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Scenario Analysis of biomass trade from Brazil to Europe: challenges and opportunities

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ABSTRACT

In this study, the compatibility of two converging environment-oriented policies is analysed. The first approach corresponds to the aim of the European Union (EU28) at reaching the energy goal established in the latest global climate agreements (i.e. COP21 and COP22), focusing in particular on diversifying the energy matrix and on increasing the energy security. The second approach is the commitment of Brazil to exploit its wide potential in terms of raw material for the production of biomass and thus bioenergy. The main question is whether the exportation from Brazil to Europe could be convenient for both parties from the economical point of view and, concomitantly, if the actual Brazilian potential is able to satisfy the external demand of biomass in term of quantity, quality and sustainability. In the first part of this study, the current global energy situation in Brazil is described, paying attention in particular to the biomass sector and underlining both opportunities and limits considering different points of view (e.g. production, logistic, policies, and laws). The present energy situation in Europe and its energy policies linked to the biomass sector are then illustrated. After this, some scenarios, in which the role of biomass trade from Brazil to Europe is assessed, are designed (using the model generator TIMES). It was possible to obtain some model's proposed trends in a time horizon that spans up to year 2040 mainly related to the international commodities trade between South America and Europe in terms of energy content. Constraints and hypothesis have been considered with the aim of realizing a model as close as possible to reality.

Results from modelling are the Brazilian biomass production and trade potential and, at the same time, the European biomass consumption and import potential. All these results are included in a current global context because obtained using a global model in which a competition between energy systems of countries from all part of the world is a key feature, respecting the actual environmental policies on biofuels. Furthermore, all scenarios results are compared with literature values. The main conclusion from the analysis is that pellet, ethanol and biodiesel trade is interesting for both parties because the implemented BR-EU corridors are always chosen by the model at expense of other corridors between EU and other external Countries. Another very important point is that the recent introduction of regulations, which force advanced biofuels penetration in the EU energy mix, will be reducing the consumption in transport sector of other energy source like first generation (1G) biofuels and hydrogen.

NOMENCLATURE

ABIPEL= Associação Brasileira das Indústrias de Pellets

ANEEL= Agência Nacional de Energia Elétrica

ANP= Agência Nacional do Petróleo, Gás Natural e Biocombustíveis

BNDES= Banco Nacinal do Desenvolvimento

CENBIO= Centro Nacional Brasilero de Referencia en Biomasa

CIF= Cost Insurance and Fraight

COFINS= Contribuicao para o Financiamento da Seguridade Social

CONAB= Companhia Nacional de Abastecimento

COP21= Conference of Parties

EU28= European Union - with 28 Member States

FIESP= Federacao das Industrias dos Estado de Sao Paulo

FOB= Free on Board

GAMS= General Algebraic Modeling System

GBEP= Global Bioenergy Partnership

GDP= Gross Domestic Product

IBGE= Instituto Brasileiro de Geografia e Estatística

ICMS= Imposto sobre a Ciirculacao e Mercadorias e prestacao de Servicos

IEA= International Energy Agency

IINAS= International Institute for Sustainability Analysis and Strategy

ILUC= Indirect Land Use Change

LCA= Life Cycle Assessment

LUC= Land Use Change

PET= Pan European TIMES model

PIS= Programa de Integracao Social

PRONAF= Programa Nacional de Fortalecimento da Agricultura Familiar

REACCESS= Risk of Energy Availability: Common Corridors for Europe Supply Security

RECOR= REaccess CORriod model

RES= Reference Energy System

ROW= Rest of World (with respect to EU)

RSB= Roundtable on Sustainable Biomaterials

TIAM= The TIMES Integrated Assessment Model

UNICA= União da Indústria de Cana-de-Açúcar

WBA=World Bioenergy Association

1. INTRODUCTION

1.1 CONTEXT

Due to favourable climatic conditions and the availability of land, Brazil is one of the world's largest producers of raw material to produce bioenergy. For example, according to a study published in 2017 [1], Brazil has 105 mega hectares of degraded area usable as forest suitable to produce biomass for the production of pellet, and it is the major producer of wood from planted forest. Moreover the Annual Average Increment (AAI[1]) of planted forest in Brazil is higher compared with the rest of the world in a range between 30% and 50%, [2]; the wood residues (from forest and from agriculture) generated in 2016 in Brazil corresponds to 47.8 Mt [2], which is almost equivalent to 14.5 Mtep; Brazil is also the second ethanol producer at world level (about 37% of the global ethanol production, with about 28 Mm^3 produced in 2016, [3]), and the first world producer of sugarcane (651,841 Mt produced in the crop of 2016/17, [4]). Hence, it is of great interest to know the potential of this country in terms of export in an era in which the biomass market in general plays an important and coveted role.

In particular it is studied here the possibility of Brazilian exportation to the European Union (EU28[2]) which is actually one of the biggest consumer of bioenergy. It is demonstrated by the last biofuels statistics [5]: around 18.1% of EU heating and cooling was renewable (2016) [6], with biomass representing the largest contribution; the EU28 is the world´s largest wood pellet consumer (about Mt 22.2 of pellet consumed in 2016 [5]), and the heat and power consumption from solid biomass is almost 45% [5]. That occur because the European Union needs to diversify its energy mix and thereby to increase its energy supply security, to reduce its GHG gas emissions which is today one of the major common targets to light the climate change. Moreover, with the modification of the Renewable Energy Directive (the RED that became RED II)[3], some mandatory percentages on the use of biofuels in transport were imposed (7% of conventional biofuels), as a contribution to ensure that EU will produce at least 27% of its energy from renewable sources in 2030. But the actual blending of bioethanol and biodiesel in transport fuels (3.3% and 5.8 % respectively [5]) are far below the targeted 10%. These data show that the EU is not able to produce biomass in enough quantity to satisfy its internal demand; thus, an importation from third countries could help in reaching its objectives.

Thanks to many studies available in literature [7, 8, 9, 10], it is already well-known that the only two competitive markets from Brazil to Europe in term of biomass are the ethanol and the pellet ones (the reasons in favour of this assumption are explained in this study). Biodiesel is excluded from the analysis because its production costs in Brazil are very high and the quantity too low to be exported in Europe with acceptable economic profits. Considering all these reasons, only pellet and ethanol are analysed here as export products.

As the statistical data of UNICA, ANP, ANEEL, CONAB etc., and literature [3, 11, 12, 13] demonstrate, the ethanol exportation is already developed and affirmed, while the participation of Brazil at the world pellet production is less than 4% (EU contribute for 50% in the pellet world production [5]), and

[1] AAI is the volume by which the forest grows per unit area over a 12 month period.
[2] EU28= Austria, Belgio, Bulgaria, Cipro, Croazia, Danimarca, Estonia, Finlandia, Italia, Lettonia, Lituania, Lussemburgo, Malta, Paesi Bassi, Polonia, Portogallo, Regno Unito, Repubblica
Ceca, Romania, Slovacchia, Slovenia, Spagna, Svezia, Ungheria.
[3] RED= Renewable Energy Directive 2009/28/EC; RED II= Renewable Energy Directive (EU) 2015/1513.

only USA and Canada have an affirmed and developed wood pellet international market. Their exportation is mostly destined to EU since Europe at the present time is the biggest producer and the biggest consumer of pellet in the world (10.8 Mt produced in 2011 [14, 15], and 15 Mt in 2015 [16]), with a final balance resulting in a deficit. The possibility for Brazil to become one of these supply countries is high but not obvious. The difficulties are discussed below. Moreover, in this study the prospective solution developed in a recent study done in the Sao Paulo University [2] was considered for the estimation of the pellet production in the future: the production of pellet from short rotation eucalypt wood and passing through a chlorine purification process[4]. This solution has been shown to be very promising and feasible end it was also mentioned by others scientific studies like the IEA pellet report [1]; for this reason, it was taken into consideration.

1.2 OBJECTIVE OF THE RESEARCH

In this work, the main objective is to simulate and analyse the exportation of ethanol and pellet from Brazil to Europe and see how it can influence the whole energy system, using the TIMES model generator. In other words, an updated set of biomass energy Corridors has been implemented in an existing world energy model; the description of the model and of the framework is available in Paragraph 1.4 The updated model has been run to study a set of scenarios based on the availability and/or forced demand of biomass.

The scenarios obtained may occur because they are based on available real data and on hypotheses considering the current situation. To do this it was necessary a preliminary deep research and bibliographic analysis to understand the problem, to have specific and reliable technical, economic and socio-economic data about the analyzed biomass (i.e. production, demand, % of exportation, trade

[4] (Why Eucalypt wood?) → From a productive point of view, Brazilian eucalypt has higher values comparing with the rest of the world: the traditional planted forests of Eucalyptus in Brazil have an average yield of 287 m3 / ha, in 7 years, around 25 tons per hectare year; while in Sweden, for example, to obtain this same production, would require 10.2 ha. In addition of this, eucalypt is known for its ability to grow in degraded fields. Despite this, for the moment, the use of wood from planted forests (currently destined to serve the pulp and wood panel sectors, among other productive sectors), does not reach competitive production costs in the biomass market for energy use as well as for the production of wood pellets, [2].

(Why short rotation?) → The solution could be to increase the number of plants per hectare aiming at the greater production of biomass in smaller useful area. This is possible with the production of forests (suitable for the production of biomass for the production of pellets) with short rotation, which allow almost twice the productivity per hectare of traditional planted forests, with the same productive cost, (yields of about 45 tons of dry mass per hectare in cycles of 1 years), [17].

(Why purification process?) → The drawback of Brazilian eucalypt wood is the high concentration of chlorine and other impurities that must be reduced to comply with the sustainability prerequisites dictated by the European standards. However, also this problem seems to be resolved thanks to a recently discovered process that consists of removing chlorine and other inorganic substances (i.e. alkali metals) from eucalypt wood, in order to allow the production of solid biofuels (wood pellets or others) free of dioxins and corrosive compounds resulting from combustion, in order to meet the requirements of the European standard, thus allowing access to the international market for wood pellets.

variables, production and transportation costs, policies, etc.), and so to be able to evaluate the long-term (up to 2040) effects of the scenario created.

1.3 METHODOLOGY

1.3.1 BACKGROUND ANALISYS

The studies that have been useful for the realization of this thesis can be subdivided into 3 different typologies: 1. Official databases and statistics for the collection of numerical data; 2. Articles and manuals for practicing the modelling tools (e.g. the use of the TIMES interfaces); 3. Scientific papers and texts to deepen the analysis and knowledge of the background concepts such as sustainability and biomass utilization, processing and trade assessments.

Among type 3 references we can mention P.F.A. Shikida et al. [18] who write about the possibility to diversify the supply of energy increasing the use of bioenergy from biofuels investigating the Brazilian and the European experiences. Another study was done in 2014 by IINAS [19] to highlight the challenges and the opportunities of the trade of energy wood for developing countries and, in particular, the case of Brazil with the cooperation of CENBIO is also studied [19]. In 2011 a report [20] on the impact of the Brazilian ethanol exportation was realized. It underlines both the impact and the potential of the ethanol exported from Brazil and its previsions result in line with the actual situation.

1.3.2 ENERGY MODELS

Taking into account all issues explained above, some scenarios have been developed here, with the aim to simulate a connection (the Corridor) between Brazil and Europe. The energy models utilized are PET, TIAM and RECOR (the union of these three models is known as REACCESS model) and all these are TIMES based. The simulations give as output the trend of the specific trade analysed in term of emissions and energy flows, from 2015 to 2040. The time horizon chosen is divided into periods and the decisions taken by the model refer to the central years of each time period (they are called ´´milestone years´´).

The optimal solution calculated by the model is found minimizing the objective function that is the system cost. The data of the base year is given as input, (like supply quantities, end-use demands, feedstock prices, technical and economic parameters, policies, etc.), on the base of the research done in the first part of this study; some of these data, projected in the future on the base of some hypothesis, are given as input too. The outputs of the model are calculated also thanks to some macroeconomic inputs (like GDP, population, etc.), called drivers.

To do this, a preliminary detailed research on Brazilian energy system was necessary to understand its real biomass exportation potential and to find all the values necessary for the realization of the scenarios. In addition to this it was necessary a preliminary knowledge of TIMES and the models used; in the next paragraph there is a brief description of them.

1.3.2.1 TIAM, PET and RECOR: a brief description.

TIMES was developed by the IEA-ETSAP (Energy Technology Systems Analysis Program) and was derived from the model generator MARKAL (MARket Allocations). It is a model generator because with it, it is possible to construct a model defining a Reference Energy System (RES), that is the description of the energy chain including the mining, the production, the transformation, the trade and the end use of all energy forms. The RES is made of several technologies and commodities logically interrelated one with the other. A technology is any process that produces, transforms and/or consumes a commodity. It is characterized by technical and economic parameters (like activity, capacity, technical life, investment cost, etc) and by emission coefficients. The commodities are any form of energy, material or emissions. The end-use is composed by five sectors (industry, agriculture, commercial, residential and transport) and each sector has a demand profile which can variate between weeks and within weeks can variate in day/night and peak periods. Energy demands are determined by several exogenous drivers (such as GDP growth, population growth) through the application of demand elasticities. In addition to the drivers, also elasticities, technology costs and parameters, climate parameters are exogenous to the model.

TIMES describes the energy system analyzed using a system of linear equations. The set of linear equations describing the model is then solved (using Linear Programming) to find the ideal solution; this is done by minimizing the objective function (which is the minimum cost of the energy system) according to a number of input and constraints defined by the user, in medium or long-term time horizons (the longer time horizon extends up to 2100).

Typical input data are:

- Demand at the base year and the projections;
- Supply;
- Policies (emission coefficient, incentive, taxes, etc);
- Technical and economical data (timelife, energy cost, investment cost, etc).

Typical output data are:

- Commodities flux in the time;
- Emissions in the time;
- Commodities prices;
- Objective function (the minimum cost of the system).

All these data are implemented using an interface, developed by KANORS company, called VEDA Front-End for the introduction of the inputs and VEDA Back-End for the reading of the output.

The optimization models that TIMES generates are: linear; rich in technological data; bottom-up forecasting; demand-driven (the energy demands are exogenous to the model); with a partial equilibrium approach. So, all the investment decisions are made by the model in each time period with full knowledge of future events (future energy demand of a sector, future price of a commodity, etc.) and with an economic equilibrium approach for the energy markets, corresponding to the point of intersection between the supply curve and the demand curve. It means that the model works always assuming an economic equilibrium for each energy market5.

PET, TIAM and RECOR are three models based on TIMES and so they have all the features just described.

[5] A market is said to have reached an equilibrium at prices p and quantities q when no consumer wishes to purchase less than q and no producer wishes to produce more than q at price p, [35]. In other words: the production of energy products is always equal to its consumption.

TIAM is the model of the energy system of the Rest of world (ROW) with respect to Europe (EU). It initially included the RES of the following 15 regions: Africa, Australia-New Zealand, Canada, Central and South America, China, Eastern Europe, Former Soviet Union, India, Japan, Mexico, Middle-East, Other Developing Asia (ODA), South Korea, United States, and Western Europe. Then, the EU was isolated as one region and 3 regions were modified: Western Europe, Former Soviet Union and Eastern Europe were substituted by Russia, Central Asia and Other Europe. Each region is linked with the others by energy trades and emission permits. The RES of TIAM contains more than one thousand technologies and one hundred commodities in each region and its time horizon is from 2005 to 2100.

PET has a separate representation of each member state (27 European Union states plus Iceland, Norway and Switzerland) and of the energy trades between the states. KANLO company defined the RES for each country model. Since it is TIMES based, the RES of each state is very well defined in technology. Each technology described with economical and technical data. PET uses the partial equilibrium of TIMES, where the demand for energy services depends endogenously on own price elasticities [36]. It may be used as an integrated EU model or as a series of stand-alone models for each member state [36] and its time horizon is from 2005 (the base year) to 2100.

