 2014a)

Note that the vast majority of lumber producers are located in Paraná, Santa Catarina and Rio Grande do Sul (figure 10). The reason behind this becomes clear when we look at the geographical distribution of eucalyptus plantations and pine plantations (figure 10). Table 20 differentiates for each 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. The area of eucalyptus plantations is bigger in every state except Paraná and Santa Catarina, where 76% of the total planted pine area in the seven selected states is situated. This coincides with the fact the majority of lumber producers are located in these states as well, indicating pine is mostly used for lumber. On the other hand, eucalyptus wood is the main source of paper and cellulose production, which is located primarily in Bahia and São Paulo. This claim is supported by the statistics in table 13, showing that the biggest volumes of roundwood for paper and cellulose are consumed in São Paulo and Bahia, while the plantations in those states constitute for 91% and 99% eucalyptus respectively. The largest volume of roundwood for other purposes is consumed in Paraná, with 76% of the area planted with pine and also having the biggest concentration of lumber producers.

Minas Gerais, the state with the largest planted area of eucalyptus and pine combined, has a fairly balanced production of roundwood for paper and cellulose and other purposes, and firewood. However, the amount of charcoal produced in Minas Gerais 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. Originally the data for charcoal production in this table was given in weight, but to match the units of the other forestry products it has been converted to volume with the ratio 375 kg/m^3 (Pereira et al., 2012).

Table 20 Forest plantation production statistics (IBÁ, 2014a; IBGE, 2015b)

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. Eucalyptus has a relative short rotation period of 7 years, while pine has a cycle of 15-16 years. So 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). Production of roundwood and charcoal (only Minas Gerais) is expected to increase faster in São Paulo and Minas Gerais than other states.

5. Results

5.1 Selection of Focus Region and Feedstocks

The concentration of population, financial resources, and agricultural and forestry production and trade in the southeast and south coincides with the fact that this is the region with the most advanced and well developed road networks (see figure 11). Every 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). Planned new pellet factories are scheduled to be built in São Paulo and several large projects in Santa Catarina and Rio Grande do Sul. Four plants with a production capacity of 400 kt each, which would become the largest plants in Brazil, are planned to be built in Minas Gerais, Espírito Santo, and Rio Janeiro. They are not displayed in figure 11, because the exact locations are not known yet (BBER, 2015a). Only the factories that are certainly going to be built are taken into consideration, meaning factories that are in the phase of building or factories with a finished business plan and guaranteed investments.

To conclude, Bahia, Espírito Santo, Minas Gerais, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul were the chosen states to focus on in this research. The combination of criteria such as agricultural and forestry production volumes (table 18 and 20), presence and quality of road-, and port infrastructure, and existing and planned pellet production facilities 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.

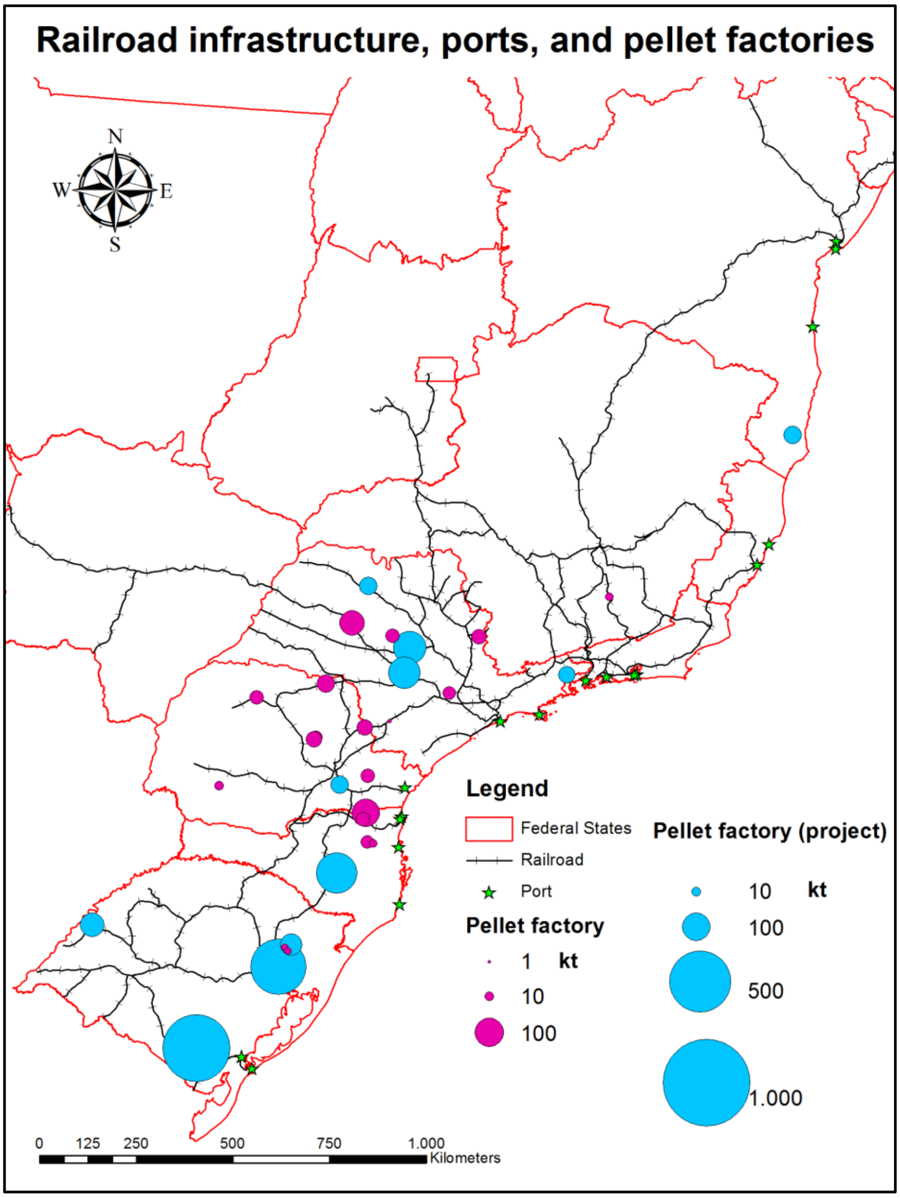

Figure 11 Railroad and port infrastructure and pellet factories in south-eastern Brazil (own work)

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%) 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 21 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 21 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 12). 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 13), corn cob and husk are removed at the corn processing plant, and the same applies to rice husk and coffee husk.

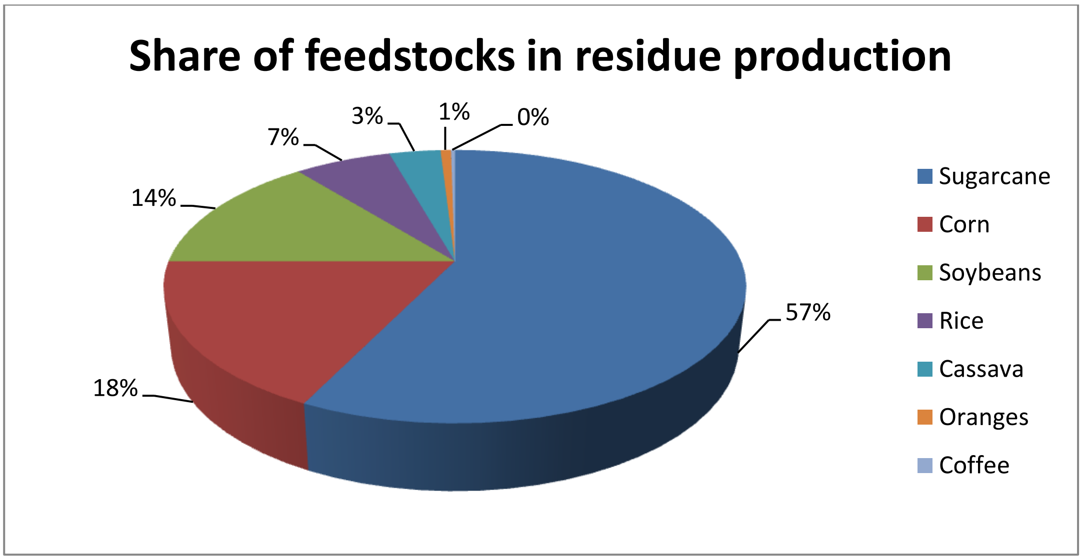

Figure 12 Share of feedstocks in technical potentials agricultural residues production

Figure 14 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 13 Sugarcane bagasse stored at the Santa Lucia mill in Araras, São Paulo (own photo)

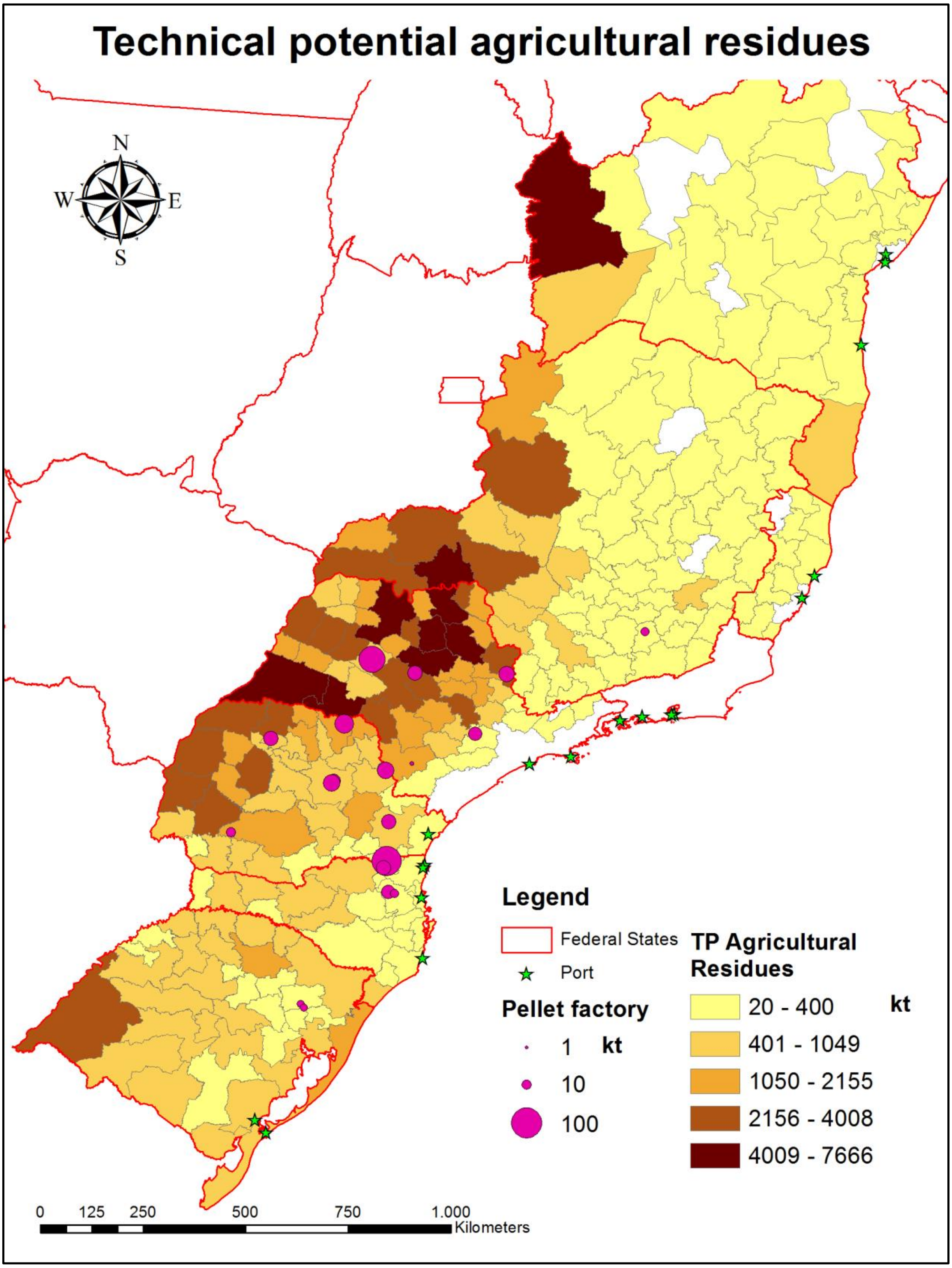

Figure 14 Technical potential agricultural residues per micro-region in 2012 (own work)

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 22). 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 22 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 a micro-region than most types of agriculture. This results in a more sparsely distribution of forestry residue production (see figure 15). When figure 15 is compared to figure 14, it is clear that the production location of either agricultural residues or forestry residues is in different micro-regions. 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.

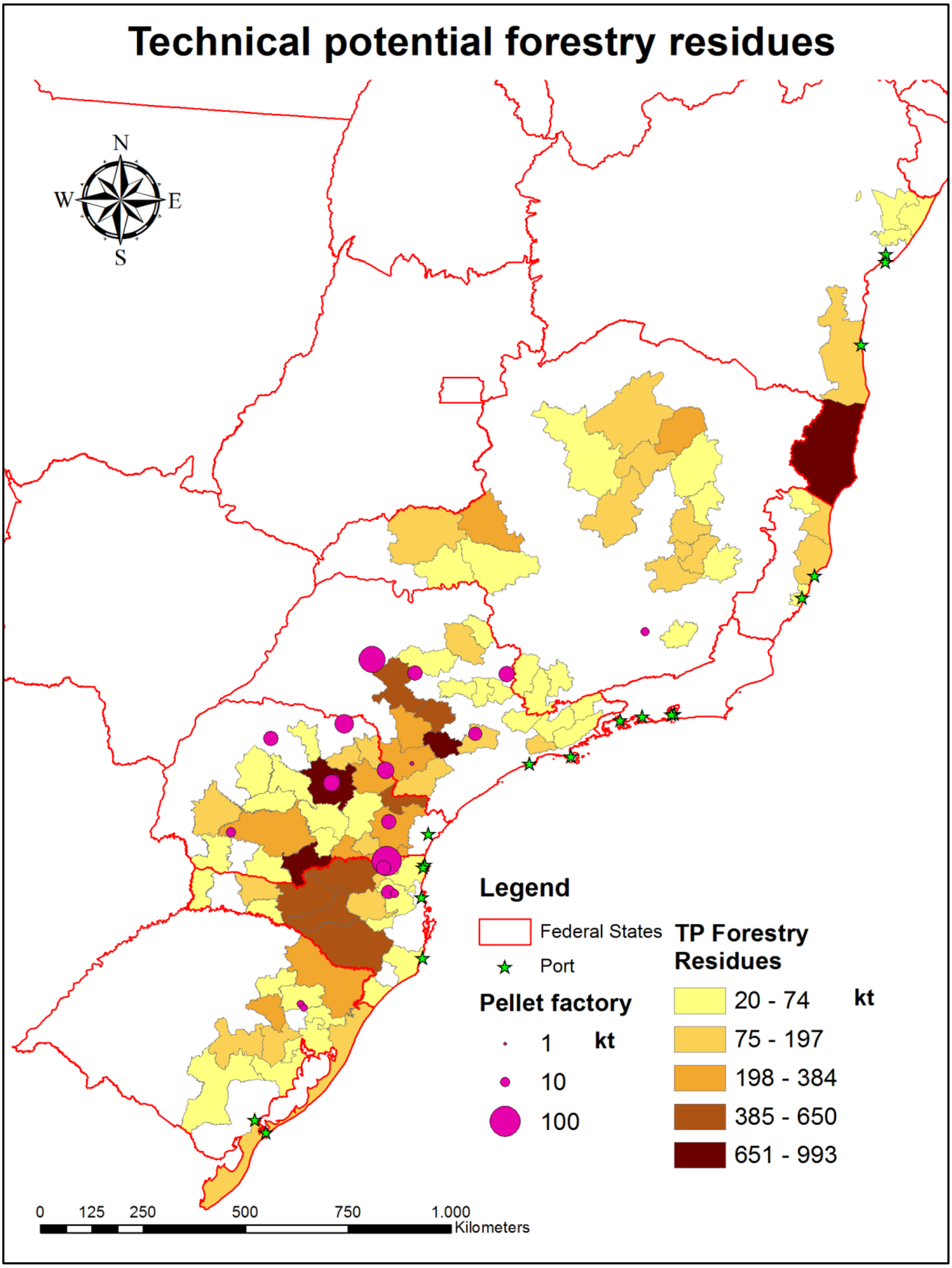

Figure 15 Technical potential forestry residues per micro-region in 2012 (own work)

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 16). 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 16 Left: sugarcane stalk with green tops and straw. Right: piled and dried sugarcane tops and straw left in field for nutrients, organic matter, and soil erosion protection. Araras, São Paulo (own photos)

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 23). 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 (50%) 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 23 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	0.50	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 it is not economically for them to harvest the residues. Klabin does harvest part of the field residues (see figure 17), 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 100% be utilized sustainably.

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 24).

Table 24 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 17 Top left to bottom left: field after wood harvest, piled up forestry residues, residues left in the field, chipping of field residues. Telêmaco Borba, Paraná (own photos)

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 25 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 25 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). Now, sugarcane straw is piled up and laid in between every few rows of sugarcane stalks (see figure 18) 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.

Figure 18 Left: steam boiler for firing bagasse. Right: stored leftover bagasse from previous season. Araras, São Paulo (own photos)

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 26 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 calls 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 26 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%

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[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 19). 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.

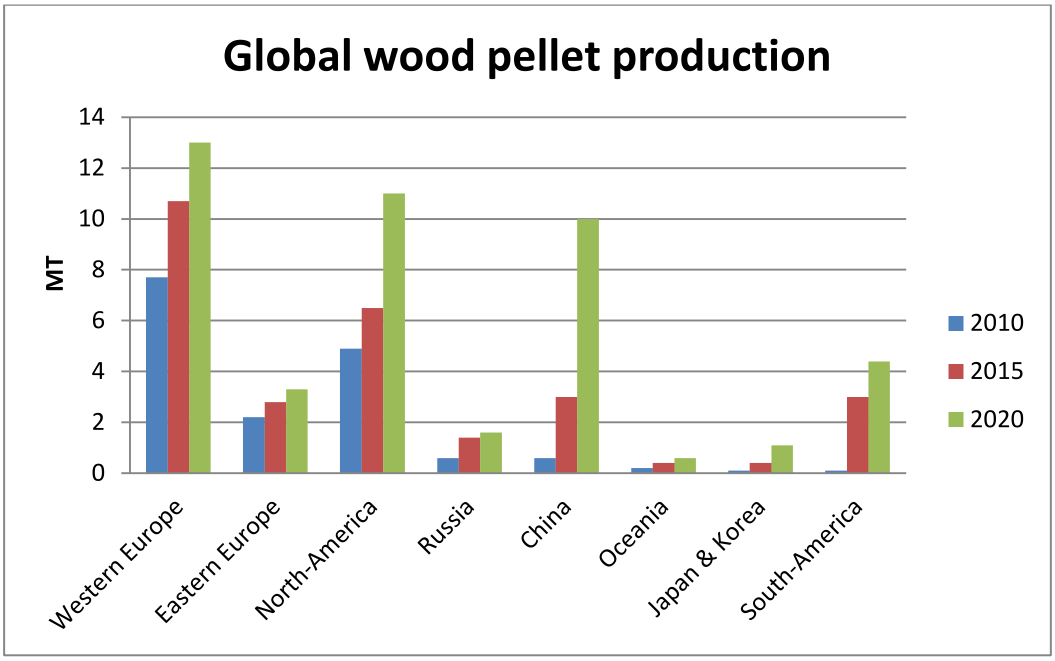

Figure 19 Global wood pellet production 2010, 2015, and 2015 (adapted from Pöyry, 2011)

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 20), 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.

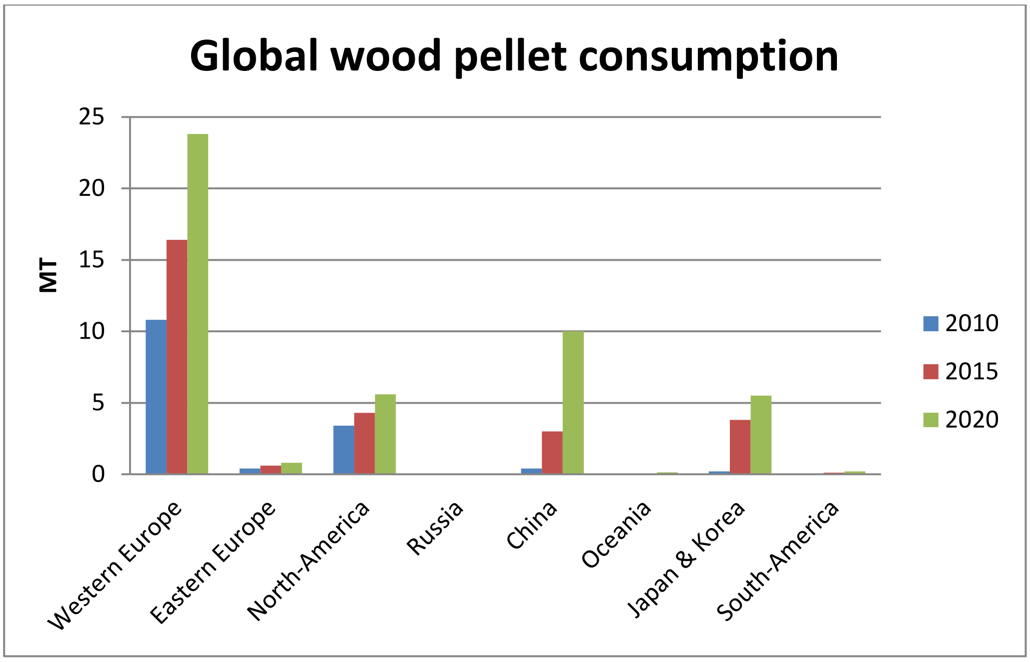

Figure 20 Global wood pellet consumption (adapted from Pöyry 2011)

5.6 Net Sustainable surplus potential Lignocellulosic Biomass Residues

5.6.1 Agricultural residues

The net sustainable surplus potential of agricultural residues, the technical potential deducted with the amount of residues left on the field for sustainability reasons and with the local demand for residues, is listed in table 27 and amounts to a total of 45 MT (739 PJ). This 35% of the sustainable potential and 21% of the technical potential.

Table 27 Net sustainable surplus potential agricultural residues (MT dry matter)

Feedstock	**Type of residue**	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul
Sugarcane	Bagasse	0.10	0.07	1.06	6.09	0.72	0.01	0.01
	Tops/straw	0.27	0.19	2.81	16.16	1.91	0.02	0.04
Soybeans	Straw	0.96	0.00	0.91	0.47	3.25	0.32	1.77
Corn	Stalk	0.15	0.01	0.61	0.36	1.32	0.23	0.25
	Cob	0.05	0.00	0.19	0.11	0.40	0.07	0.08
	Husk	0.04	0.00	0.16	0.10	0.35	0.06	0.07
Cassava	Straw	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	Straw	0.01	0.00	0.02	0.04	0.06	0.35	2.48
	Husk	0.00	0.00	0.00	0.01	0.01	0.06	0.41
Coffee	Husk	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oranges	Peel	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total Mt	**1.58**	**0.27**	**5.67**	**23.32**	**8.02**	**1.12**	**5.12**
Total PJ	**22**	**5**	**95**	**404**	**121**	**17**	**75**

Whereas in the sustainable potential sugarcane bagasse was by far the biggest residue potential, it is now the second biggest with 8.1 MT (143 PJ), due to the fact 90% of bagasse is used for electricity production at the sugar mill (see table 20). Sugarcane straw has the largest net sustainable surplus potential with 21.4 MT (372 PJ). São Paulo has the largest net surplus residue potential, 23.3 MT (404 PJ), almost entirely made up of sugarcane residues. Relatively speaking São Paulo has the biggest decrease from sustainable potential to net surplus potential, again due to the 90% utilization rate of sugarcane bagasse. Figure 21 shows the breakdown of the technical-, sustainable-, and net surplus potentials per state.