RECOR was born after (2009) the other two models as a tool to analyze the European energy imports and the risk of European energy availability. It links PET and TIAM in a macro energy model composed by 45 regions: 30 European states of the PET model plus 15 regions of the ROW of the TIAM model. The integration of TIAM with PET was done subtracting the European region from TIAM, in this way was created a continuity in the supply and demand energy of ROW: the resource supply of TIAM is represented by a separate module that also feeds the European model (PET) through the corridors. A corridor is represented as a process. It starts from the region of the ROW and goes to Europe. A corridor can be considered as a series of different branches because in each region it has to have parameters (like cost, risk, etc) typical of that region. The branches also include feeder branches that collect energy in some region of the ROW and concentrate it in one or several corridors. RECOR includes hundreds of corridors each composed of several branches. This new process type was coded in the GAMS code of TIMES and is now a permanent feature of the TIMES generator [35].

1.4 THESIS STRUCTURE

The structure of this work is basically divided into 3 main parts:

1. Review of the actual energy system of both European Union (EU28) and Brazil, and description of the actual energy policies linked with the biomass sector (chapters: 2, 3, 4, 5);
2. Description of the scenarios, of the hypothesis done to generate them and of the results obtained by the simulations (chapter 6);
3. Summary and conclusions (chapter 7).

The development of the first part of the work (research statement, review, state of the art, data collection, hypothesis) took place at the Institute of Environment and Energy (IEE) of the San Paolo university in Brazil. This was essential for getting to know the Brazilian reality concerning biomass, as well as the real potential and current interests in this field. The opportunity to speak personally with specialists in the field and receive information on site, helped to grasp some details that probably could not have been grasped if working from Italy.

For the second part of the work (simulations and analysis of the results) instead, the time spent at the Turin Polytechnic was fundamental having direct access to the model and to a workstation needed for the simulations.

2. GLOBAL OVERWIEW OF BRAZIL ENERGY SECTOR

This chapter aims at giving an idea of the current energy balance in Brazil in order to highlight its export capacity, in terms of energy, to the rest of the world.

2.1 MAIN CHARACTERISTIC OF THE COUNTRY

With an extension of about 8,515,767 km^2, Brazil is the biggest of South America's countries and the fifth largest in the world in terms of area and population. It counted about 207,000,000 of inhabitants in 2016 and about 209,000,000 in 2017 [37]. It was estimated an average growth of 0.6% during the next ten years, [38]. The biggest growth will be in the North and Central-West area.

About the economic activity, Brazil manifested a hard decline on GDP during 2015 (-3.8% with respect to 2014), and during 2016, (-3.6% with respect to 2015), [39]. Looking at the historical series, this was the largest worsening in the history of the country, with a similar occurred in 1930-1931. A fall in GDP means that the country had an economic recession.

The GDP at current prices[6] registered in 2016 was 2,080 GUS$ [39].

Since Brazil is a big player in the world market of agricultural commodities and it has an increasing exportation of primary sector products (agriculture and mining), an economic revival is likely in the next years but for the moment Brazil is still under the world GDP averages. In the following line graph (Figure1), there is the comparison between different GDP time series at current prices in GUS$, [40].

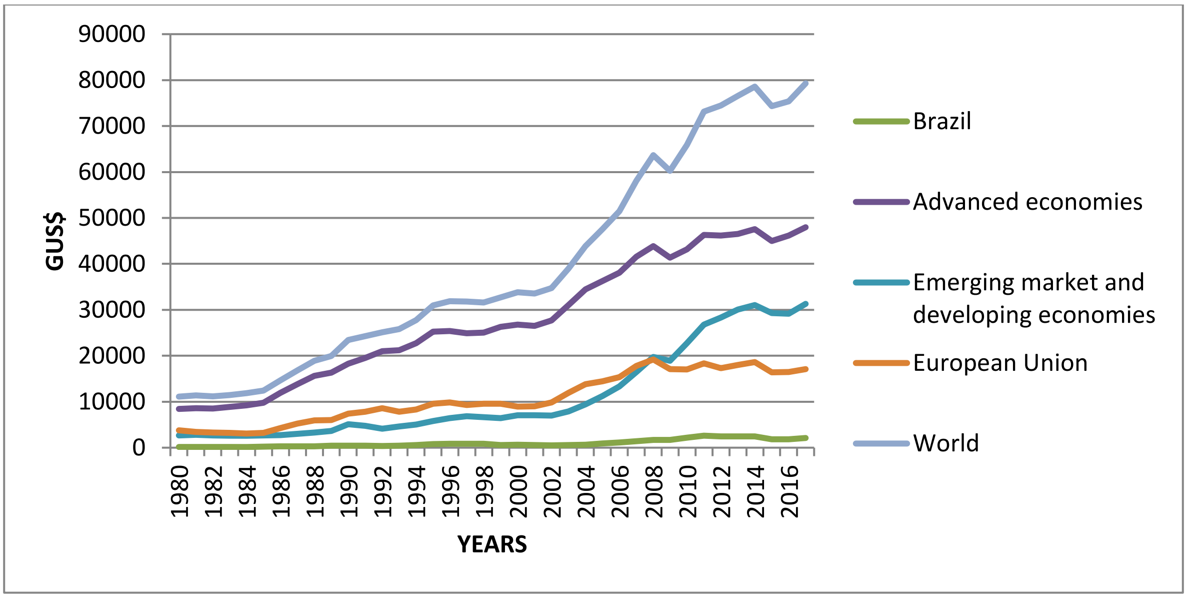

Figure 1: GDP at current prices in GUS$; comparison between Brazil, developed countries, developing countries (Brazil is included here), EU28 and world trend [40].

[6] Gross Domestic Product represents the total value at current prices of final goods and services produced within a country during a specified time period.

2.2 CURRENT ENERGY SUPPLY IN BRAZIL

The actual (2016) internal available energy[7] in the country is about Mtep 288, and the various percentage contributions on total showed in Figure2 [38].

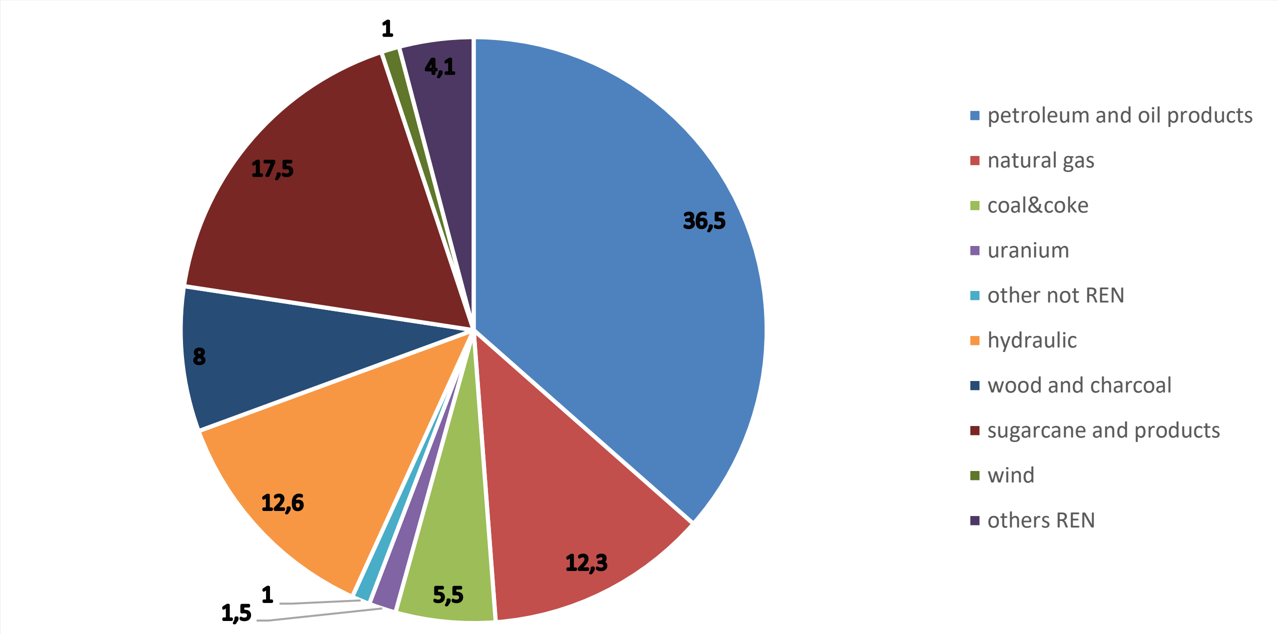

Figure 2: Brazilian energy supply, [%] [38].

The previous pie chart (Figure2) includes the whole Brazilian energy supply divided into energy type in terms of percentages. It can be described splitting the renewable energy sources from the not renewable one as Figures 2.1 and 2.2 show.

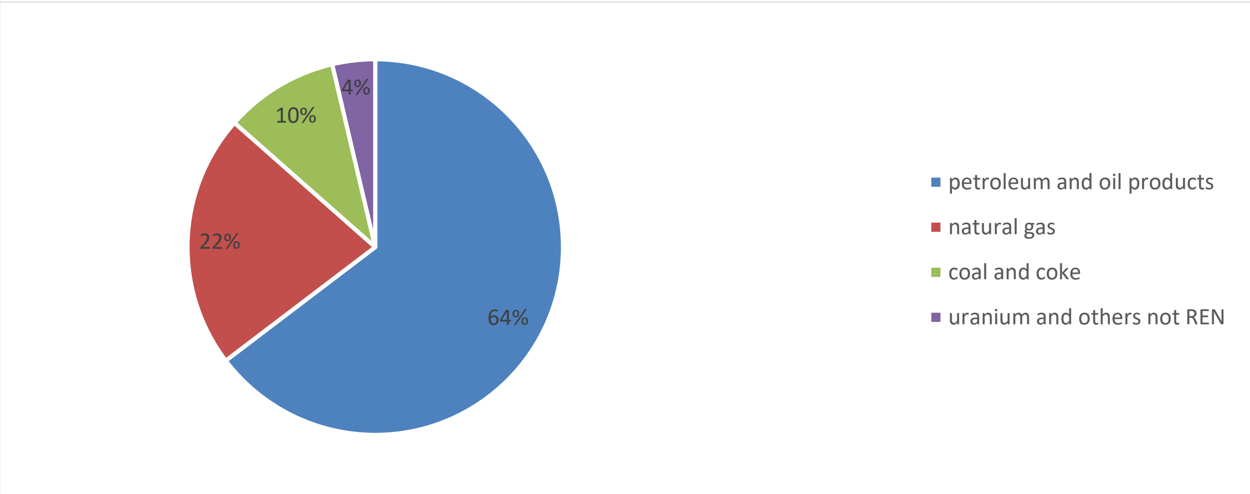

Figure 2.1: Share of not renewable Brazilian energy supply in 2016 [38].

[7] It is calculated as the algebric sum of production (+), export (-), import (+) and losses, reinjection and changes of stocks (+ or -) [38].

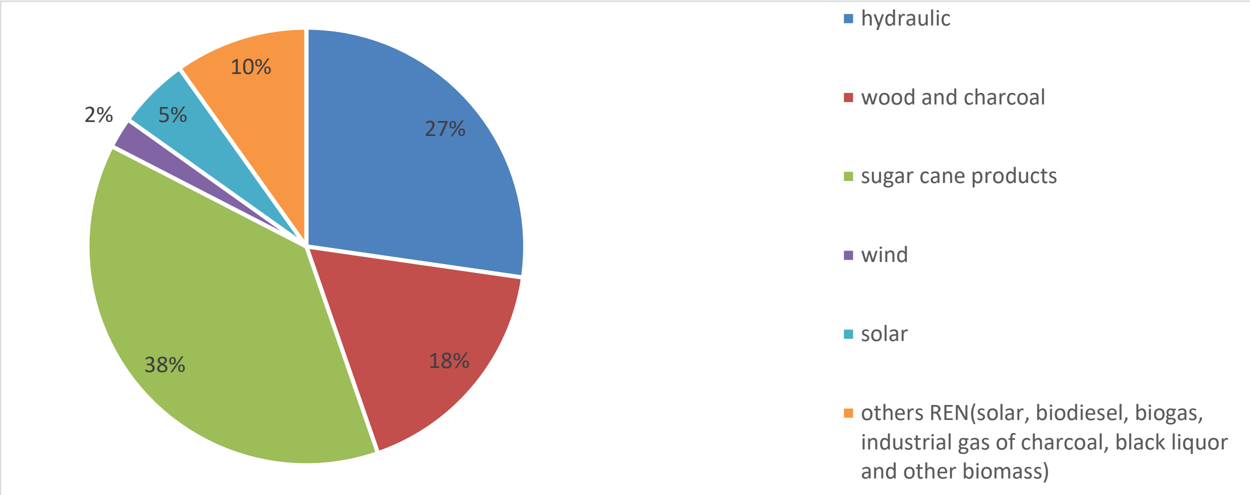

Figure 2.2: Share of renewable Brazilian energy supply in 2016 [38].

Considering these values, the amount of fossil fuels in the domestic energy supply is about Mtep 163 and the renewable sources represents about 45% of the Brazilian energy mix (see Figure 2). This percentage is higher than the world´s average registered in 2016 and at the same time higher than the one registered in Brazil in 2015 (about 43%). A direct consequence of the reduction of energy production by fossils sources is the reduction of CO_2 emissions (it decreased from 1.55 tCO_2/tep in 2015 to 1.48 tCO_2/tep in 2016) [42].

Among the fossil sources (Figure2.1) the largest parts in terms of quantity are: petroleum and oil products (64%) and natural gas (22%); among the renewable ones (Figure 2.2): sugarcane products (38%) and hydroelectric (27%), [42].

2.3 ELECTRICITY SUPPLY IN BRAZIL

It is interesting to show the domestic electricity supply by source (Figure 3).

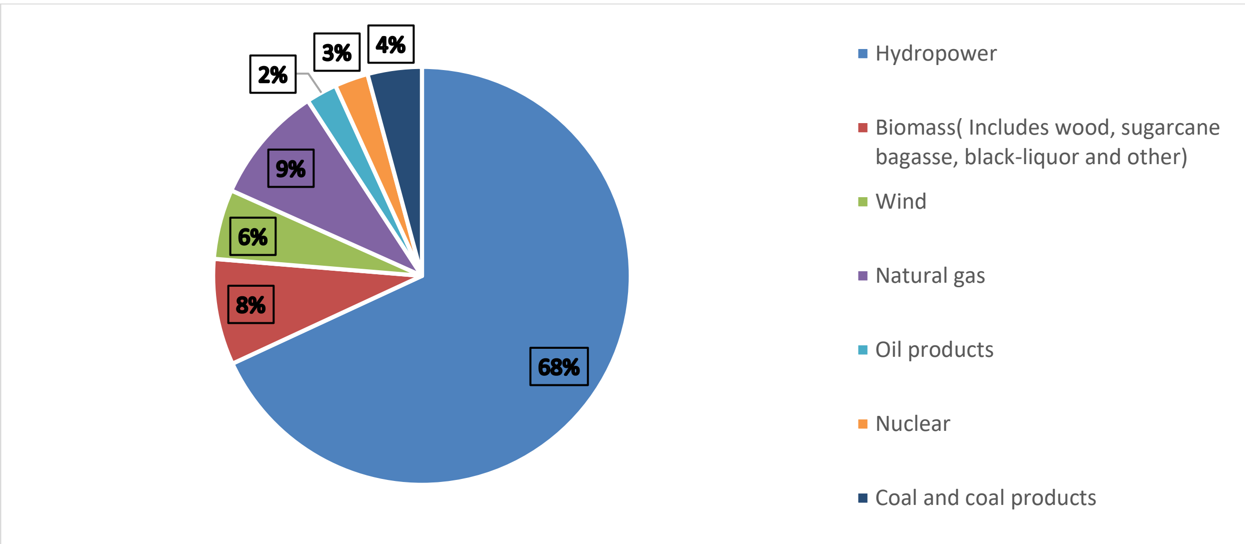

Figure 3: Domestic electricity supply by source [%] [38].

As Figure 3 shows, the electricity production by not renewable sources in 2016 is of 18% and it was of 25,9% in 2015 [38]. The generation of electric power in 2016 was of about 59,971 ktep and, as is shown in Figure 3, the main source of generation was the hydraulic [38].

2.4 CURRENT FINAL ENERGY CONSUMPTION IN BRAZIL

The main indices of the final energy consumption[8] are listed in the table 1:

Index (2015)	Values
Final use of energy [Mtep]	256
Final use of energy per capita[tep/capita]	1.43
Energy intensity [9] [tep/kUS$(2010)]	0.1

Table 1: Brazilian final energy consumption index (2015) [43].