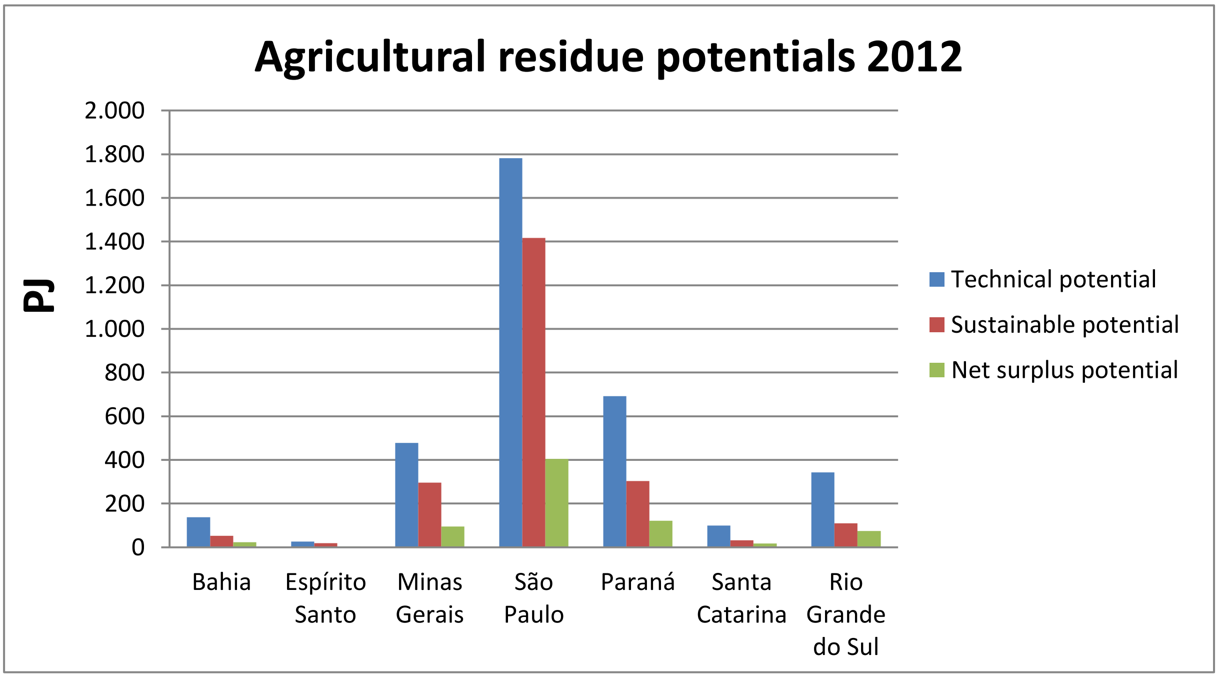

Figure 21 Breakdown of different agricultural residue potentials for 7 Brazilian states (base year 2012)

Figure 22 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).

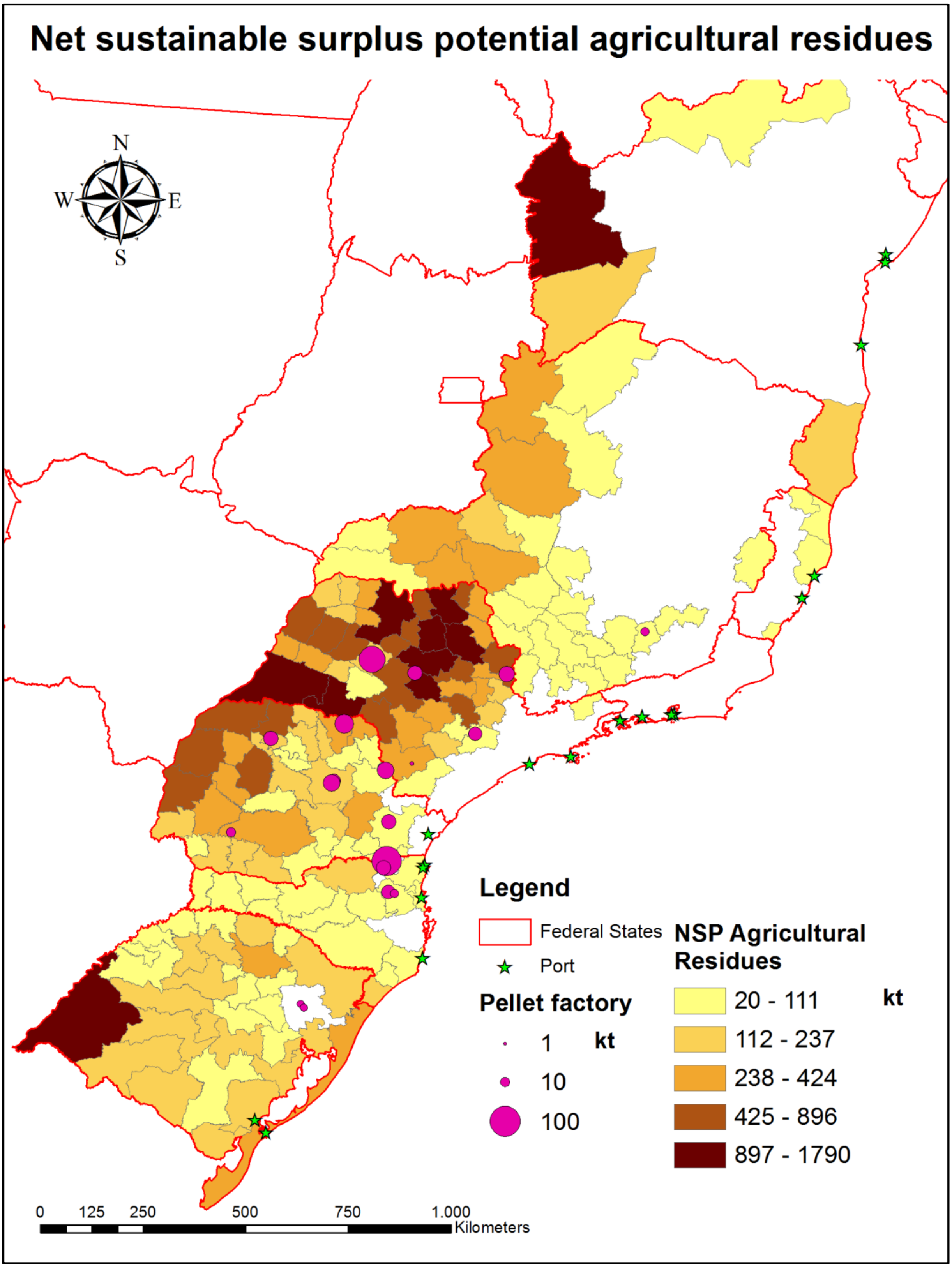

Figure 22 Net sustainable surplus potential agricultural residues per micro-region in 2012 (own work)

5.6.2 Forestry residues

The net sustainable surplus potential of forestry residues amounts to 6.3 MT (117 PJ), 14% (in terms of volume) or 16% (in terms of energetic content) of the net sustainable surplus potential of agricultural residues. Field residues represent the largest part of the net surplus potential with 3.1 MT (60 PJ), they currently have no use, while 70% of the residues from paper and cellulose production and processing are utilized for various purposes (see table 28). Paraná, São Paulo, and Santa Catarina together generate 69% of the total volume of net surplus residues.

Table 28 Net sustainable surplus potential forestry residues (MT 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	0.17	0.06	0.07	0.22	0.14	0.14	0.03
	Processing	1	18.18	0.01	0.01	0.31	0.45	0.86	0.44	0.22
			Total Mt	**0.55**	**0.20**	**0.72**	**1.39**	**1.82**	**1.14**	**0.46**
			Potential PJ	**10**	**4**	**13**	**26**	**34**	**21**	**9**

Figure 23 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.

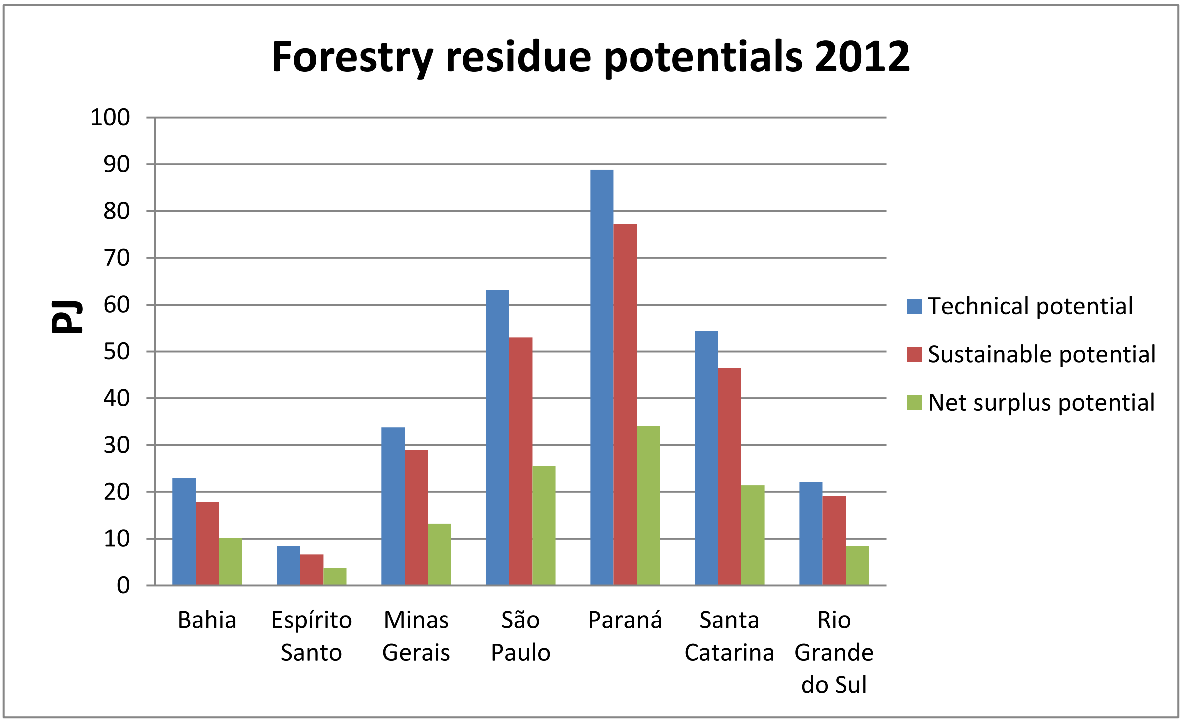

Figure 23 Breakdown of different forestry residue potentials for 7 Brazilian states (base year 2012)

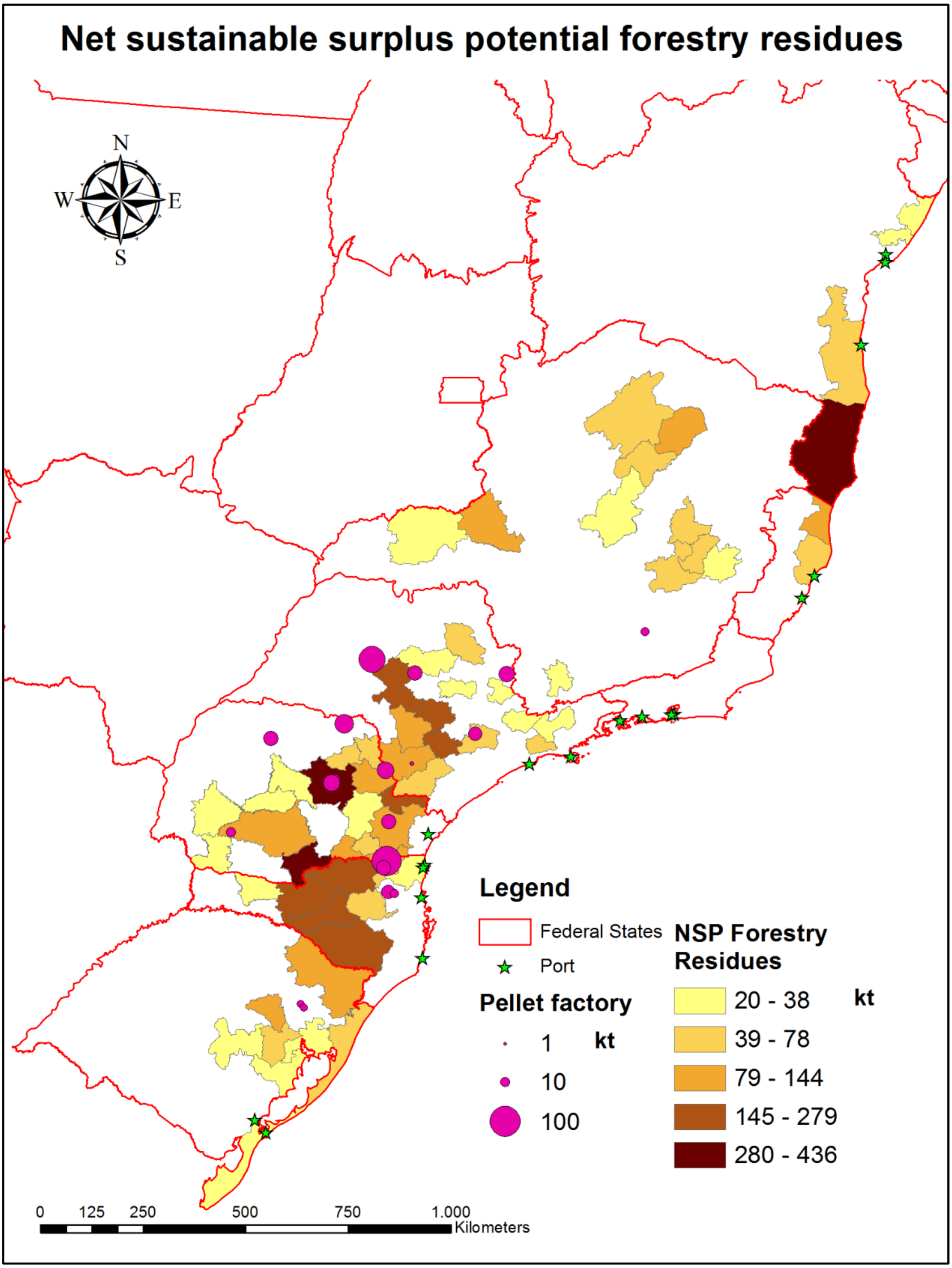

Figure 24 Net sustainable surplus potential forestry residues per micro-region in 2012 (own work)

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.

5.7 Biomass Cost-Supply Curves

The 18 pellet factories in south- and southeast of Brazil have a combined production capacity of 470 kt, as of mid-2015. With an assumed production capacity factor of 80% the total supply is 377 kt. This is far less than the net surplus potential of 45 MT agricultural residues and 6.3 MT forestry residues. Thus, wood pellet production capacity is in the current situation the limiting factor for biomass residue export to the EU. Figure 25 shows the cost-supply curves of the four agricultural feedstocks with net surplus residue potential (sugarcane, soybean, corn, and rice), and forestry residues. Delivery costs range from €5.92/GJ (sugarcane) to €13.57/GJ (forestry) (figure 28). However, only a small amount of sugarcane residue pellets can be delivered at that cost, similar as only a small amount of forestry residue pellets is delivered at the high price. Corn residue pellets have the smallest range with €6.49/GJ – €10.06/GJ. Rice residues are only produced at specific locations in Rio Grande do Sul and Santa Catarina, where the pellet production capacity is very low (see figure 24). The total pellet production capacity could therefore not fully be met with rice residues.

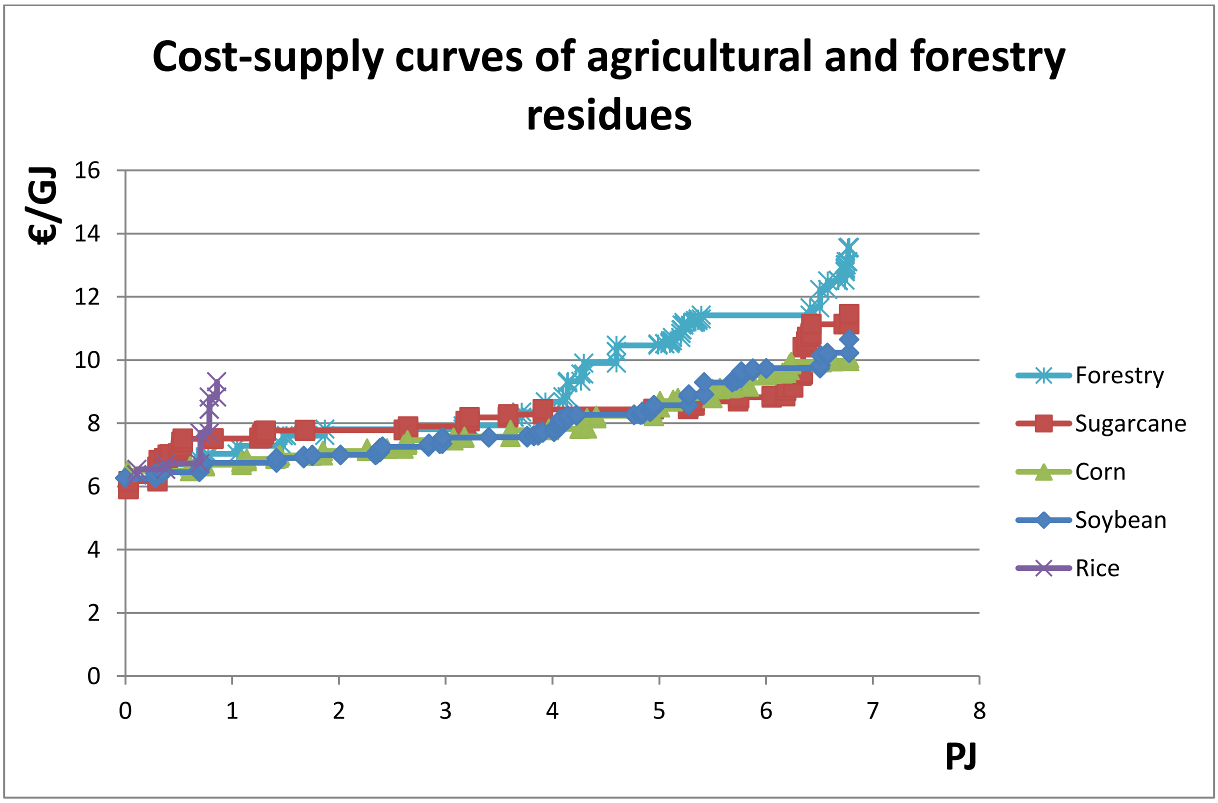

Figure 25 Biomass cost-supply curves for agricultural and forestry residues in 2012 (delivered at export harbour)

Delivery costs of one ton pellets are on average around €150 for agricultural residues and €185 for forestry residues. Lowest delivery costs are for sugarcane residues from Blumenau, Santa Catarina. This micro-region can deliver 1.7 kt pellets at €106.56 via pellet factory Elbra. Field-factory distance is 15 km and factory-harbour distance is 81 km (Itajaí). The highest delivery costs are 0.6 kt forestry residues pellets at €244.27 from Cianorte via pellet factory BrBiomassa (110 km) to harbour Paranaguá (567 km). The wide range of delivery costs of pellets at the export harbour is in line with 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.

First truck transport from the field to the pre-treatment facility seems to be the most important variable for low delivery costs. Transport of fresh biomass residues is expensive due to the low density and high moisture content. Micro-regions with a low first truck transport generally have the lowest supply costs, where one km transport of raw material from the field to the pellet factory weighs more on the costs than transport of the wood pellets to the export harbour.

6. BAU and optimistic scenario for 2020 and 2030

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 higher compared to 2012 (+14 PJ) (see table 29). The growth in agricultural production is at the same time met with a BAU local demand for residues. This means sugarcane bagasse is not available anymore, while it is expected to be 100% used for co-firing. The effect of the local utilization of sugarcane bagasse and straw becomes even clearer in the 2030 BAU scenario: it is lower than 2012 and 2020 BAU, because bagasse is not available and sugarcane straw is increasingly used for co-firing and second generation bio-ethanol.

Table 29 Net surplus potential of agricultural residues for 2012/2020/2030 and the BAU and optimistic scenario

Potentials (PJ)	**2012**	**2020 BAU**	**2020 OPT**	**2030 BAU**	**2030 OPT**
Sugarcane bagasse	143	0	168	0	288
Sugarcane tops/straw	372	463	498	308	563
Soybean straw	95	146	188	152	282
Corn stalk	51	61	90	72	175
Corn cob	15	17	26	21	50
Corn husk	9	11	17	13	32
Rice straw	47	50	58	64	70
Rice husks	7	5	11	0	14
Total net surplus	**739**	**753**	**1,055**	**631**	**1,475**

Rice husks are also not available anymore, they are completely used for steam generation and drying at the mill, and for chicken bedding. The other feedstock residues increase slightly between the 2020 BAU and 2030 BAU scenario. Between 2012 and the 2020 optimistic scenario the net surplus residue potential increases about 30% to 1055 PJ, and between 2020 optimistic and 2030 optimistic with a similar rate to 1475 PJ. Sugarcane bagasse utilization remains 90%, same as in 2012, and straw use increase slower compared to the BAU. Together with the increased agricultural production this results in an large growth in residue availability. Other feedstocks are also available in larger volumes.

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. Utilization rates for all residues increase, although the net surplus potential still increases to 131 PJ in the 2020 BAU scenario and 135 PJ in the 2030 BAU scenario. This is due to increase in net surplus of field residues, since the net surplus of processing residues decline due to increasing utilization rates taking over the growth in the technical potential of the residues.

Table 30 Net surplus potential of forestry residues for 2012/2020/2030 and the BAU and optimistic scenario

Potentials (PJ)	2012	2020 BAU	2020 OPT	2030 BAU	2030 OPT
Field	60	71	75	83	86
Paper and cellulose production	15	16	20	13	26
Lumber processing	42	44	53	38	97
Total net surplus	**117**	**131**	**147**	**135**	**209**

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, 70%, and for field residues it increases at a slower pace compared to the BAU. Net surplus potentials increase to 147 PJ and 209 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.

7. Discussion

The aim of this research was to calculate the net sustainable surplus residues from agriculture and forestry in Brazil for export to the EU. To collect field data an internship at the university of Campinas in São Paulo state was conducted. The goal of this internship was to perform interviews with local farmers, forest plantation holders, the wood pellet industry, and other relevant stakeholders. This field data was of crucial importance to assess the local conditions of biomass residue generation, such as sustainable recovery factors and local demand for residues for alternative uses. Doing research in Brazil has proven to be very difficult. The social relationship between students and seniors and superiors is different compared to the Netherlands. A stronger hierarchy exists which makes it difficult to get into contact with people. The language barrier is also a problem, especially when contacting farmers, since they rarely speak English. Due to the lack of gathered field data a lot of assumptions had to be made according to literature. These sources do not always apply universally to specific case studies like this research on Brazil. Although literature is carefully reviewed on whether or not a certain value or assumption would be valid for the case of Brazil, there is uncertainty in some key parameters that influence the calculated net surplus potential of biomass residues in Brazil.

First of all the sustainability criteria and corresponding sustainable recovery rates. Some of the values are obtained from Brazilian sources (either literature with field experiments in Brazil or farmers/plantation holders), but for corn, soybean, cassava, and rice residues they are taken from literature that does not specifically apply to Brazil. Differences in soil characteristics, field inclinations, and weather conditions can cause the sustainable recovery rates for feedstocks to be different in different locations.

The local demand and uses for biomass residues is a very important aspect to prioritize in this research. Residues should not be taken from the local market, where it could already have a sustainable application, and be exported to the EU. For soybean straw and rice straw they are taken from literature that does not specifically apply to Brazil. Also, the percentage of use of corn stover is estimated on the assumption that ‘the majority’ is used for cattle feed. This gives uncertainty to the validity of the local utilization rate of these residue types.