In the left side of Figure 4 is visible Brazil is far from the average consumption per capita level of the developed countries (2015). Infact it has only 1.43 tep per capita placing itself at the penultimate place compared to the seven countries shown in the graph. After him only India.

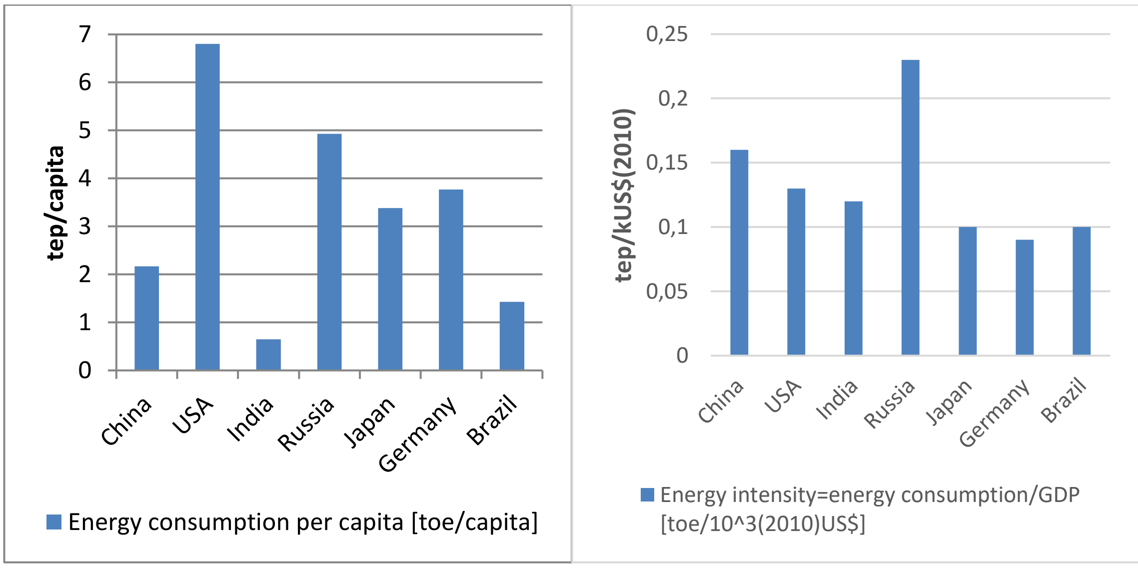

Figure 4: Energy consumption per capita and energy intensity of some representative countries of the world (2015) [43].

Generally, less energy is consumed when economies are experiencing a recession and this is proved by the economical values shown in the previous chapter (decrease of GDP between 2014 and 2015).

[8] It not includes losses in distribution and storage energy and losses in transformation processes. The sum of the Final Energy Consumption, losses in distribution and storage and losses in production processes is called ``Gross Inland Energy Consumption``, also known as Domestic Energy Supply.
[9] It is the total energy consumption per unit of GDP (PPP).

In the right side of the same Figure 4, it is represented the energy intensity of the same seven countries in 2015. Excluding Russia, which ranks first, distancing itself a lot from other countries, the values oscillate between 0.16 of the China and 0.09 of the Germany. Brazil, as well as Japan, has an energy intensity of 0.1.

In accordance with the ANP statistics, there was a reduction of energy intensity compared with the previous year (2014), despite the GDP fell from 2014 to 2015, and it is linked with an increase of the energy efficiency and the change in the request of energy by the different sectors.

Looking at the final energy consumption by sector, it is evident how the predominant sectors are the industrial sector (31.5%) and the transport ones (32.2%). Between the 2015 and 2016 there was a reduction of 2.2% (5 Mtep) in the energy consumption. Figure 5 quantifies the consumption by sector in 2015 and in 2016:

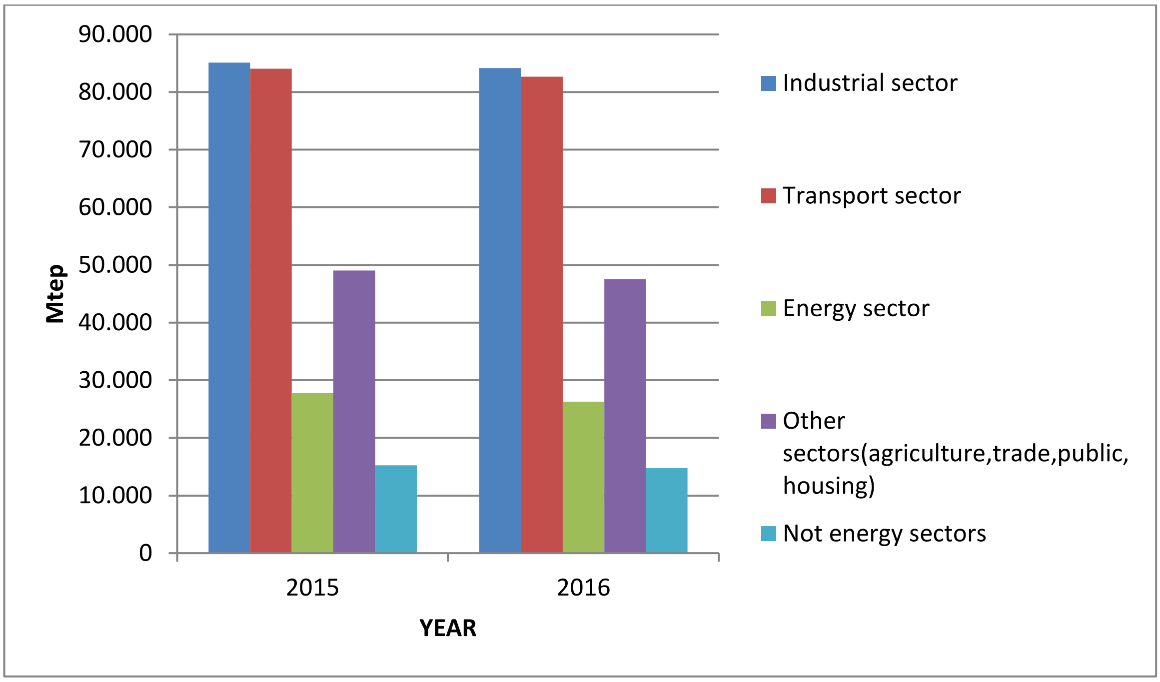

Figure 5: Energy consumed by different sectors in 2015 and 2016, [Mtep] [42].

As far the transport sector is concerned it is estimated an increment of the passengers and freight vehicles of 4% and 3.5% until 2026 [44] and an increment of about 4% in rail's transports [44]; this means that there will be obviously consequent growth of the total energy demand. The estimated average growth is 1.6% between 2016 and 2026 [44] and it will be satisfied by a larger percentage of ethanol (17%) and diesel oil (43%) with respect to the other forms of energy.

With regards to the energy consumption by source (see Figure 6 and Table 2), the fossil sources (natural gas+coal+oil products) exceed the renewable share (wood and charcoal+sugarcane products) with a percentage on the total energy consumption of 53,5%. However, considering the actual environmental policies and energy targets, they are not destined to grow in quantities because the contribution given by the source of energy with less GHG gas emissions (electricity from renewables, sugarcane derivatives, biodiesel, waste obtained in the pulp production process, charcoal) will probably become more and more important. Infact, it can be considered that the electricity is destined to increase (thanks to the electric cars), as well as the cane derivatives, like ethanol because it can substitute heavy vehicle gasoline. It has to be underlined the ethanol in Brazil can be blended with gasoline in its anhydrous form, with fixed percentage which, with the Brazilian low n° 13.033 (September 2014), must fall within the blending range of 18% to 27,5%. While hydrate ethanol can be sold as is without blending. As well as biodiesel will increase thanks to the actual law n° 13.263 (March 2016) that says it has to be share with diesel at a rate of 8%. Waste from paper production will also increase because the cellulose production is always growing in Brazil. On the contrary, wood and vegetal coal will decrease in the final consumption because there are other sources with a bigger energy efficiency (like LPG in the residential sector, for example).

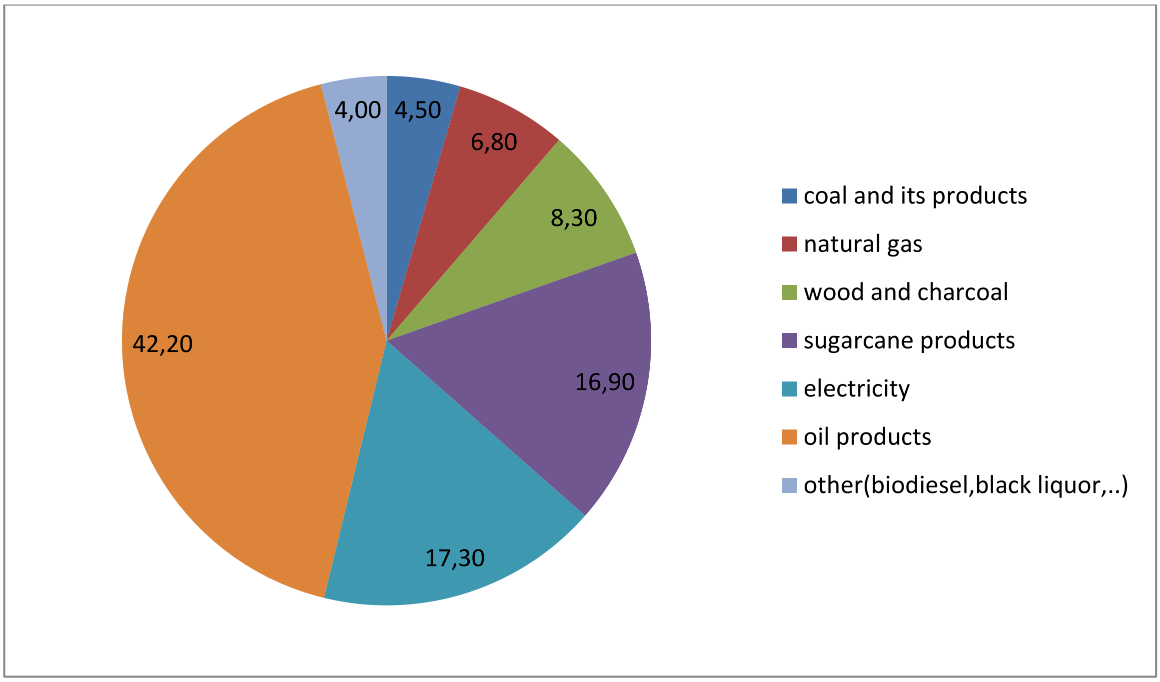

Figure 6: energy consumption per source (2015), [%] [38].

ENERGY SOURCE	ktep	%
Sugarcane products	43,264	16.9
Wood & charcoal	21,248	8.3
Electricity	44,288	17.3
Coal coke, tar, steam coal	11,520	4.5
Natural gas	17,408	6.8
Oil products	108,032	42.2
Other (biodiesel, black liquor, ...)	10,240	4

Table 2: ktep consumed in Brazil per sources [38].

2.5 BRAZILIAN POTENTIALS AND CHALLENGES

Brazil is actually the second major exporter of ethanol in the world but its actual exportation of other biomass is limited compared to its real production potential. For example, only 2% of the total wood from the planted forest is actually exported [21]; furthermore, most of the wood residues generated from wood factories are left in the fields. It is necessary for the soil regeneration but the percentage that the soil requires is much lower than the one is left on it, so the wood residues remain only a potential gain since it could be reused or used to produce bioenergy (production of vegetable coal, thermal energy and electricity).

Comparably to what is explained in the literature [11, 16, 22] these limitations are caused by problems linked to external and internal legislation, lack of subsidies and investments, a need of specific policies for the use of lignocellulosic residues, and other diverse economic and social aspects. For example, the high import duties imposed on ethanol imports in EU to protect European producers, which are subsidized, make the exportation less profitable. Besides, while the Brazilian logistic structure is well consolidated for ethanol, it is not the same when one considers the wood pellet: in Brazil there is lack of adequate ports for biomass export and the storage and transport systems are inadequate for the market.

In addition to this, the sustainability is another big challenge. To achieve the goals of GHG emission savings and to use alternative energy sources instead fossils ones (such as coal, oil, natural gas), it is necessary that the fossil-replacing energies be sustainable under all the points of view. For this reason, the EU28 policy for renewable energy (composed by Climate Change Package and Fuel Quality Directive) includes the RED II that regulates the sustainability of all kinds of biomass with specific requirements. These criteria are available in term of quantities in a certification system called ENplus[10] for residential use and ISO18122 for industrial use. The certification is valid for the internal trade and for imports, and it is based on the following main characteristics: (1) the greenhouse gas emission savings from the use of biofuels must be at least 50 % (in 2017) compared to fossil fuels; (2) the biomass is not to be derived from land with high biodiversity value; (3) the biomass is not to be derived from land with a high carbon stock (lands that contribute in a particular way to reduce CO_2 from the atmosphere, thanks to the process of photosynthesis of plants) [6]. Consequently, the commodities made available from the supply country, and in this case from Brazil, must have these characteristics to be exported and, at the same time, be socially and economically competitive. That is the principal challenge of solid and liquid Brazilian biomass trade to the European Union.

2.6 THE BRAZILIAN ENERGY SUSTAINABILITY

There are a lot of studies on the Brazilian biomass sustainability due to the general awareness that an impact on the system and on the ecosystem needs to be avoided. The predominance of biomes in the Brazilian soil (the 62% of the total 851 Mha of the country is constituted by biomes like Amazon forest, Pantanal (wetland), etc.), has always raised the question on the impact on biodiversity, direct and indirect change land use (LUC; ILUC), misuse of the land (food VS biofuels crops), deforestation. These are considered the most important environmental impacts to address, mainly for GHG and ecosystems, but they are not the only ones. Moreover, the sustainability is not only linked to environmental aspects but to social and economic aspects as well.

According to the IBGE [23] the problem of the land availability in Brazil is mainly linked to agriculture and breeding, that are in a continuous increase year after year. For example, the deforestation linked with pine and eucalyptus cultivation (used for energy wood production) representsonly the 2% of the total area of the country; moreover since the sugarcane expansion mainly concerns the Center-South of Brazil, the deforestation cannot be linked to sugarcane expansion crop because it is far from biomes and also because the climatic conditions for a good growth of sugarcane are different from the ones of Amazonia or the other Brazilian biomes; while the 65% of deforestation of the Brazilian biomes, is caused by the agriculture expansion and the 33% by the breeding expansion [23]. Other Brazilian studies [18, 24, 25, 26] show that the land needed by sugarcane production is small compared with other large-scale crops (cacao, coffee, corn, etc.); in addition to this and according to a study done in 2011 [27], the indirect land-use change (ILUC) effects of ethanol expansion resulted in only about 0,14 ha of new land coming from previously unused land for each new hectare of sugarcane and this value is higher than the values found in Brazilian literature [27]. However,

[10] It is avaible in the annex a table reporting the ENplus and the ISO certification.

there are also some studies which show the impact that would occur if the biofuels production expanded into biomes the consequence of which should not be overlooked.

To keep under control the growing crops (like sugarcane, palm, corn, etc.) utilized for the biofuels production, in Brazil there are dedicated mapping systems that take into account various sustainability indices that must be respected. The land zoning is an important methodology that facilitates the correct use of the soil thanks to established guidelines that aim to protect and recover forests and water sources in sugarcane plantations, to control erosion and the content of the water flow, to stipulate a proper pesticides management, to encourage the reduction of air pollution and solid waste from industrial processes. All this allows to estimate some fundamental environmental parameters (i.e. water consumption, emissions of atmospheric pollutants, existing biome conservation, soil and topographical restrictions, etc.).

3. GLOBAL OVERWIEW OF EU28 IN ENERGY SECTOR

This chapter will describe the current European energy situation with the aim of highlighting the current import trend in the sector.

3.1 MAIN CHARACTERISTIC OF THE EU

In this study it is chosen to consider only the 28 countries of Union Europe (EU), so all data refer to them.

It has to be remembered that each EU country is a unique reality. This means that GDP and demographic growth, for example, may vary greatly from one country to another. Each country also applies its own strategy.