The BAU and optimistic scenario’s for future residue potentials are developed based on assumptions. Especially the growth projections of agriculture and forestry production in the optimistic scenario are subject to uncertainty. Extreme weather conditions, as experienced earlier in the south- and southeast of Brazil in the 2012/2013 harvest season, can influence extrapolations of yield increase and production growth. Especially when it affects sugarcane cultivation, as it did in 2012/2013. Sugarcane residues are by far the largest source of net surplus residues in every projection for 2012/2020/2030 and the BAU and optimistic scenarios.

Costs in the biomass residue supply chain was partly obtained from interviews with farmers, plantation holders, and the Brazilian pellet industry and literature that does not specifically apply to Brazil. This is the case for harvesting costs for soybean, corn, and rice straw. However, the calculated delivery costs of biomass residue pellets to the export harbour were in line with calculations of the Brazilian Biomass Industry Association and a case study performed in São Paulo state

8. Conclusions & Further Steps

The agricultural and planted forestry sector in the south- and southeast of Brazil produce an enormous amount of lignocellulosic biomass residues. Three stages of residue potentials are calculated: the technical potential, the sustainable potential, and the net surplus potential. The technical potential of agricultural residues from sugarcane, soybean, corn, cassava, rice, coffee, and oranges amounted to 216 MTdm (3556 PJ) in 2012, with São Paulo accounting for 47%. Sugarcane trash and bagasse make up 57% of the total technical potential. The technical potential of forestry residues from the field, paper and cellulose production, and lumber processing is 16 MTdm (295 PJ). 86 MTdm of agricultural and 2 MTdm of forestry field residues has to be left on the field for irreplaceable environmental services provided by the residues. The sustainable potential of agricultural residues is 130 MT (2229 PJ) and of forestry residues 14 MTdm (249 PJ). Local demand of residues for cattle feed, fuel, energy, and other purposes have priority over exporting residues to the EU. The local market should not be disrupted. Many residues have, partially, local applications, like co-firing to produce electricity (bagasse, rice- and coffee husk, forestry residues), feed for cattle (corn stover), and substrate for chicken bedding (rice- and coffee husk). Cassava-, coffee-, and orange residues are 100% locally utilized and are not available for export to the EU, also not in the future. The net sustainable surplus potential of agricultural residues in 2012 is 45 MT (739 PJ), mainly located in São Paulo and Paraná. The net sustainable surplus potential of forestry residues in 2012 is 6.3 MTdm (117 PJ), mainly located in Paraná, São Paulo, and Santa Catarina.

Currently, this net surplus potential cannot completely be exported in the form of wood pellets. The production capacity of the wood pellet industry in the south- and southeast of Brazil is a limiting factor. It has a production capacity of 470 kt, and with a capacity factor of 80% 376 kt wood pellets can annually be produced, corresponding to about 7 PJ. Less than 1% of the energetic value of the net surplus of biomass residues. However, part of the available residues are situated too far away from pellet factories and/or from export harbours. This makes these uneconomical. Cost-supply curves for the feedstocks with available surplus residues, sugarcane, soybean, corn, rice, and planted forest, show that current production capacity of wood pellets can be delivered at an export harbour with costs ranging from €5.92/GJ to €13.57/GJ. The price per delivered ton of wood pellets at the export harbour ranges from €106.56 to €244.27, which is in line with prices of €120-€160/t and €180/t of the Brazilian Biomass Industry Association and a case study in the state of São Paulo respectively.

The calculations for net sustainable surplus potentials in 2020, and 2030 in the BAU scenario show an initial increase for agricultural residues to 753 PJ and then a decrease to 631 PJ in 2030. This is due to the fact that sugarcane straw is for 50% utilized for co-firing and production of second generation bio-ethanol in 2030, offsetting the growth of residue production due to improving yields and expansion of cultivated area. In the optimistic scenario utilization rates develop at a slower pace compared to the BAU and net surplus potentials increase to 1,055 PJ in 2020 and 1,475 in 2030. The sustainable net surplus potential of forestry residues is calculated to grow to 131 PJ in 2020 and 135 PJ in 2030 for the BAU scenario and to 135 PJ in 2020 and 209 PJ in 2030 for the optimistic scenario. The growth rates of residue production are higher than the growing utilization rates.

The pellet production capacity of the south- and southeast of Brazil is growing to 3.7 MT (~67 PJ) in 2020, with new factories confirmed to come online in the next few years. For 2030 a growth is projected to 12 MT (~216 PJ). Considering the projected available net sustainable surplus biomass residue potentials for 2030 it can be assumed enough raw material is available to fill the wood pellet production capacity.

Further research into this topic needs to consider the GHG balance of the biomass supply chain and compare these to traditional fossil fuel energy sources. The cost-supply curves need to be calculated for 2020, 2030 and the two scenario’s. Sustainable recovery rates, local uses, growth projections, and infrastructure logistics need to be assessed in Brazil with field experiments to validate the assumptions made for these parameters, when no field data could be gathered during the internship in Brazil.

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Appendix

1. Breakdown of potentials for 2012/2020/2030 and BAU/optimistic scenario

Agriculture 2012

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	138	25	478	1.781	691	100	344	3.557
Sustainable	53	19	297	1.416	303	31	110	2.229
Local demand	31	15	202	1.012	182	15	35	1.491
Net surplus	22	5	95	404	121	17	75	**739**

Forestry 2012

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	23	8	34	63	89	54	22	294
Sustainable	18	7	29	53	77	47	19	249
Local demand	8	3	16	27	44	25	11	132
Net surplus	10	4	14	26	34	21	9	**117**

Agriculture 2020 BAU

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	191	32	600	2,160	963	108	484	**4,538**
Sustainable	71	26	369	1,728	420	34	149	**2,797**
Local demand	46	21	273	1,367	267	20	49	**2,043**
Net surplus	25	5	96	361	152	14	100	**759**

Forestry 2020 BAU

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**

Technical	38	11	29	86	124	56	31	**375**
Sustainable	29	9	24	73	107	48	27	**318**
Local demand	14	4	14	42	67	29	17	**187**
Net surplus	16	5	11	31	40	19	10	**131**

Agriculture 2020 OPT

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	226	35	693	2,366	1,154	130	535	**5,138**
Sustainable	83	28	413	1,883	487	40	164	**3,098**
Local demand	47	21	269	1,341	263	16	39	**1,996**
Net surplus	37	7	144	542	223	25	125	**1,102**

Forestry 2020 OPT

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	38	11	29	86	124	56	31	**375**
Sustainable	29	9	24	73	107	48	27	**318**
Local demand	13	4	13	38	61	26	16	**171**
Net surplus	17	5	12	35	46	22	12	**147**

Agriculture 2030 BAU

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	234	40	889	2,757	1,240	137	574	**5,872**
Sustainable	70	32	563	2,220	547	35	177	**3,644**
Local demand	45	29	470	1,982	398	18	72	**3,014**

Net surplus	26	3	93	238	149	17	105	**631**

Forestry 2030 BAU

Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	56	14	45	128	175	66	41	**526**
Sustainable	43	12	38	109	153	56	36	**447**
Local demand	23	6	25	74	116	42	27	**313**
Net surplus	21	5	13	35	36	15	10	**135**

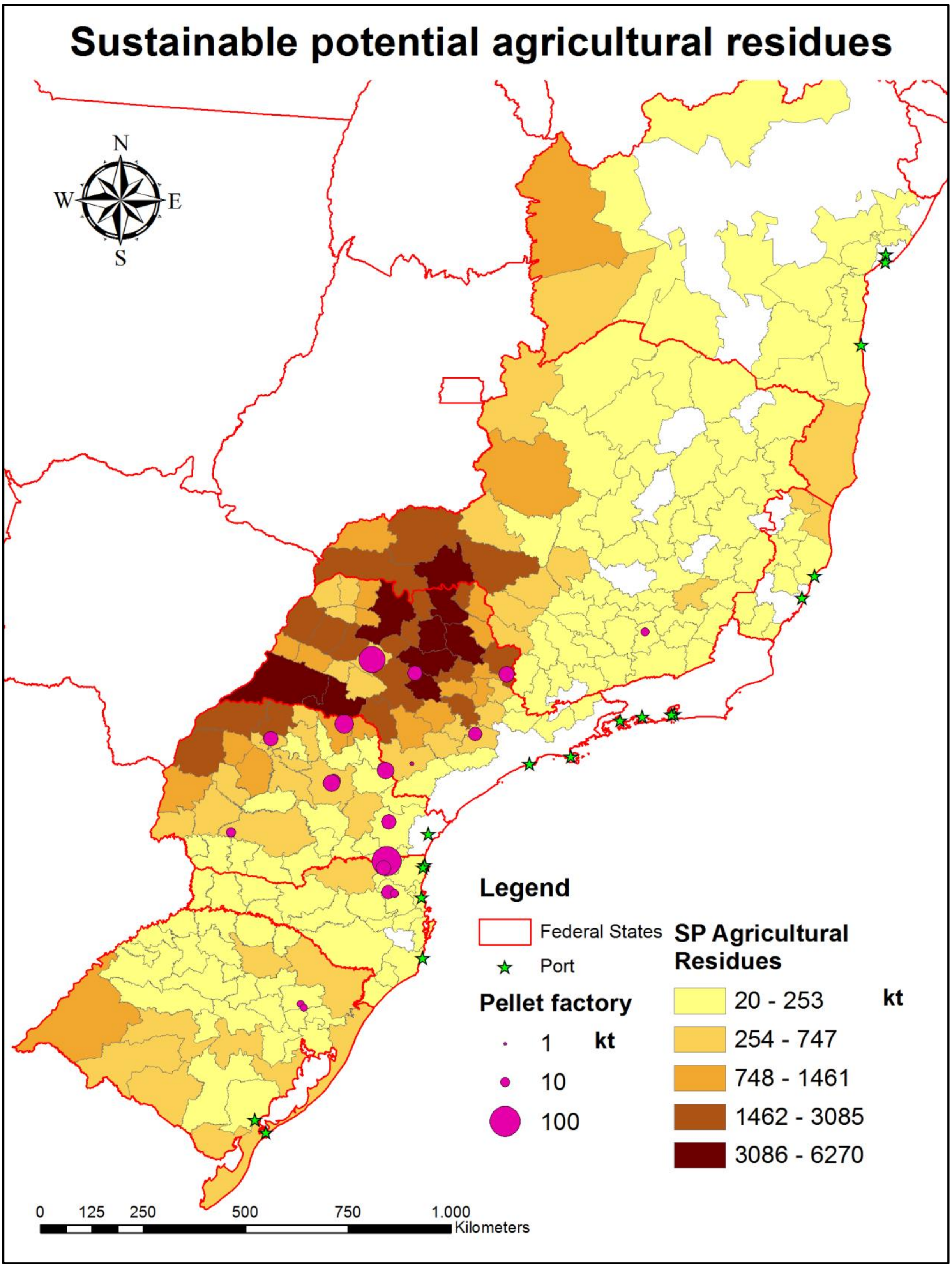
Agriculture 2030 OPT

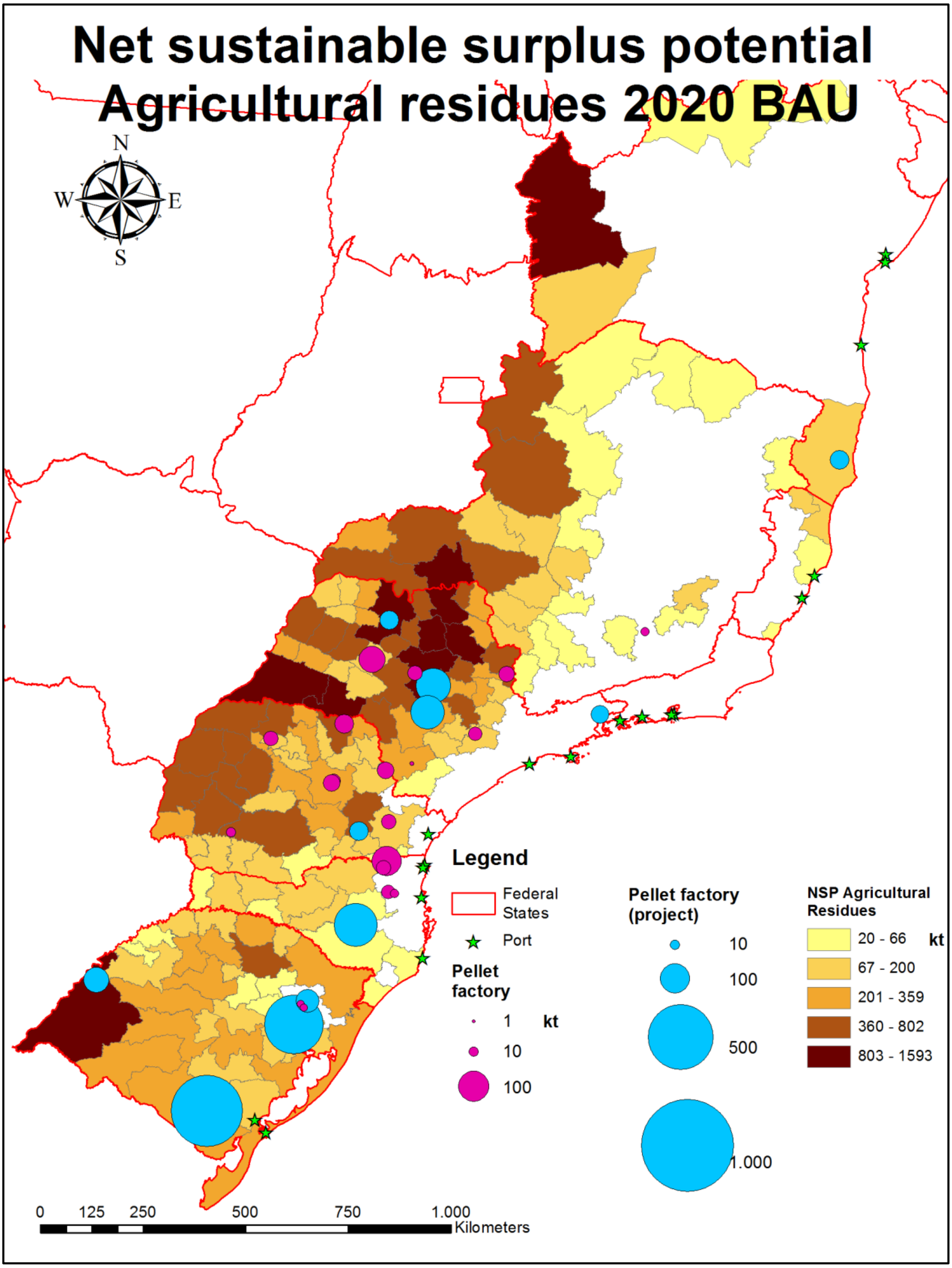
Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	293	49	1,128	3,371	1,621	171	671	**7,303**
Sustainable	104	39	698	2,707	697	44	204	**4,494**
Local demand	50	31	470	2,057	359	12	41	**3,019**
Net surplus	54	8	229	650	339	32	163	**1,475**

Forestry 2030 OPT

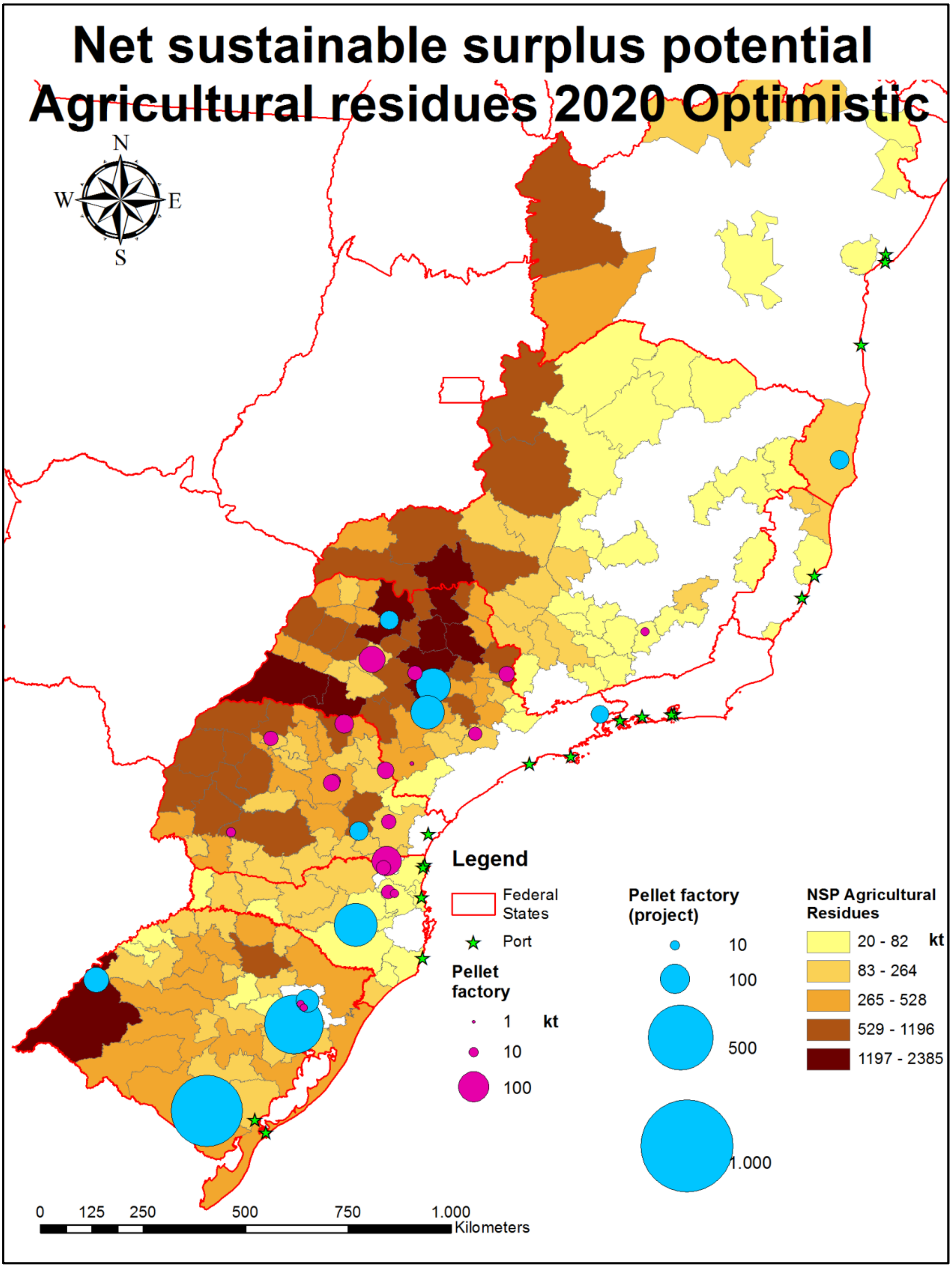
Potentials (PJ)	Bahia	Espírito Santo	Minas Gerais	São Paulo	Paraná	Santa Catarina	Rio Grande do Sul	**Total**
Technical	83	21	64	183	245	95	58	**749**
Sustainable	65	17	54	155	214	80	51	**635**
Local demand	40	11	36	106	154	42	36	**426**
Net surplus	25	6	18	48	59	38	15	**209**