However, since the purpose of this study is to analyze the biofuels flow from Brazil to Europe, here the EU is seen as a single entity and so all data describe an average trend of all 28 countries.

Europe extends over 4,326,253 km^2 and counts about 508 million of inhabitants, [45]. Every year births outweigh the deaths so the European population is increasing. The population increases also for the positive migratory balance.

The economic situation of EU28 is described by a GDP at current (2016) prices in GUS$ of 17,110 [40].

Just to give a full view of the differences in the GDP values of the 28 countries of EU, Figure 7 below shows the historical series (from 1980 to 2016) of GDP per capita in US$ per capita.

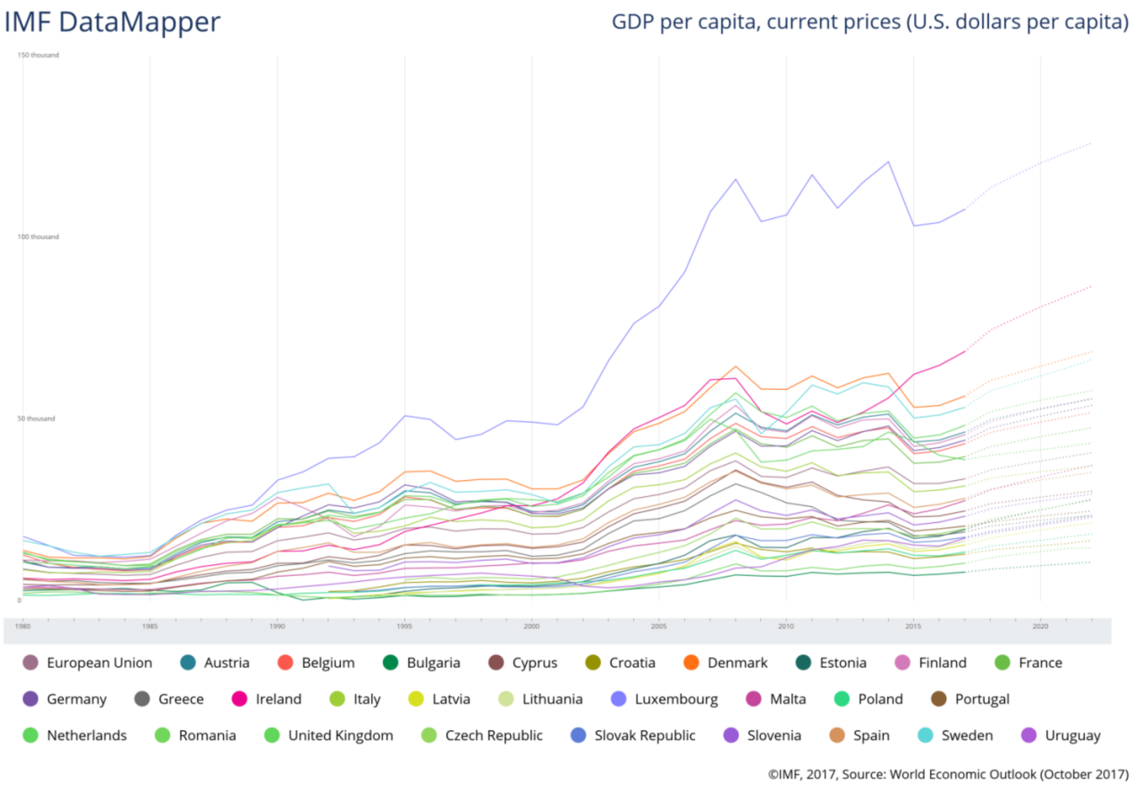

Figure 7: GDP per capita, current (2016) price; US$ per capita: values for the 28 countries of EU from 1980 to 2016 [40].

It can be seen how the trend is almost similar for all 28 countries during the time: it is continuing to increase with some oscillations. The most relevant increase was from 2001 to 2008.

Luxembourg is the only state that differs from others with a GDP per capita of 103,160 GUS$ per capita in 2015 (it is much higher than the EU28 average GDP per capita registered in the same year: 32,280 GUS$ per capita); while all the rest of the countries registered values between 7,020 (Bulgaria) and 62,340 (Ireland) GUS$ per capita, in 2015.

3.2 CURRENT SUPPLY ENERGY MIX IN EU28

The total primary energy production in 2015 in EU28 was of 767 Mtep; 0.8% lower than in 2014 [45]. That is splitted into source type with the percentages showed in Figure 8.

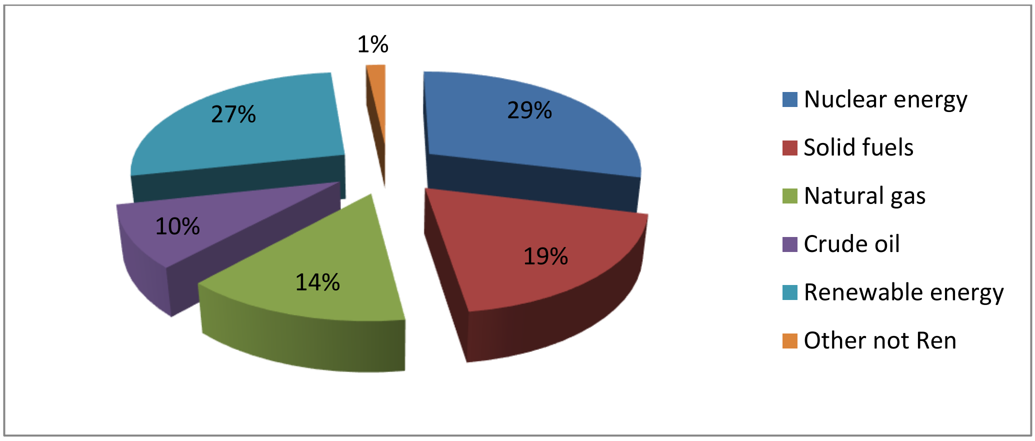

Figure 8: PRODUCTION OF PRIMARY ENERGY IN EU-28 (2015), Mtep [45].

The share of renewable energy is 27% of the total production (see Figure 8) which is equivalent to 205 Mtep. It is composed by the contributions of the different renewable energy sources as Figure 9 shows. The higher percentage is given by the wood and other solid biomass with a production of 91.4 Mtep (44% of the total renewable energy produced).

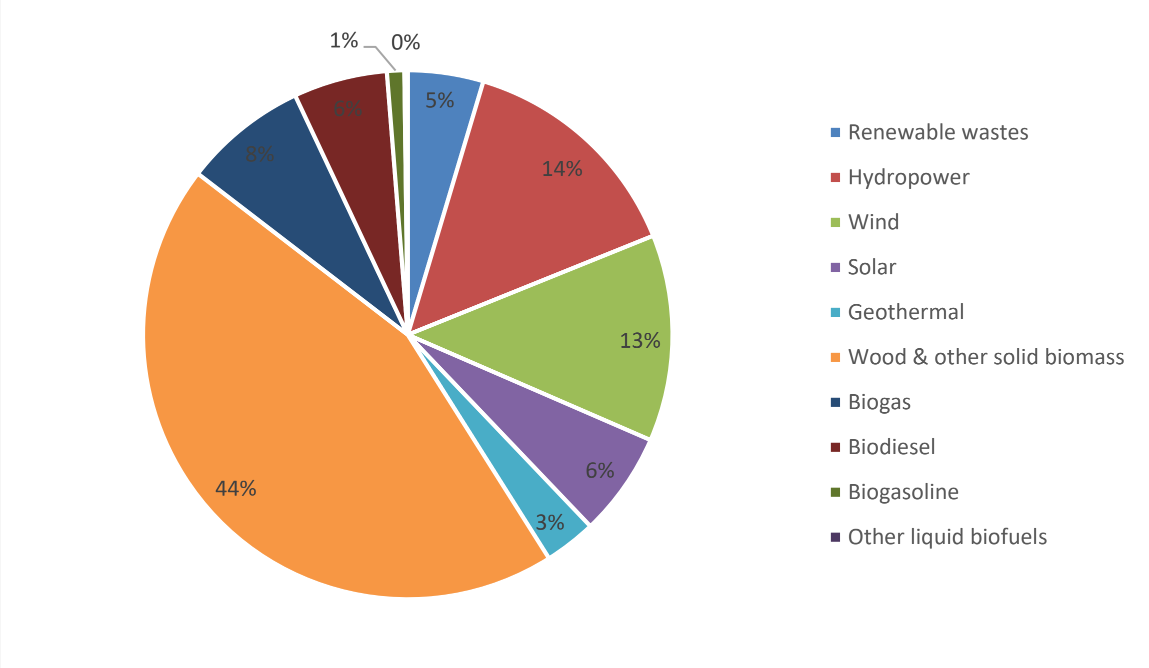

Figure 9: RENEWABLE ENERGY PRODUCTION (2015), [%] [45].

According to the EUROSTAT database, in the last ten years, there was a positive trend in production of renewable energy and, at the same time, a negative trend in primary energy production of fossil fuels and nuclear energy. The biggest decrease occurred in the production of oil products (-43.9%) and in natural gas production (-43.5%) [45]. This resulted in an increase in the import of primary energy and energy products.

The actual main suppliers of energy sources to EU28 are Russia, Norway, and Algeria for natural gas; Colombia, USA, and Russia for solid fuels; Russia, Norway, Nigeria for crude oil. An important thing to not compromise the security of the supply is to diversify the external suppliers.

The total energy imported in 2015 was of 1,482,203 ktep [45] and it is subdivided into the energy sources reported in the table 3:

Source of Energy imported in 2015	Coal	Crude oil	Oil products	Natural gas	Electricity	Biofuels and waste
ktep	151,511	600,353	338,103	341,181	35,289	15,761

Table 3: European (EU28) energy import in 2015 [45].

Imports were much lower than exports, in 2015. The total energy exported in 2015 was of 575,502 ktep [45] and it is subdivided into the different energy sources listed in the table 4:

Source of Energy exported in 2015	Coal	Crude oil	Oil products	Natural gas	Electricity	Biofuels and waste
ktep	39,205	51,357	347,429	93,958	34,063	9,484

Table 4: European (EU28) energy export in 2015 [45].

3.3 FINAL ENERGY CONSUMPTION OF EU28

The final energy consumption in 2015 was 1,113 Mtep, while the Gross inland consumption of energy[11] within the EU28 in 2015 was 1,627 Mtep, 1.2% higher than in 2014.

As it mentioned, each member of EU28 has its own energy system, energy mix, economy and since final energy consumption depends on these aspects, it is very different among all Member States.

The different shares of the final energy consumption in terms of type of energy are listed in the table 5, (2015):

Type of energy	Coal	Crude oil	Oil products	Natural gas	Geothermal, solar	Biofuels and waste	Electricity	Heat
ktoe	35,701	2,389	462,514	241,080	2,525	87,770	235,707	45,874

Table 5: European (EU28) final energy consumption; ktep [45].

Oil products continue to be the most important energy source for the European economy while natural gas remains the second most important energy source. According to Eurostat studies, the contribution of renewable energy is increasing. It was about 13% in 2015 but there are very different values between the member countries of EU28: in Latvia and Sweden, renewable energies accounted for over 35 % of their gross inland energy consumption in 2015 (35.1 % and 40.5 % respectively) while the lowest share of renewable energy in gross inland consumption was in Malta (2.6 %), Netherlands (4.7 %) and Luxembourg (4.9 %) [45].

Looking at the consumption by final use sector, the biggest part of energy in EU28 in 2015 was used in energy transformation (26.0 %), followed by the transport sector (22.0 %), industry sector (16.8 %), residential sector (16.9 %), services (9.0 %), non-energy use (5.9 %) and other (3.2 %). If we do not include the energy for transformations and losses and the energy used for not energy consumption[12], we obtain the final energy consumption that was 1,113 Mtep (as discussed in the previous paragraph). It includes three dominant categories: transport (33.1 %), households (25.5 %) and industry (23.5 %) as it can be seen in Figure 10:

[11] Gross inland energy consumption represents the quantity of energy necessary to satisfy inland consumption of the geographical entity under consideration. It is defined as primary production plus imports, recovered products and stock changes, less exports and fuel supply to maritime bunkers (for sea-going ships of all flags). It describes the total energy needs of a country, covering: consumption by the energy sector itself; distribution and transformation losses; final energy consumption by end-users; non-energy use of energy products and statistical differences, (EUROSTAT definition [45]).

[12] It includes fuels that are used as raw materials and are not consumed as fuel or transformed into another fuel. Non-energy consumption in 2015 amounted about 97 Mtoe, [45].

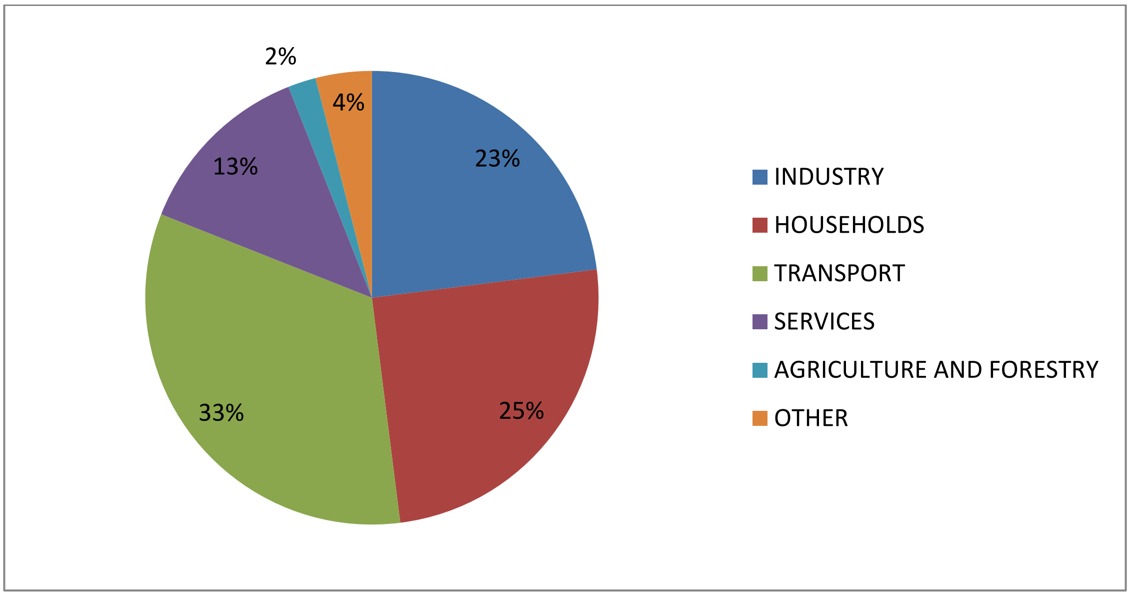

Figure 10: Final energy consumption in EU28 (2015) per sector of final demand [45].

4. THE MAIN ENERGY AND ENVIROMENTAL POLICIES IN BRAZIL AND EU28

In this chapter the general objectives and some of the most important directives of the Brazil and EU are listed; in addition to these, a lot of projects are already ongoing and always in phase of evolution to improve and guarantee the biomass production chain continuity and the growth of biomass market at the global level.

We are in a century in which there is the need to diversify the energy mix in order to increase the security of supply. One of the global interests is also to reduce the greenhouse gases (GHG) emissions.

One way to do this for any country is to try to use renewable energy resources instead of fossils as much as possible because it increases security in providing a service that it is vital for economic and social development.

In 2014 the European Commission planned to reduce the greenhouse gas emissions of 40 % below 1990 levels, to increase the use of renewable energy to at least 27 % of total consumption and renewed the objectives of 20-20-20 on energy efficiency policies (i.e. to reduce the primary energy consumption by 20% by improving energy efficiency). All these objectives have been planned in order to be reached in 2030.