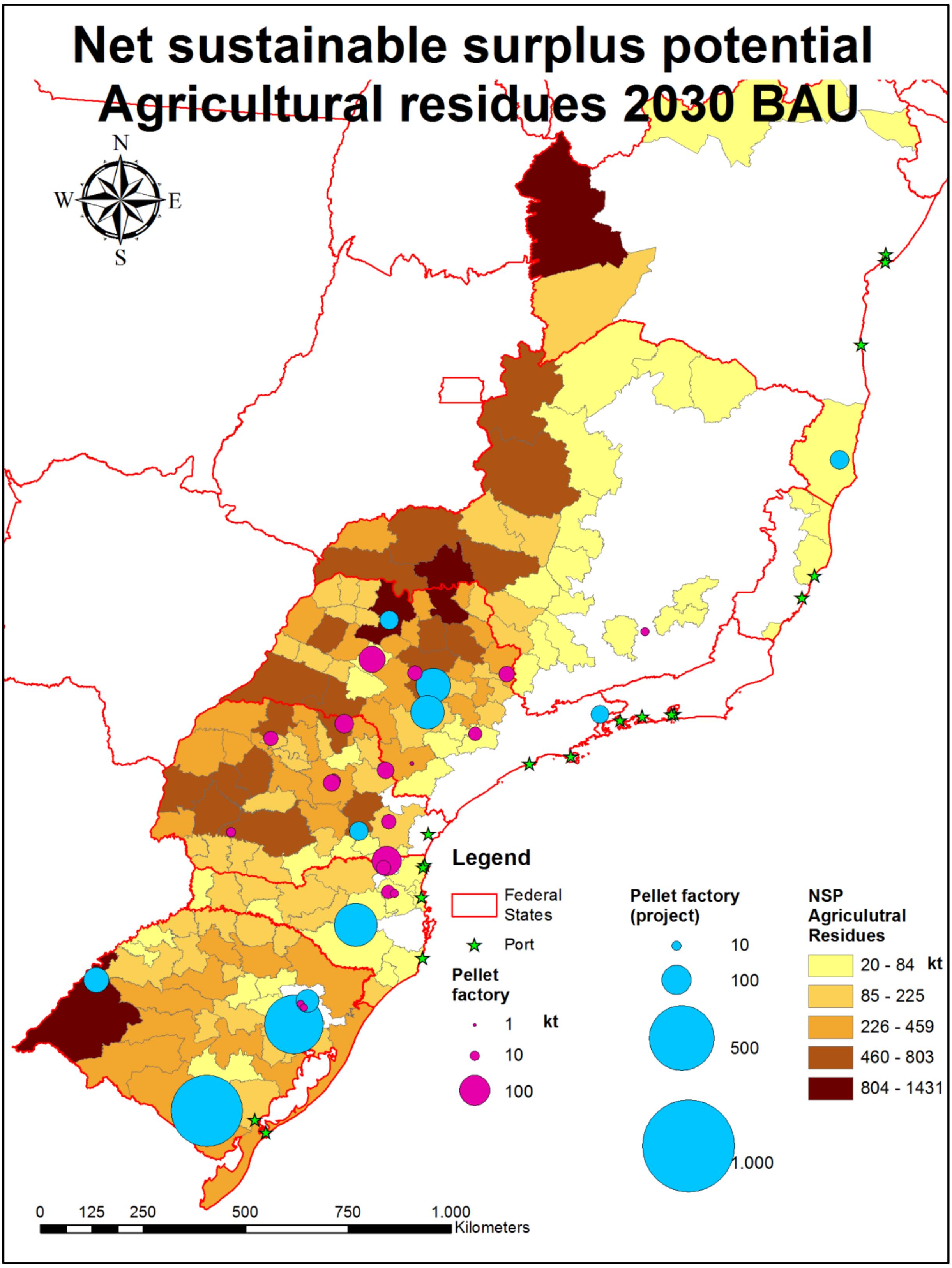
2. ArcGIS maps of residue potentials



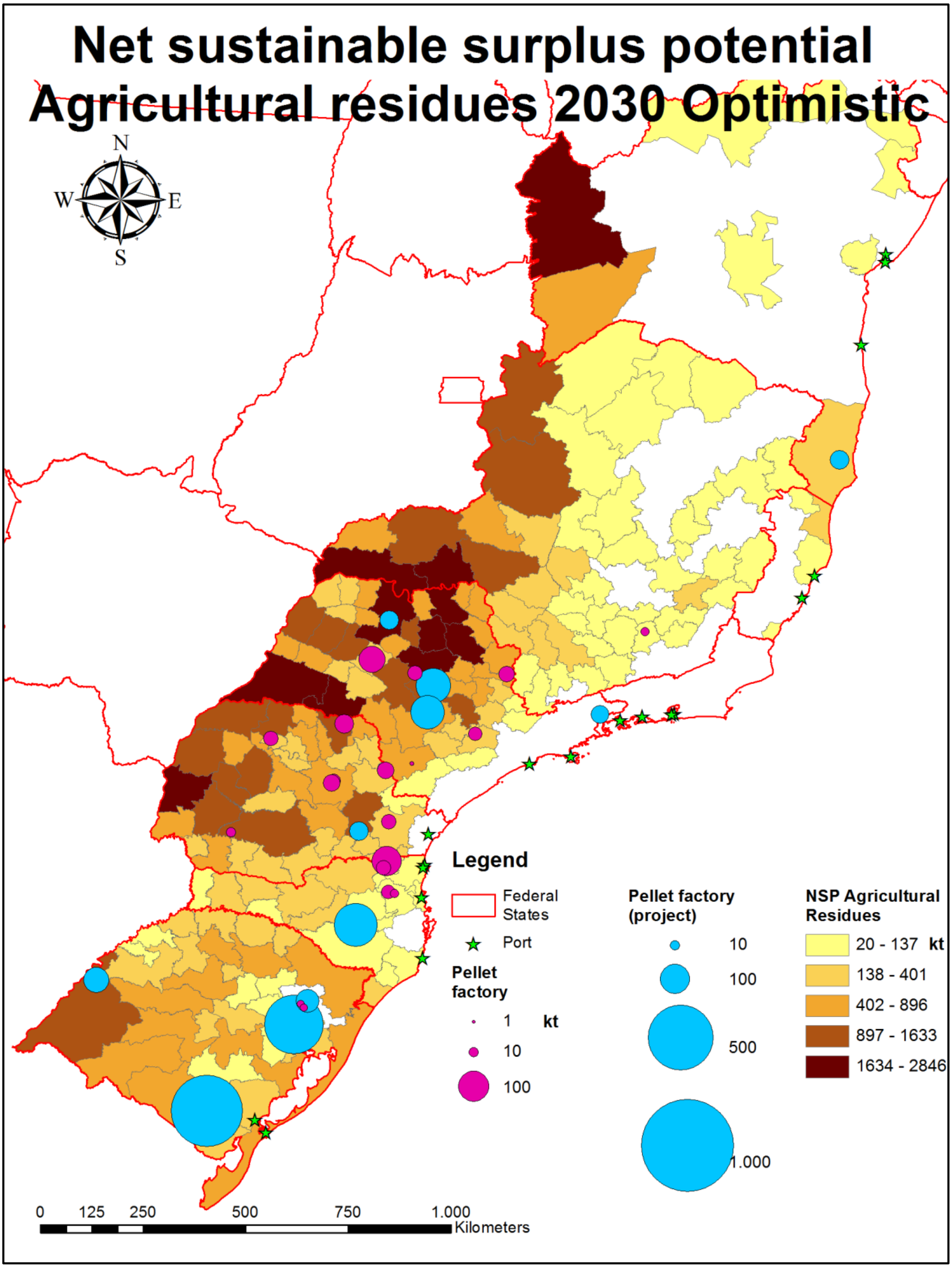


Net sustainable surplus potential Agricultural residues 2020 BAU

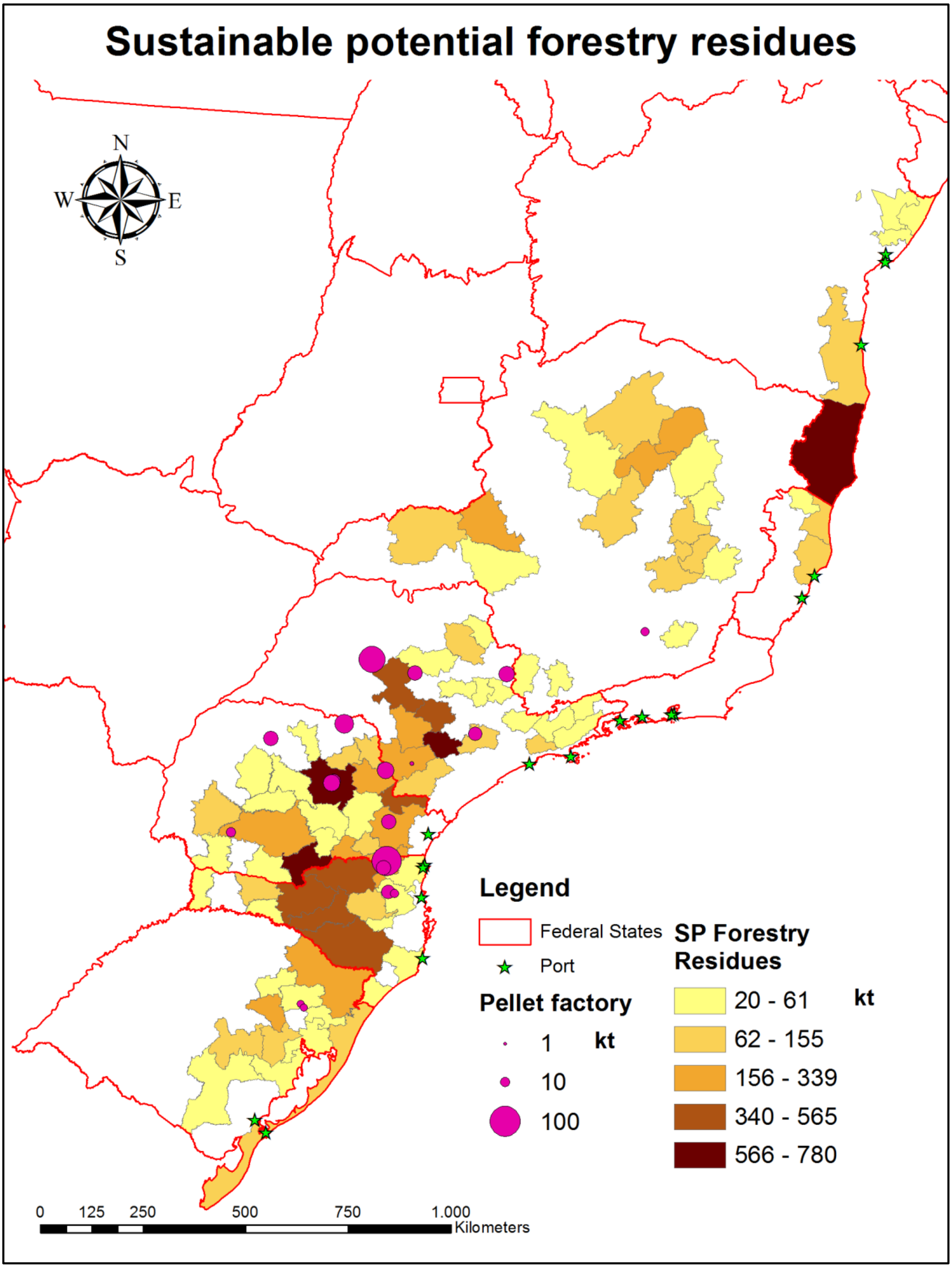

Net sustainable surplus potential
Agricultural residues 2020 Optimistic
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
Pellet factory (project)
10
100
500
1.000
NSP Agricultural Residues
20 - 82 kt
83 - 264
265 - 528
529 - 1196
1197 - 2385
0
125
250
500
750
1.000
Kilometers