The European Commission, which has taken into account all the goals planned, also proposed a set of measures to reach those targets. Among the proposed measures there is the one aimed at increasing the share of energy from renewable sources and low carbon emission in transport. The practice was known as the Directive 2009/28/CE or RED (Renewable Energy Directive) and consisted of introducing biofuel blending obligations with traditional fuels. It established for all Member States the obligation in 2020 to cover 10% of the energy needs of the transport sector through renewable sources but now it has been modified with the Directive 2015/1513/CE. This defines the maximum limit of 7% (within 10% expected) for the use of first-generation biofuels (like from cereals and sugary and oily crops) in the mix of final energy consumption in transport; the remaining 3% must be covered by fuels derived from raw materials other than food (like second generations biofuels from waste, lignocellulosic, discards or algae), by electric vehicles or electrified rail transport. This change in the Directive has been made considering the potential impact deriving from the use of soil for dedicated crops but also to protect the European biofuels producers. The same Directive, according to the principle that biofuels must comply with specific sustainability criteria, also set a target of 50% reduction of GHG emissions produced in the entire lifecycle of biofuels with respect to fossil fuels (from 2010 to 2017 the reduction was of 35% and since 2018 must be 60%).

These proposals, like the others, are made based on analysis of current energy modeling scenarios projected in the future, to avoid negative impacts on the current economy and society.

Referring to the world energy targets, there were two important conferences known as COP21 and COP22:

- the first in Paris in December 2015 in which the temperature limit increase was established to be below 2 °C (before 2100) compared to pre-industrial average and it has been said to try to extend this limit to 1.5 °C.

- the second in Marrakesh in November 2016 in which the agreements reached in Paris from 55 members states (representing the 55% of the world GHG emissions) has been ratified.

In particular, during the COP21, Brazil established to reduce the GHG emissions of 37% (compared with 2005) until 2025 (43% until 2030), to increase the use of renewable energy in the Brazilian energy mix up to 45% in 2030 and to increase the sustainable bioenergy[13] up to 18% of the total energy mix in 2030. These targets are based on some premises:

- The 13.263 law (March 2016) that give the obligation to use biodiesel mixed with fossil diesel with the percentage of 8% (B8) in 2017, 9%(B9) in 2018 and 10%(B10) in 2019.

- The 13.033 law (September 2014) that give the obligation to blend gasoline with anhydrous ethanol with a percentage that must fall within the blending range of 18% to 27,5%.

- The target production of 45 [Mm^3] of ethanol in 2025 e of 54 [Mm^3] in 2030.

- The construction of two nuclear plants by 2030.

As for Europe, also for Brazil, every energy choice is evaluated based on scenarios and on the history of policy´s mechanisms adopted previously [46].

In the table 6 the goals of EU28 and Brazil that to have to be reached in 2030 are summarizedd:

Country	Reduction of GHG emissions	Share of energy from renewable sources	Energy efficiency: reduction of primary energy consumption	About transport consumption
EU28	40%(wrt 1990 level: Mt CO2eq 5,244.2 [16])	27% (% of the total final consumption)	20%	10%RES in transport= 7% from first generation biofuels + 3% from second generations biofuels
Brazil	43% (wrt 2005 level: Mt CO2eq 827.5 [16])	45% and 18% of bioenergy (% of tot supply energy mix)		Obligation on blending the diesel with specific percentage of biodiesel

Table 6: Enviromental goals for EU28 and Brazil up to 2030.

With COP22, it was also funded the ´´Biofuturo´´ (the initiative started by the Brazilian government): an international platform (20 countries relevant in the world market of advanced biofuels), which is committed to maintaining the agreements reached in COP21 and accelerating the development and diffusion of advanced biofuels, as a sustainable alternative to fossils.

In addition to this, at the European Biomass Conference & Exhibition (Stockholm, 2017), a project called BECOOL was presented. It is a project conceived in Italy and it is being developed in synergy with another Brazilian project called BIOVALUE which deals with the same themes. The main objectives of the projects are: to identify integrated crop systems both for food production and for energy production, to identify advanced

[13] Every biomass product (liquid, solid, gas), that can be used to produce energy.

logistics systems for the biofuels supply chain and to optimize the biochemical and thermochemical transformation processes of biomass.

As far as Brazil is concerned, the Renova Bio is a plan that wants to increase the use of biofuels in Brazil (for example, doubling the ethanol production from the actual 28 to 54 [Mm^3] in 2030). It is based on the exchange of "emission reduction certifications" measured in tons of carbon and not in subsides.

Currently, the only incentives in force are allocated to the acquisition of new vehicles in the Taxes on Industrialized products (IPI) and in the Tax on the Circulation of Goods (ICMS) [47]. These subsidies correspond to a tax on carbon of 80 US$ per tCO_2 [47]. With the Renova Bio, the CO_2 emitter becomes a creditor in proportion to its emission. These credits are called CBIO (Biofuel Decarbonization Credit) and can be traded in a "carbon market", which functions as a specific stock exchange for this purpose. These CBIO will be a financial asset, traded on the stock exchange, emitted by the biofuel producer [47].

It is also important to mention some directives and bills related to solid biomass sector. In 2012, for example, the bill 3.529/2012 has been promoted which, although it has not yet been approved, proposes the electric generation from biomass and to make its price fall. It tries to guarantee investment on bioenergy that is a social, environmental and economic benefit for Brazilian society. To do this it is essential to give tax benefits and do competitive actions. There are also some financing programs from the government (PRONAF Florestal e Eco PRONAF, Propflora and BNDES Florestal) and other private financing, that aim to help the reforestation and the restoration of protected and degrades areas.

5. BIOMASS IN BRAZIL

In the first part of this chapter it is briefly described the entire biomass mix in Brazil. Then, considering the Brazilian biomass balance, biomass that represents the major potential of exportation is described in detail.

First, it is useful to remember that biomass could be categorized according to its own origin and its final utilization to better understand its production chain, potential and limits. One way to divide the origin of biomass suitable for the Brazilian case is to differentiate woody, non-woody and organic residues biomass. The following graph, elaborated by CENBIO, presents that classification and the main processes of conversion of biomass into energy, [49]:

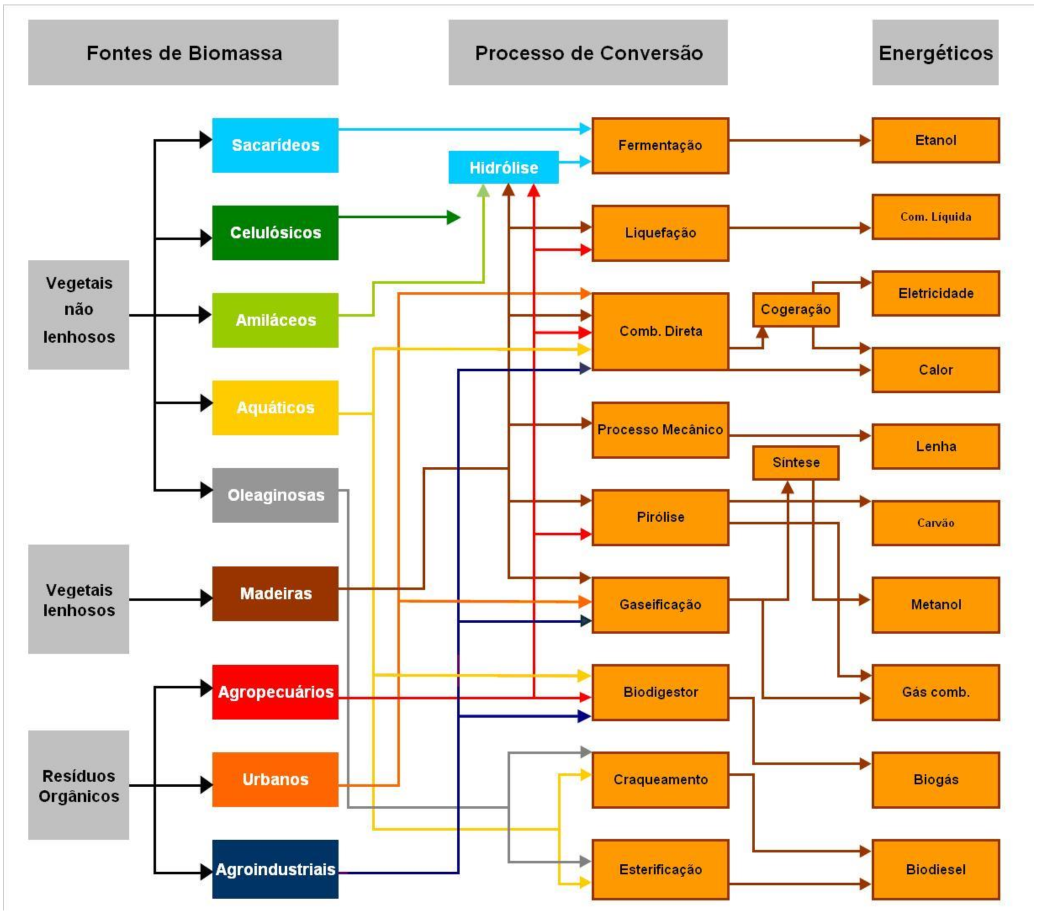

Figure 11: Biomass classification and conversion process from biomass to energy [49].

All the type of biomass available in the Brazilian energy mix belongs to one of the 3 macro sectors just mentioned because it derives from a raw material (i.e. biodiesel can derive from residual frying oil, vegetable oils, animal fat, etc.; ethanol can derive from sugar cane juice or from molasses) that belongs to one of these three sectors.

As discussed in the previous chapters, among the renewable energy sources available in Brazil today (45% of the total energy mix), about 30% includes biomass (of all forms: liquid, solid, gas). The percentages and values in tep (2016) of each kind of biomass are listed in Table 7 [41] and showed in previous Figure 2 and 2.2:

Type of biomass	wood and charcoal	sugar cane derivatives (17.5% = 50.3 Mtep), of which:		Others (4,5% = 12,9 Mtep)				
Unit quantities	23.1 Mtep	Ethanol: 14.4 Mtep	Cane bagasse: 35.9 Mtep	Biodiesel: 3,009 ktep	Biogas: 137 ktep	Black liquor: 8,447 ktep	industrial gas of charcoal: 83 ktep	others biomass: 1,130 ktep
Percentage	8%	5% of the total energy mix	12,5% of the total energy mix	1%				

Table 7: The biomass (liquid, solid, gas) of the Brazilian energy mix [41].

To sum up, the contribution of bioenergy to the total primary energy supply registered in 2016 was of 86.2 Mtep [41].

In the final use of energy, the biomass represented the 30% in Brazil and so it counted 73,709 ktep in 2016 [41]. The use of biomass could be divided into 3 different main sectors: to produce electricity; to produce thermal energy and as a fuel in transport.

The total final consumption in transport sector in 2016 was of 82,651 ktep [3] and the share of biomass was of 20% (16,530 ktep).

Looking at the electric sector only, in the same year (2016) the share of renewables in electricity production was about 81% [41]; in particular 49,236 GWh of electricity were produced from biomass (wood, cane bagasse and black liquor) [41] representing about the 7.9% of the total primary electricity supply (619,693 GWh).

In the thermoelectric generation (2016), the biomass (sugarcane, black liquor, wood and others) contribution was of 31% [41]. The 17% of the total electricity generated by thermoelectric power plants is given by solid forest biomass (black liquor, charcoal and other wood residues).

The different types of biomass used to produce bioenergy in Brazil are:

- Firewood: this could be also a raw material because it can be used to produce charcoal and not just electricity. For example, in 2016, of the total 51,603 kt of firewood, 22,997 kt were used for charcoal production and 1,301 kt was used to produce electricity, while the rest of tons are lost during the transformation processes, (15,997 ktep (2016) = 6.3% of the total final use) [41].

- Sugar cane bagasse used to produce electricity, (29,791 ktep (2016) = 11.7% of the total final use) [41].

- Black liquor used to produce electricity, (6,246 ktep (2016) = 2.4% of the total final use) [41].

- Ethanol used as fuel to transports and agricultural aircraft, (13,889 ktep (2016) = 5.6% of the total final use) [41].

- Biodiesel used as fuel to transportation (3.8 Mm^3 [42] which correspond to 2,970 ktep, calculated considering a pci of $8,88*10^{-4}$ tep and a density of 880 kg/m^3 = 1.16%). It grows up until 4.4 Mm^3 in 2017 [42].

- Biogas used to produce electricity and thermal energy, (it was around 3,680 ktep= 1.44%, calculated for difference between the total [→ total mean the sum of biodiesel and biogas that is around the 2.6% of the total final use and so it is around 6,656 ktep], and the biodiesel value which is around 2,970 ktep).

- Charcoal used to produce thermal energy but also used in the steel and iron production (3,529 ktep (2016) [15] = 1.4% of the total final use).

Table 8 illustrates the energy balance of all types of biomass (in liquid, solid and gas form), in tep unit. Summing all values of biomass energy, the total bioenergy obtained is shown in the second line of the Table.

Mtep in 2016	Available supply	Final consumption	Exportation	Importation
TOTAL BIOENERGY	**86.2**	**73.7**		
ETHANOL	14.4 (28.3 Mm^3)	13.9 (27.7 Mm^3)	(1 Mm^3)	0.935 Mm^3
BIODIESEL	3 (3.8 Mm^3)	3 (3.8 Mm^3)		
BIOGAS	0.137	3.7		
WOOD AND CHARCOAL	23.1	Wood: 16; (57.5 Mt) Charcoal: 3.5; (5.5 Mt)		0
BAGASSE	35.9	29.8 (136.2 Mt)		0
BLACK LIQUOR	8.4	6.2		
OTHER	1.2			

Table 8: Energy balance per type of biomass (2016) [41].

As Table 8 shows, from the quantitative point of view the biomass exportation potential in Brazil could be characterized by two main sources of energy: ethanol (Brazil is already the major exporter at word level), and wood (actually Brazil is just a potential exporter because of some technical problems linked to many factors that are discussed in chapter 5.2).

From literature [50, 51, 52] it is also known that, in addition to being produced in quantities necessary to satisfy the domestic demand, the production cost of Biodiesel is too high and therefore not competitive on the international market. This is due to a series of socio-environmental barriers that Brazil has not been able to overcome yet.

The bagasse and the black liquor are sub products of ethanol and paper industry, respectively; they just contribute, after being transformed into energy, to feed the same industry of which they represent the waste.

For these reasons, it makes sense to deal exclusively with ethanol and wood biomass exportation. However, they are some issues as well that need to be taken into consideration and that will be explained in the next chapters.

5.1 ETHANOL IN BRAZIL

Ethanol is a chemical substance with a C_2H_6O molecular formula. It is one of the two major biofuels utilized in Brazil. It is used in internal combustion engines with spark ignition (Otto cycle). The other one is biodiesel, which is used in compression ignition (Diesel cycle) engines. So, both are mainly used in Brazil as fuel in automotive substituting, partially or totally, fossil gasoline and diesel respectively. Brazil is the first in the world as biofuels consumer with about 18% of fuels utilized.

Ethanol is produced mainly through the fermentation of sugars and the Brazilian ethanol feedstock is principally represented by sugarcane[14]. It is a first generation (1G) biofuel (1G biofuel means that it came directly from saccharine, like sucrose fructose and glucose), since the second generation (2G) is still under development. In addition, biodiesel and biogas are 1G biofuels but they derive from different materials and process. The 1G ethanol produced in Brazil could be anhydrous (water content of 0.5%) which is used blended with gasoline, or hydrated (water content of 5%) which is used in the engines specially designed for this type of fuel (called flex-fuel engine).

The 2G ethanol comes from cellulose, hemicellulose or starches; consequently, its production process is more difficult and more expensive because a previous step is required before fermentation. For these reasons, it is not widespread yet. However, there are already a lot of pilot projects and laboratories working on these technologies[15]. Moreover in 2014 Brazil started to produce 2G ethanol destined to exportation, but the production capacity is still inconsistent.

There are 3 types of sugarcane plants: only sugar producers, only ethanol producers, both sugar and ethanol producers. Today, there are 378 production units of both ethanol and sugar in Brazil (2017) [42]. Their actual production capacity is about 750 Mt of sugarcane (considering a capacity factor of 90% of the nominal value). All units authorized to produce ethanol have anhydrous and hydrated ethanol production capacity of about 120,000 and 219,000 m^3/day respectively [42]. Then, considering a typical number of harvesting days, an average of production capacity is 23 and 41 Gliter/year, respectively [38].

Considering for example the 2016/2017 crop and according with UNICA, a production of 651,841 kt of sugarcane (607,137 from center-south and 44,704 from north-east) was registered. From this, 38,734 kt of sugar and 27,254,000 m^3 of ethanol were produced (of which the anhydrous was 11,589,000 and the hydrated 15,665,000 m^3).

In addition, two new production units are being installed thus production will increase. With this numbers Brazil is the second producer of ethanol in the world (about the 37% of the world production) and the largest sugarcane world´s producer. The 92.4% of the Brazilian ethanol production came from the Centre-South region (San Paolo, Minas Gerais, Goias, Parana' and Others) and the rest from the North-East region (mainly the State of Pernambuco). Figure 12 shows where the actual ethanol plants are localized in Brazil:

[14] Ethanol could derives from other feedstock like: corn (mainly used in USA); sugarbeet(wide used in EU); wheat (used in EU); agricultural residues; wood; dedicated crops.

[15] See ABENGOA site in the section dedicated to the 2G biofuels or TASK 39 of IEA Bioenergy.

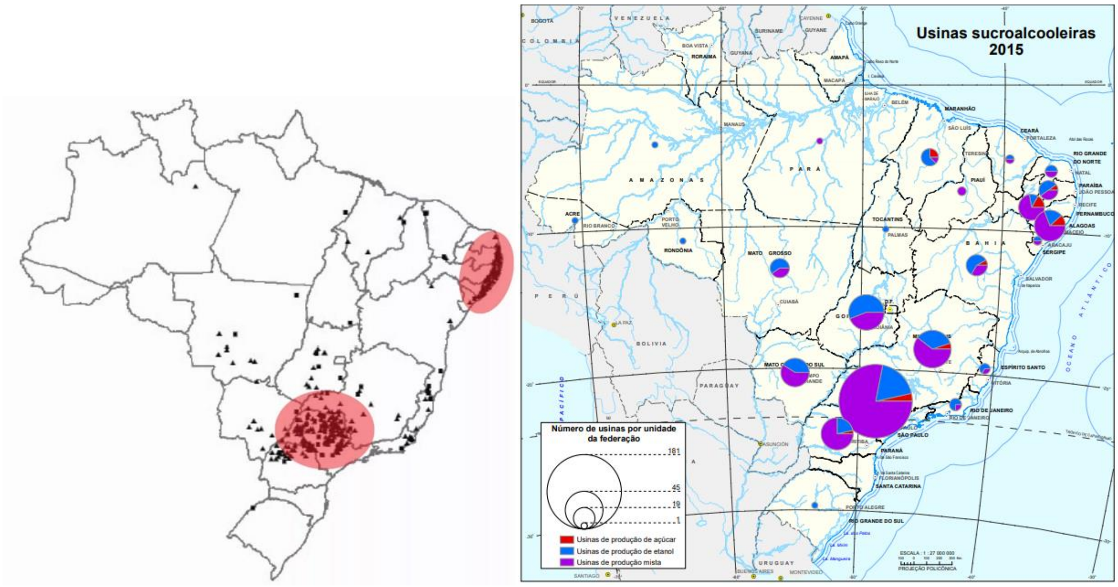

Figure 12: On the left the localization of the ethanol/sugar plants in Brazil registered in 2017 [42]. On the right, the characterization per type (only ethanol=blue, only sugar=red, sugar+ethanol=violet production) of the Brazilian plants, updated at 2015 [IBGE].

As shown in the map, it is evident that the plants are localized like that due to logistic reasons. The proximity of the production plants to the sugarcane plantations is essential in order to reduce transport costs and emissions and to facilitate distribuition as well.

According to some studies [53, 54, 55, 56, 57, 58, 59] a new promising region for the increase of sugar cane plantation is the so-called MATOPIBA[16](see Figure 13).

Figure 13: MATOPIBA geographical region in Brazil.

According to the IBGE [59], the planted area with sugarcane registered in 2017 in that region was (see table 9):

[16] MA-TO-PI-BA: Maranhao-Tocantins-Piaui´-Bahia.

Region	Sugarcane planted area in 2017 [59]
MARANHAO	52,367 ha
TOCANTINS	38,140 ha
PIAUI´	17,454 ha
BAHIA	108,461 ha

Table 9: hectare of sugarcane planted area in 2017 [59].

Thanks to the UNICA database it was possible do the following line graph (figure 14) that shows the evolution of sugarcane planted area of the MATOPIBA area from 2010 to 2017.

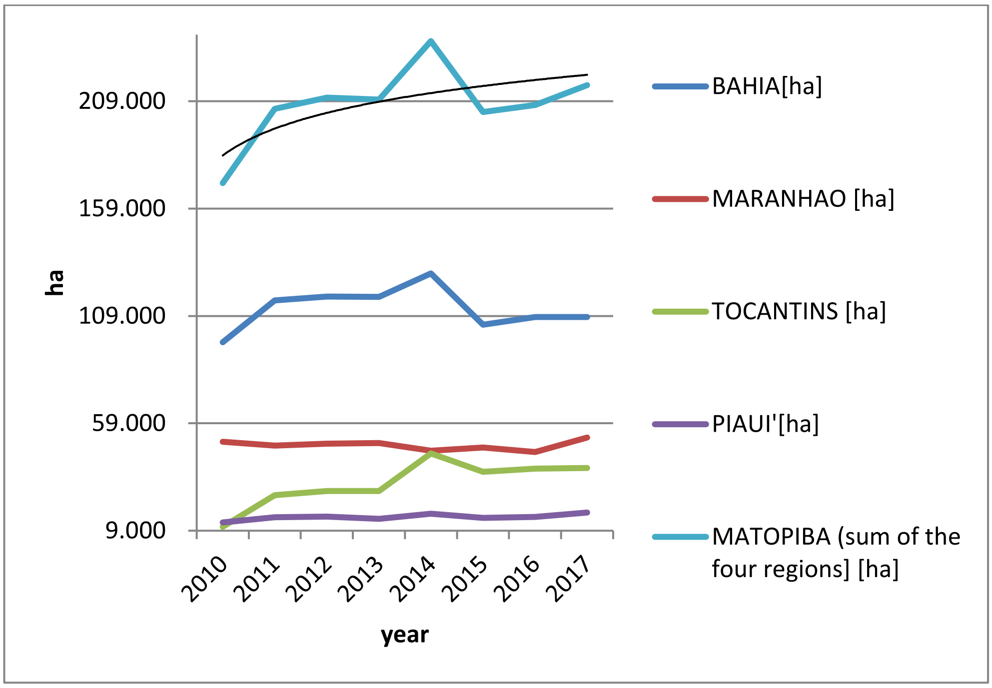

Figure 14: hectare of sugarcane planted area [UNICA].

Sugarcane is growing up considerably. The biggest contribution given to this rise was due to the Tocantins region. According with CONAB [66], the production of sugarcane has grown a lot from 2010/11 to 2016/17 in Tocantins, as shows the Figure 15:

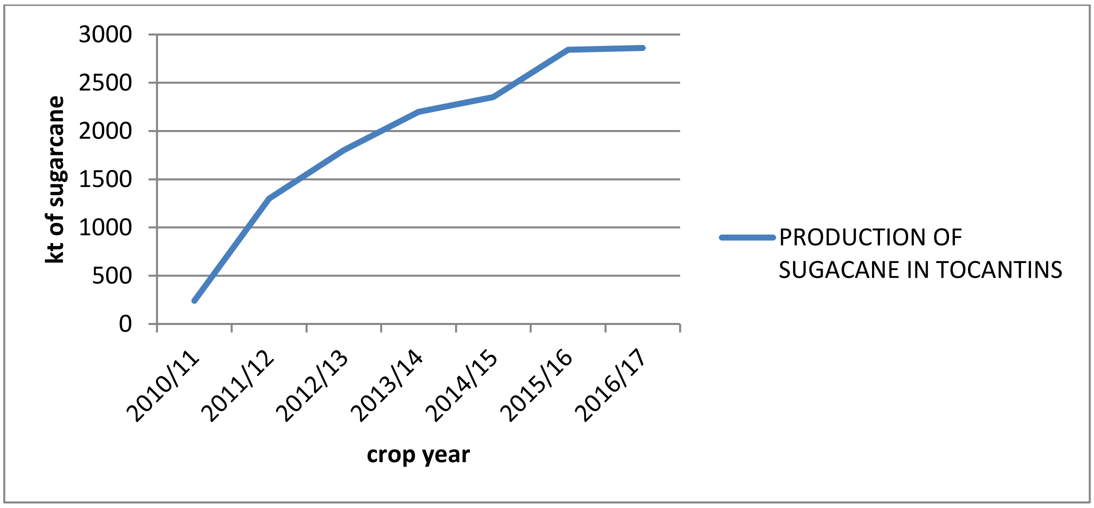

Figure 13: production of sugarcane in the state of TOCANTINS from 2010/11 to 2016/17 [66].

This rapid growth represents the evidence of an interest in production expansion in that area by producers. This is because there is on one side the need to increase the production of ethanol and on the other the favorable conditions for doing it in this area.

From these considerations and from the research done, a potential for further future growth has been estimated here. According to Carneiro Filho el al., the MATOPIBA region still has a total of 9,671 Mha of potential area suitable for agriculture [60]. Of these, 6,100 Mha belong to the native vegetation, the rest to pastures and others uses. So, considering that the remaining 3,571 Mha, could be used to plant sugarcane to produce ethanol, it is possible to do an estimation of the ethanol production potential of this region:

$$potential\ volume\ of\ ethanol = (potential\ sugarcane\ planted\ area) * (\text{ethanol production efficiency})$$

Where:

- potential volume in liter;
- potential area in Mha;
- production efficiency in liter/Mha

Considering the actual average efficiencies of production (75 ton of cane per ha; 85 liters of ethanol per ton of cane), the potential production of ethanol from MATOPIBA area would be of 22,765,000 m^3. On one hand this value could be underestimated because it is expected that also the efficiencies of production used for the calculation will grow and because it does not consider in the calculation the 6,100 Mha that belong to native vegetation; but on the other hand it could be overestimated because it was considered null the production of sugar (all the sugarcane harvest used to produce ethanol) and null the production of soy, cotton or other products that today represents a high percentage of the total agricultural production.

Speaking now about the logistic, in the following pictures (Figures 16 and 17) it is represented the actual transport network for gas, oil and ethanol [61].

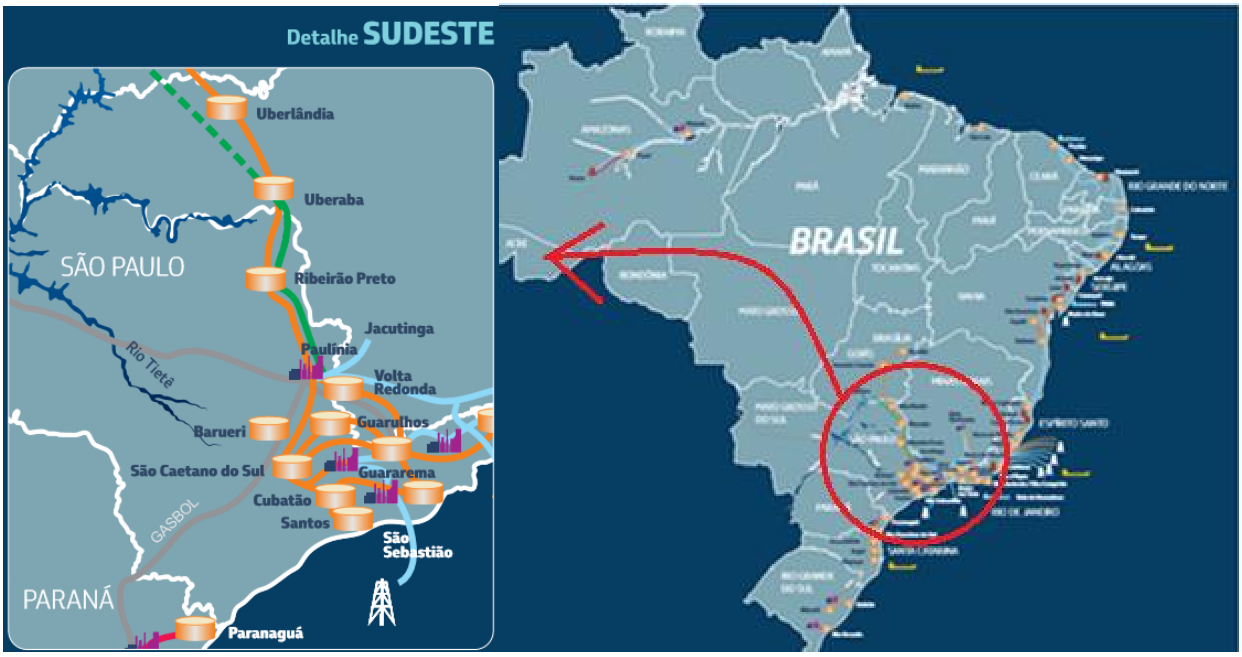

Figure 16: Detail of the Brazilian transport network: the ethanol, oil and gas line in the south-east of the country [61].

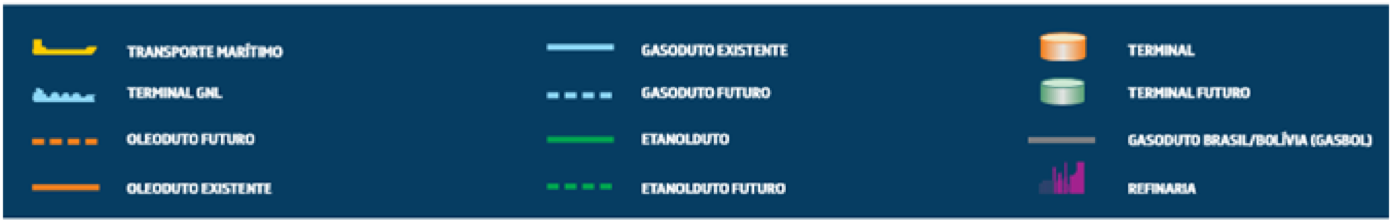

Figure 17: Legend of the figure 14 [61].

Another source that gives detailed information about the logistic is the IBGE [23]. Below there is a brief description of the logistics related to biofuels. The logistic for the internal market could be divided into 3 levels: distribution (it's the wholesale with retailers or big consumers), resale, and consumption. Each base of distribution has a storage capacity. Of the 282 liquid fuel distribution bases in Brazil, 91 are located in the Southeast Region, which corresponds to 32.3% of the total units. The South Region, the second in number of bases, concentrates 22.0% of the total. The biofuels stored are then injected in the mesh thanks to the connections between the base of distribution and the most important road axes of the territory and with the network of pipelines. In this way, biofuel pass from the refineries to the bases and from these to the retailers. The two main infrastructures for liquid fuels are the retailers and the transporters retailers[17], [62, 63]. Infrastructures responsable for the retail trade of liquid fuels are present in almost the entire national territory, but not homogeneously. The most populous cities of the country are among those that have more resellers [23]. Despite this, population concentration is not the only factor that explains the dispersion of the stations, since they also have significant concentrations in municipalities and in areas that are connected to major circulation and logistic axes [23]. The types of internal consumption of biofuels are different, but for the ethanol (also for biodiesel) the main consumption is for transport (almost 95.6% of ethanol) [41].

As far as logistic of exports[18] are concerned, the path made by ethanol is different because it has to be transported from the distribution bases to the export port (mainly to the Santos and Paranagua´ ports). Santos is the major Brazilian port (87.74% of the Brazilian exportation) with a total capacity of 3,400,000 m^3/y [65]. The ethanol can be transported to the Santos port by trucks or by train. The most utilized way is the first one: in 2008, 99. 85% of the ethanol that arrived at the Port of Santos was by road [65]. It is not the same for the Paranagua´ port where the railroad has a significant relevance: in 2008, this way of transport carried 395,800 m^3 of ethanol destined for export to that port, which represent the 42% of the total ethanol drained there [65]. In 2009, the total shipping capacity of this port was of 1,100,000 m^3 [SETTEN, 2010].

The production, export and import of ethanol registered in the year 2016 are [Mm^3] [41, 42]:

- Production: 28.3 (of which: 11.7 anhydrous and 16.6 hydrous);

- Exportation: 1.0;

- Importation: 0.9.

[17] These type of retailers market and deliver diesel oil to specific types of consumers who can not move to supply. This is the case of agricultural machinery, for example, or of industrial machinery and production of electricity by diesel oil [23].