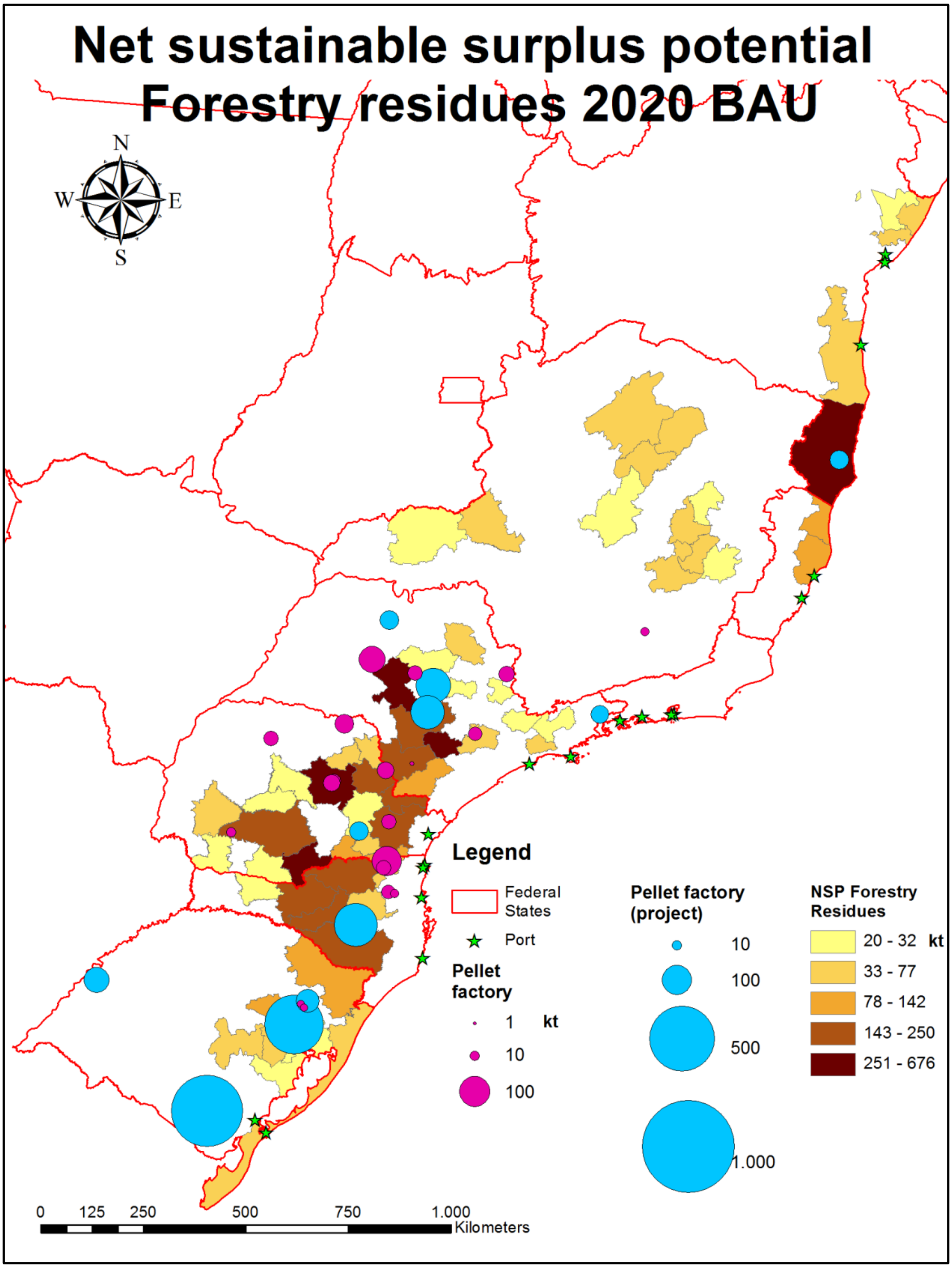


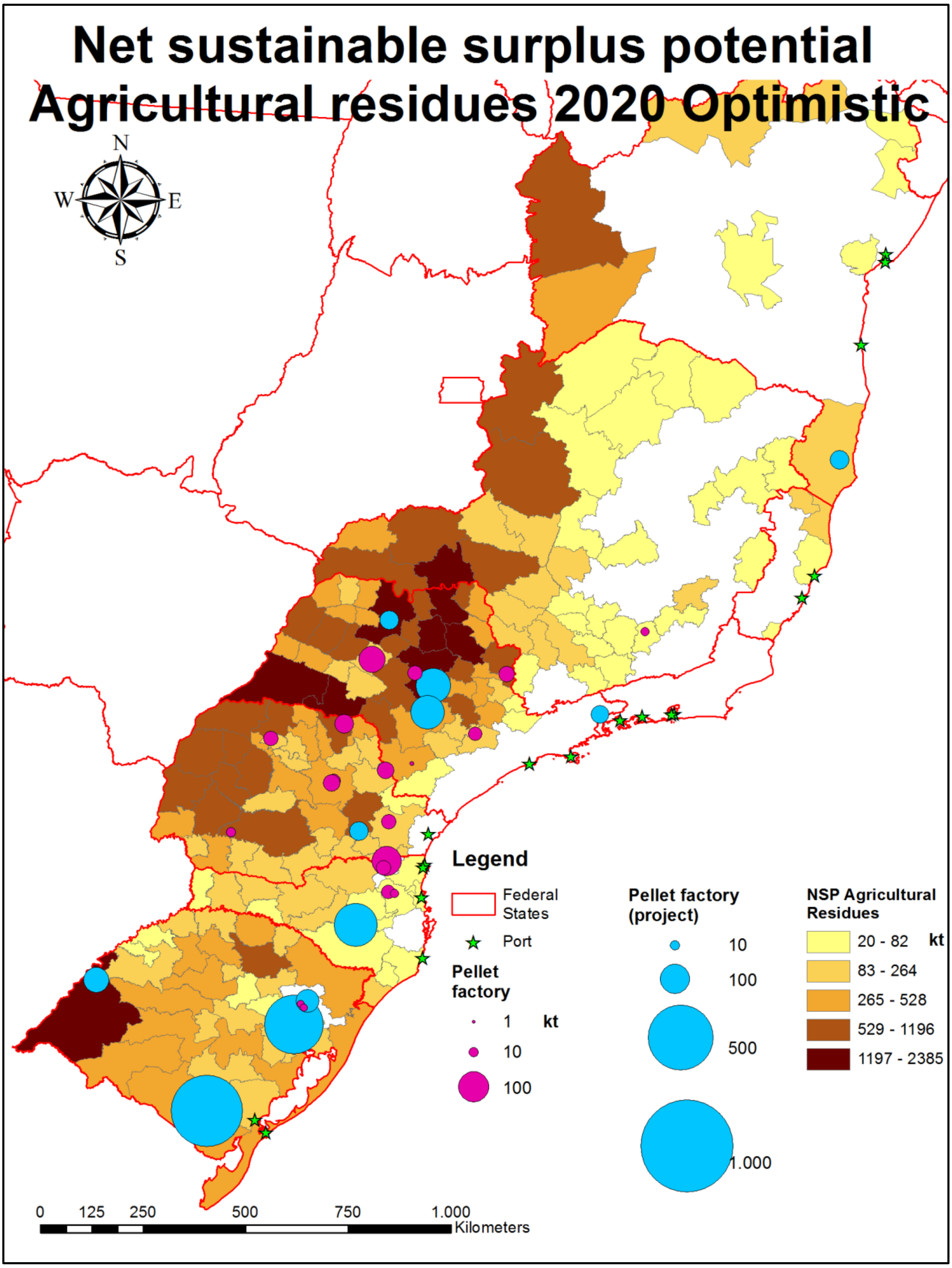
Net sustainable surplus potential Agricultural residues 2030 BAU

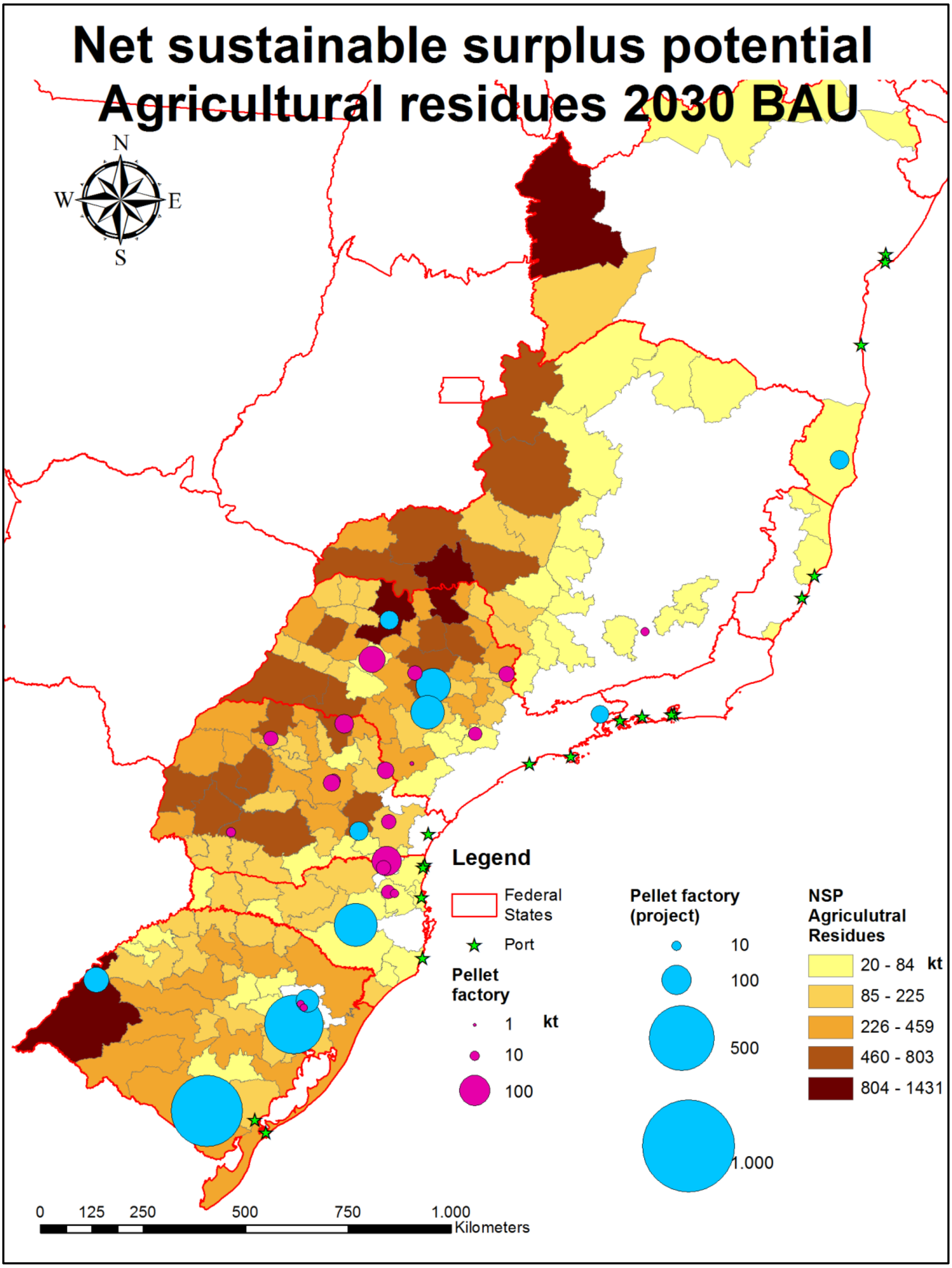


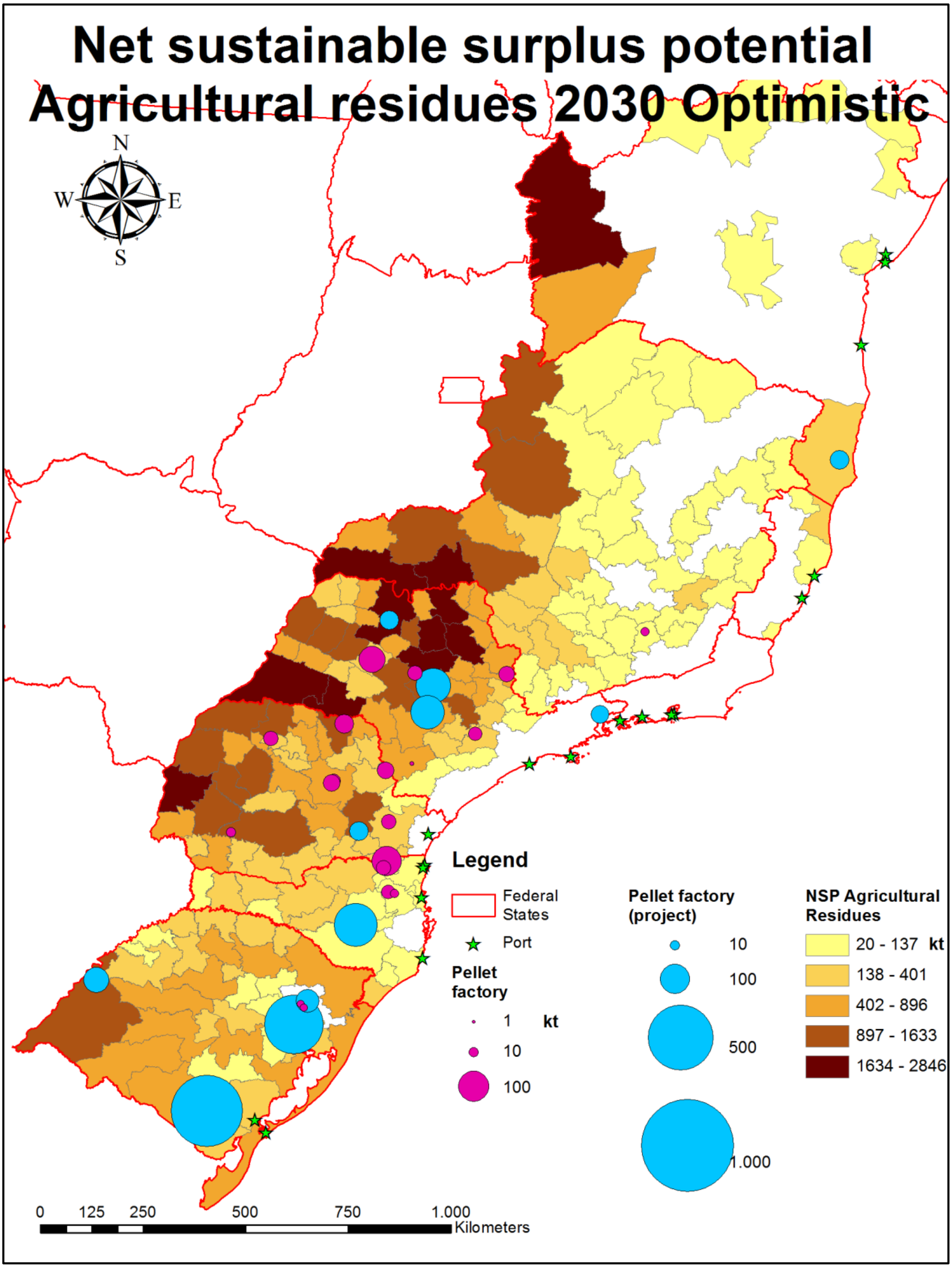
Net sustainable surplus potential Agricultural residues 2030 Optimistic


Sustainable potential forestry residues
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
SP Forestry Residues
20 - 61 kt
62 - 155
156 - 339
340 - 565
566 - 780
0 125 250 500 750 1.000
Kilometers


Net sustainable surplus potential
Forestry residues 2020 BAU
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
Pellet factory (project)
10
100
500
1.000
NSP Forestry Residues
20 - 32 kt
33 - 77
78 - 142
143 - 250
251 - 676
0
125
250
500
750
1.000
Kilometers


Net sustainable surplus potential
Agricultural residues 2020 Optimistic
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
Pellet factory (project)
10
100
500
1.000
NSP Agricultural Residues
20 - 82 kt
83 - 264
265 - 528
529 - 1196
1197 - 2385
0
125
250
500
750
1.000
Kilometers


Net sustainable surplus potential
Agricultural residues 2030 BAU
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
Pellet factory (project)
10
100
500
1.000
NSP Agricultutral Residues
20 - 84 kt
85 - 225
226 - 459
460 - 803
804 - 1431
0
125
250
500
750
1.000
Kilometers


Net sustainable surplus potential
Agricultural residues 2030 Optimistic
N
W
E
S
Legend
Federal States
Port
Pellet factory
1 kt
10
100
Pellet factory (project)
10
100
500
1.000
NSP Agricultural Residues
20 - 137 kt
138 - 401
402 - 896
897 - 1633
1634 - 2846
0
125
250
500
750
1.000
Kilometers