[18] More information about the logistic in the document of IBGE [64].

Brazil is an affirmed ethanol exporter if comparing its exported quantity with the ones exported by the rest of the countries of the world; for the moment (2017), it is in fact the second in the world after the USA. In the following line graph there are the production, importation and exportation trends of the total ethanol (hydrous and anhydrous) in Brazil from 2006 to 2016, (unit of measure: 10^3 m^3):

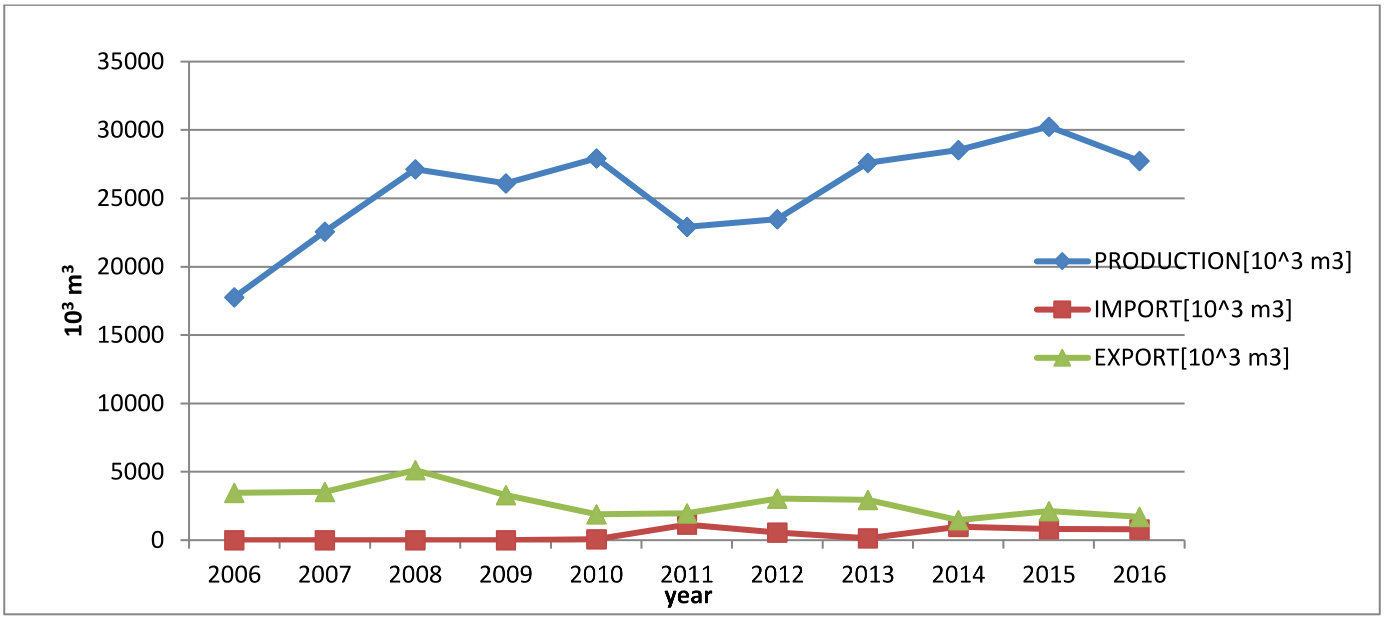

Figure 18: BALANCE OF ETHANOL IN BRAZIL; [10^3 m^3] [42].

The ethanol imported arrives in Brazil mainly from the USA. But Brazil also exports ethanol to USA (mainly to California). That occurs because the Brazilian ethanol has the best footprint carbon emission, because it is produced from sugarcane and the American one from corn; so, Brazil earns subsidies by selling ethanol to USA. But, at the same time, Brazil must respect the obligations of blending ethanol with gasoline in a limit range between 18 and 27.5% (Brazilian low N° 13.033, September 2014) and, when the export is higher than the right value to satisfy the internal demand, Brazil is forced to import ethanol.

According with the UNICA [4] data, the total volume of exported ethanol to the rest of the world registered in 2017 was 1,418,927 m^3. Of these, 45,930 m^3 were destined to Europe with a value of 23,694,000 US$ FOB[19], (it means about 0.516 US$/liter) [4].

There are a lot of issues linked to the supply and the production of the sugarcane:

- the yield plantation (for example the plantation recorded in 2016 compared to the previous year was less than 1%, so fewer sugar canes in the crop [66]);

- the performance of sugarcane [kg di ATR[20]/ton of sugarcane], that can be affected by a premature harvest or a deterioration in agricultural techniques which had a negative impact on the amount of sugar cane with a consequent decrease in agricultural production (for example: the performance has been deteriored by the increase of 4% of vegetal impurities in the sugar cane harvest between 2007 and 2016 [38]).

[19] FOB contracts relieve the seller of responsibility once the goods are shipped. After the goods have been passed the ship's rail, they are considered to be delivered into the control of the buyer.
[20] ATR= Açucar Total Recuperable; [kg di ATR/ton of sugarcane] = quality of sugarcane/industrial efficiency.

However, there is technological potential for improving performance, but the presence of debt in the sector has prevented the implementation of such practices.

In this context, sugar cane destined for ethanol production was 54% in 2016 [38].

One of the residuals of sugar and ethanol production is the “bagasse”, which is used to produce electric or thermic energy as mentioned in the introduction of chapter 5, or 2G ethanol. It also used to produce pellet [67], even if in low quantity. The line graph below shows the quantity of bagasse produced every year from 2006 to 2016 [66].

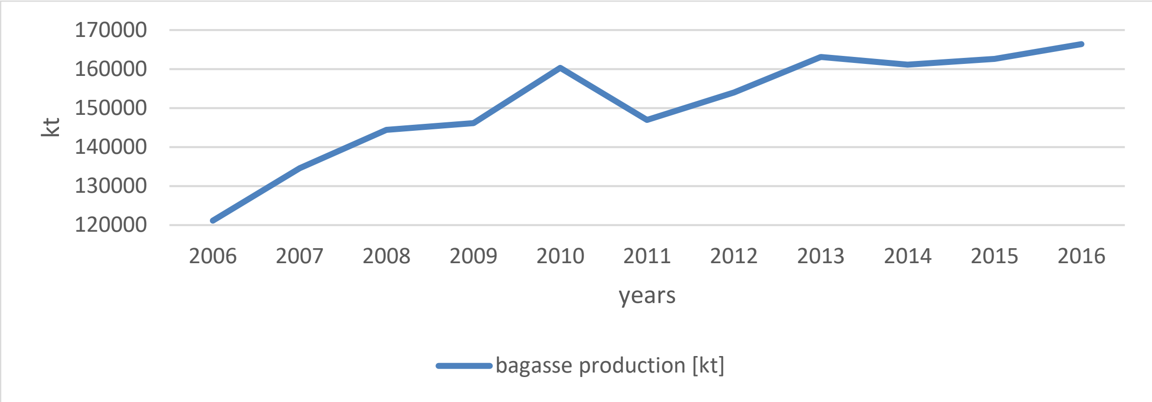

Figure 19: Bagasse production from 2006 to 2016, [kt] [66].

The electricity produced, classified as bioelectricity, is used to feed the sugarcane plant itself and the surplus is exported to the distribution network. The sugar-alcohol sector is self-sufficient in the electricity production and the surplus that is sold to the national network system (‘’SIN’’= ‘’Sistema interligado nacional’’) is growing year after year. In fact, the surplus of bioelectricity from bagasse in Brazil grew up from 20.5 to 21.1 TWh between 2015 and 2016 (the total bioenergy production from bagasse was 35.2 TWh, which only 14.1 TWh used for self-consuming). This kind of bioelectricity is an important alternative to the hydroelectricity generation because its production occurs precisely during the dry seasons, when the reservoirs are at the lowest level.

In addition to this, the cane also produces “tops and leaves” ("palhas and pontas", it is the 30% of the cane), which is potentially usable for the production of second generation biofuels (i.e. lignocellulose) or for the production of electricity (both technologies are under development). Its introduction in the market, however, currently sees many issues such as the transport of raw material from fields to the 2G ethanol production plant.

Another residual of the cane is the "vinasse" from the fermentation of which it is possible to produce biogas and therefore electricity, as is the case in the Bonfim industry (SP). However, the cost of production chain is high, for this reason it is not widespread yet.

An important aspect of the Brazilian ethanol production is the sustainability of the production process. A lot of studies show that both the energy balance and the carbon footprint of the chain production are the best, compared with ethanol produced with feedstock different from sugarcane (i.e. sugar beet, corn, soybeans).

In addition to the problem of the water pollution due to the vinasse disposal has been solved, thanks to the CETESB (environmental Agency of Sao Paulo) that in 2006 started to control the amount of vinasse discarded on soils with the aim to avoid the contamination of the underground water. The problem of air pollution due to bagasse burning in boilers for cogeneration and of the sugarcane before the harvesting was solved in 2002 with the introduction in the state of Sao Paulo of an environmental legislation (the Green Protocol) establishing to stop sugarcane burning and introducing the mechanized harvest. Regarding the burning of bagasse, the problem was solved thanks to the systems of control on the pollutant emission.

As far as concern the land use is concerned, a lot of debates occurred but it is confirmed that the deforestation is not linked to ethanol production. It must be taken into account that the amount of land available for agriculture in Brazil was 355 Mha in 2015 and from these 24% used for agriculture and only 2.5% occupied by sugarcane ethanol.

A negative but inevitable point on sugarcane crops is the need to utilize agrochemicals that kill all organisms that could compromise the right growth of the plant and that speed up the growth of the cane. However, the fertilizer used in Brazil are less than that used in other countries (i.e. the fertilizer used in Australian sugarcane crops is 48% bigger than the Brazilian one). Furthermore, the crops of sugarcane in general do not require large amounts of fertilizers compared with crops of the same extension as coffe, corn, soybeans; besides, with the use of vinasse as fertilizer (that helps the productivity and the potassium content of the soil) the quantity of agrochemicals needed to sugarcane diminishes even more.

Beyond the sustainability aspects, it is important to take into account the economic ones. At each logistic level corresponds an ethanol price: price at the producer; price at the distribution base; price of retail; final consumer price. Moreover, there is also a different price for the ethanol destined to be exported.

The overall production process in 2006 reached a cost ranged from 0.18 to 0.25 US$/l, that was at that time the lowest cost of biofuels in the world [29]. However, from 2006 to now many improvements in the production technologies and higher input costs have been done, so the overall costs have risen.

The production cost of hydrated and anhydrous ethanol could be calculated dividing the sugarcane cost [R$/ton of sugarcane] by the industrial production efficiency of ethanol (hydrated and anhydrous) [liter ethanol/ton of sugarcane]. According to PECEGE report (2016) [100], the production cost of sugarcane in 2016 was of 97 R$/t [21] (29.65 US$/t). So, considering an industrial production of 74.66 l ethanol anhydrous/tcane and of 77.8 ethanol hydrous/tcane [100], the production cost of anhydrous and hydrous etanol result in 1.29 (0.39 US$/l) and 1.24 R$/l (0.38 US$/l) respectively, (i.e. 0.383 US$/l anhydrous and 0.368 US$/l hydrous[22]). These values agree with CEPEA platform [68]. Then, according to CEPEA platform (2017), the average price at the producer plant is 0.57 US$ per liter of hydrous ethanol and 0.59 US$ per liter of anhydrous ethanol [68]. Almost the 80% of the ethanol price is composed by the cost of the sugarcane (the raw material) and it varies a lot year after year because it depends on the ATR cost[23] that in turn depends diverse aspects (for example, it depends on the percentage of sugar and ethanol produced in that year) [69]. The distribution price and the price for the consumers are obviously higher because they include, besides the production costs, also the transport costs and taxes. For example, the internal consumer price in the same year (2017) was around 0.91 US$/l (3 R$/l) [70].

[21] It was calculated as arithmetic average between 3 different values from 3 diferents regions of Brazil; see table 4 of the [58] reference.
[22] Currency Exchange 2017: 3,369 R$/US$.
[23] The price of sugarcane (raw material), can be calculed starting from the average price of the kg ATR (total açúcar recuperável) which is calculed using a formula valid for all Brazilian region and avaible in the manual of Consecana [57].

Since ethanol is mainly used as automotive fuel instead of gasoline, it is interesting compare the Brazilian ethanol price with the Brazilian gasoline price. Figure 20 gives an idea of the current price (for the final internal consumer) of the hydrous ethanol[24] and the gasoline in Brazil [4].

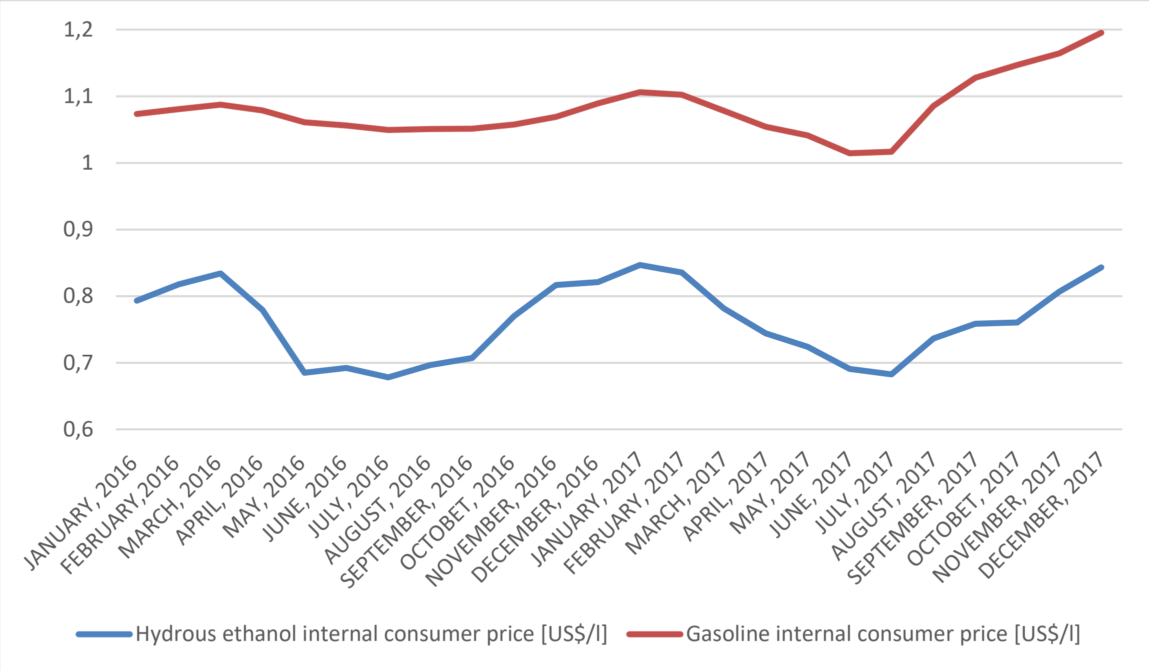

Figure 20: trend of price for the internal consumers of hydrated ethanol (used as fuel) and gasoline in Brazil; years: 2016 and 2017 [4].

Looking at the Figure 20, it is evident that gasoline and ethanol prices have almost the same trend but ethanol is cheaper than gasoline for the consumers. It is confirmed also by other IBGE´s studies [12] and the historical trends available in ANP database [71] demonstrates that it was the same also in the past years.

It is interesting to observe that the ethanol´s export price result lower than the ethanol´s internal sale price. This occur because there are not export taxes for ethanol in Brazil so the exported ethanol´s price is given only by production costs and transport costs, while the price of internal consumed ethanol includes also some taxes like ICMS, PIS and COFINS.

Figure 21 shows the change in the exported ethanol´s price of the lasts four years and the change of the exported volume of ethanol of the same years [4].

[24] Is given only the hydrous ethanol price because the anhydrous ethanol is not sold alone in the internal market but only mixed with gasoline.

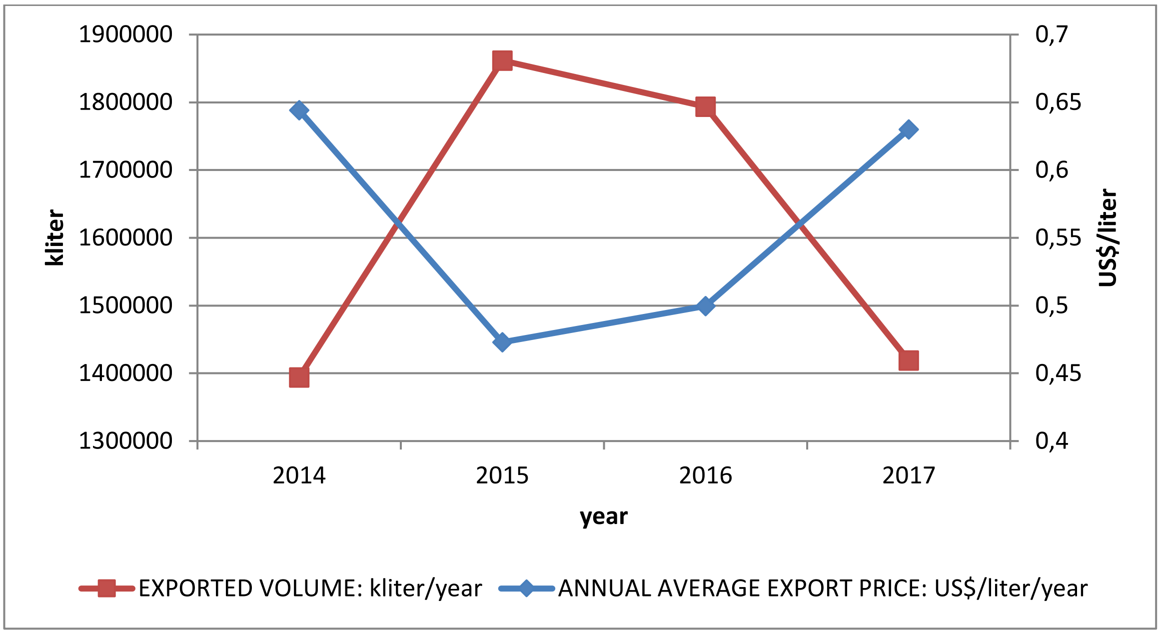

Figure 21: annual average export price and annual volume of ethanol exported by Brazil [4].

It is obviously evident that at lower exported volumes correspond higher prices per unit of volume and vice-versa. This price is in the range of 0.47 to 0.64 US$/l [4] and it refers to the total (anhydrous and hydrated) ethanol exported from Brazil without specifying from what port or to what country. However, the prices per port may vary for several reasons. For example, freight may be larger for a port, because it is more distant from the destination, or because it has higher taxes, or because it has less draft or less availability of backloads. Moreover, since the shipments are not necessarily regular throughout the year, the average FOB price will be higher for the port that has shipped the most during the high price period (i.e. in the off season).

It is considered now the variation of the annual production cost per crop and the variation of the volume produced (first of anhydrous ethanol and then of hydrous ethanol) in the same crop. The following graphs (Figure 22 and 23) show it:

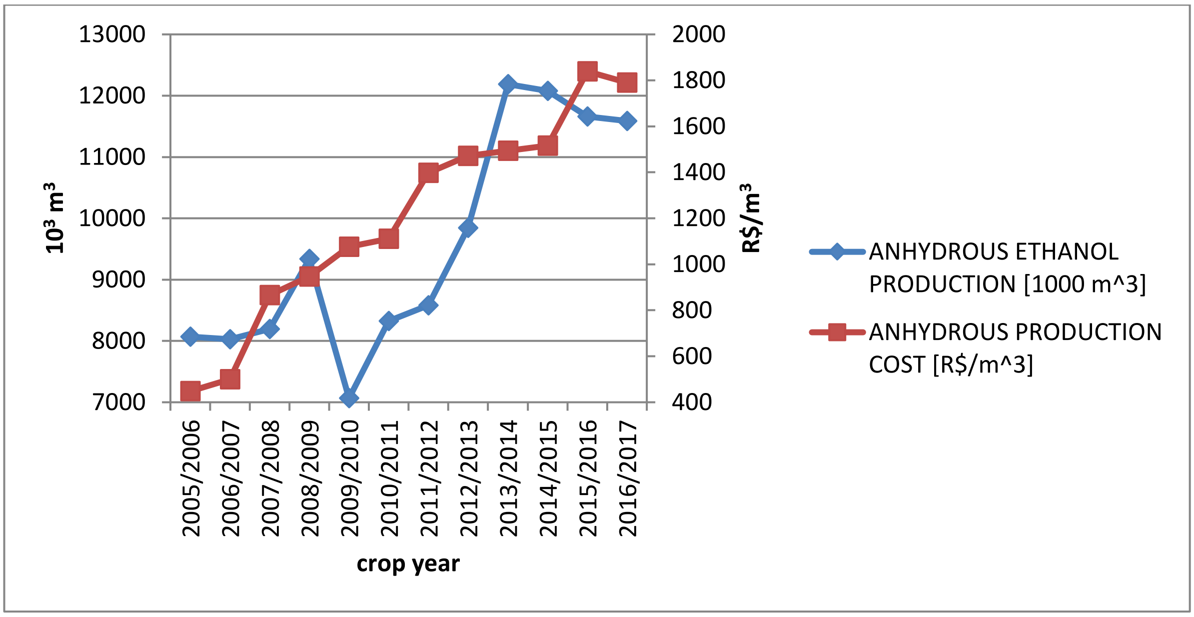

Figure 22: PRODUCTION [4] AND UNIT PRODUCTION COST [30] PER SUGARCANE CROP.

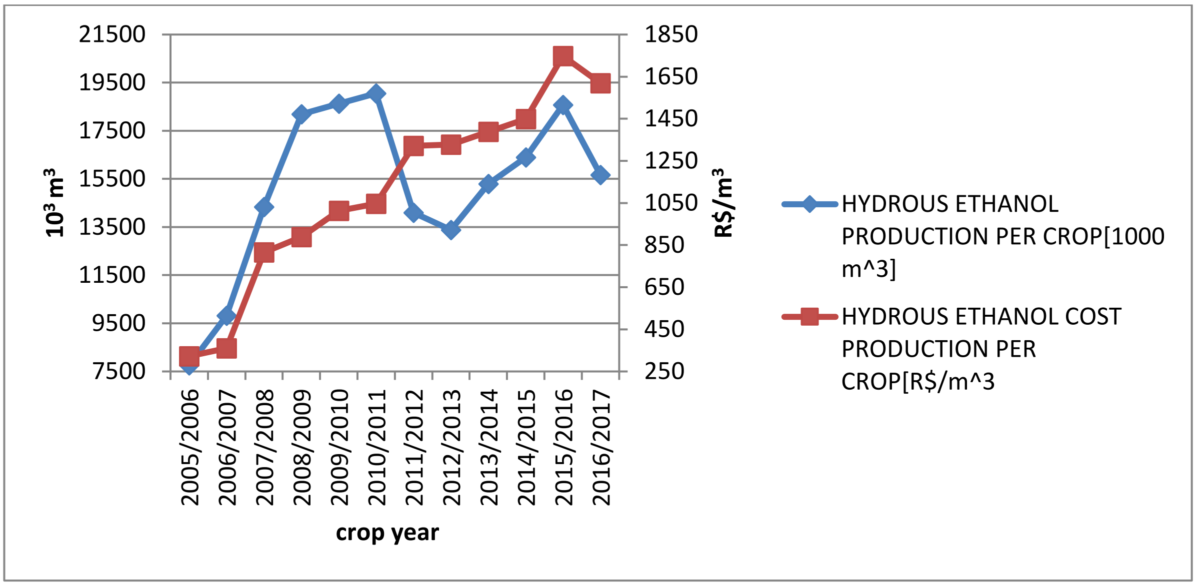

Figure 23: PRODUCTION AND UNIT PRODUCTION COST PER SUGARCANE CROP; [4, 30].

It can be noticed that the production trend is very unstable for both anhydrous and hydrated ethanol. This is due to various factors such as harvest efficiency, percentage of sugar produced in that year, market prices and others, (all these factors vary a lot from year to year). However, if we consider the total production we can say that it almost continuously grew up from 2006 to 2016 as it can be observed in the figure 18.

As far as production costs are concerned, it is evident how they are increasing from the 2005/2006 crop to the last crop. It occurred both for anhydrous and hydrous ethanol in the same way because the production process has evolved over time becoming more sustainable and efficient but at the same time more expensive, as it is well explained in [29].

Just to compare the cost of ethanol production in Brazil and Europe, below some values are listed. These values could fluctuate in wide ranges because the cost of biofuels mainly depend from the biomass feedstock prices which can change between different European countries and it account for 60-80% of the final price of ethanol. The technologies of ethanol production are now mature and little changes and improvements on it do not influence the production cost much. The following table 10 contains some production costs of European ethanol that were found in literature:

Source	Type of feedstock	Production cost
ECN report [73]	Sugar beet (North West Europe)	0.32-0.53 Euro/litre
Setis.ec.europa.eu, 2012 [74]	Wheat; sugar beet	0.64 Euro/litre
BTG report, 2004 [73]	Wheat	0.59 Euro/litre
BTG report, 2004 [73]	Sugar Beet	0.60 Euro/litre

Table 10: ethanol production costs found in literature.

As it is shown in the table, the most recent information found dates back to 2012. According with it, the most recent cost of ethanol (without distinguishing what kind of feedstock was used), was around 0.64 Euro/l. The same paper reports that this cost is forecasted to increase to 0.82 Euro/l in 2020. However, another source [75] says that in 2013 the price of European ethanol was 0.62 Euro/l but with the pressure of the strong global competition (mainly USA and Brazil) which have encouraged a duty-free ethanol import, the European ethanol price had a drop [75]. It has also to be noticed that the European ethanol price remain uncompetitive with respect to third countries (like for example Guatemala, Bolivia, Pakistan, Peru, Costa Rica), because their ethanol production is driven by a solid form of support and bilateral free trade agreements. Importing ethanol from Brazil for example, could mean to have a good quality of ethanol in terms of sustainability at low price compared with the domestic one [75, 76, 77]. Unfortunely recent data regarding ethanol production costs in Europe are hard to find. According to the Europe´s energy portal, the average annual gasoline price in 2012 was 0.533 Euro/l without taxes, but including excise duty and VAT it became 1.292 Euro per liter in the same year. In table 11 are reported some characteristic values as a guideline to compare the European case with the Brazilian one:

Region	Year	1G Ethanol production cost	Gasoline internal price
Brazil	2011/2012	1,40 R$/l anhydrous [30]; 1.32 R$/l hydrous [30] (0.65 US$/l anhydrous; 0.61 US$/l hydrous)	2.75 R$/l[25] (1.27 US$/l[26])
EU28	2012	0.64 Euro/l [74] (0.84 US$/l[27])	1.29 Euro/l[28] (1.70 US$/l)

Table 11: ethanol and gasoline price and cost comparison in EU28 and in Brazil.

All the values reported in the previous table are also explained in the chapter 7.1.3.2 of this work; despite being approximative, these values demonstrate how the ethanol production costs in Brazil are much lower than in Europe and also lower than the gasoline prices.

5.1.1 THE BRAZILIAN ETHANOL SUSTAINABILITY

Considering the sustainability of ethanol, some other issues must be considered, like the energy balance in the production chain and other environmental aspects (i.e. water and air pollutions, use of agrochemicals, GHG emissions balance etc.). Most studies and several LCA studies demonstrate an emission reduction compared with their fossil fuel counterparts. In particular, the sugarcane from ethanol has the best energy balance (considering the entire production chain from the collection of the raw material to the ethanol production: for each 9.3 of energy unit produced, 1 unit of energy is used) among the different biomass available in Brazil and also among the ethanol from corn in USA (for each 1.4 of energy unit produced, 1 is used), and the highest reduction of GHG emissions (89%) compared with corn or beet (that are other feedstock mostly utilized in USA and EU respectively to produce ethanol), [28]; also, the deriving ethanol has the higher percentage of GHG emissions reduction when compared with other biofuels [29]. Water and air pollution and water consumption in ethanol production are problems that have been solved many years ago. It is not the same for the pollution deriving from agrochemicals that are needed to permit a fast and better harvest; however, the fertilizer utilized for sugarcane crops are less than the ones utilized in other crops like corn [29] and according to the UNICA [4] the quantity of fertilizer utilized for sugarcane in Brazil is the lowest in the world. Moreover, the costs (about 1.32 (hydrated) – 1.39 (anhydrous) R$/l29, 2011/2012 [30]; 0.43 (hydrated)-0.45 (anhydrous) US$/l, 2016 [29]) for Brazilian ethanol production from sugarcane are very

[25] Source: ANP, december 2012.
[26] Change: 2.164 R$/US$, (2012).
[27] Change: US$/EURO= 1.3194, (2012)
[28] Source: Europe´s energy portal (www.energy.eu), 2012.
[29] This values were calculated doing an arithmetic average of the production cost of 3 different regions (expansão, tradicional, nordeste) reported in the tables 14 and 15 of the reference [30]. Considering a currency exchange of R$/US$=1,792 (2011/2012), it is possible to estimate the cost in US$.

competitive when compared to other biofuels production costs, like for example European biodiesel (1US$/l [31]), or to ethanol costs production in other countries (i.e. in Australia) [29].

5.2 BRAZILIAN WOOD PELLET AS EUROPEAN RESOURCE

As described in the previous chapters, it is evident that not only the liquid but also the solid biomass plays an important role in the energy production and final energy consumption in Brazil: wood and charcoal[30] represents the 8% of the Brazilian energy mix and black liquor about 1%; about the final consumption, the sum of all solid biomass is around 21%). In Brazil solid biomass manly means wood biomass, because solid biomass from herbaceous or fruit are negligible.

Woody biomass is used to produce electricity, heat and charcoal.

Of the total electric energy generated in 2016, the part produced with biomass derived from forests in the form of chip, black liquor or charcoal, represents almost the 8% [41], but if we consider only the thermoelectric generation, the participation of biomass is almost 30% of the total produced in 2016 [41].

The industrial sector is the one with the highest heat production demand by biomass (25.1 ktons of wood to produce 29,7 Mtep [41]). The heat demand for service is of 94,1 ktep and of 6,3 ktep for residential [43].

24,773 tons of wood are requested to produce about 6.301 Mt of charcoal per year [41].

However, the use of solid biomass that is traded internationally in the form of wood pellet, briquettes, woodchip and other modern biomass that are certified by recognized programs of sustainability (i.e. ENplus, RSB, WBA, GBEP, ISO), is still underdeveloped. Brazil does not have a good position in both the production (almost 50% of production is accounted for by the EU, followed by North America with 33%; China and Russia together are about 13% [16]), and the international wood pellet trade, and this is in contrast with the potential of the country [21]. The actual export situation is hampered by logistical and transport problems, lack of infrastructures, of a regulation for the determination of quality standards of the Brazilian pellet and of strategic plans for this type of market.

The traditional solid biomass that is still used as domestic fuel, especially in rural areas without the access to electricity or other form of energy, is subject to a series of issues such as low efficiency, degradation of environment, gases emissions, sustainability, overexploitation and other possible negative effects. This is one of the reasons why bioenergy from solid biomass in Brazil has to shift to become a modern and competitive commodity. Another reason to reach this goal could be the energy independency and the problem of climate change, but for Brazil the driving force is the real possibility to become one of the most important exporters of pellet within a framework in which that type of trade, together with biofuels for transport is increasing a lot in the last years. This would represent an opportunity for a domestic industrial development and an internal economic growth; so, it is worth to give opportunities to Brazilian wood biomass to become sustainable and competitive at world level through economic and technological support.

The reasons why Brazil has a wide potential in this sector are basically linked with the followig elements:

[30] Charcoal derives from wood and it is used for cooking or for smelting iron and/or other metals in many countries.

- Brazil currently counts 105 Mha of degraded area usable as energetic forest;
- According to IBA´ [78], the 1% of the Brazilian soil (7.84 Mha) is occupied by planted forests (72.7% eucalypt=5.7 Mha; 20.4% pines=1.6 Mha; 6.9% others);
- Being Brazil in tropical zone, it shows favorable climate and soil conditions for biomass production;
- The Annual Average Increment (AAI[31]) of planted forest in Brazil is higher compared with the rest of the world in a range between 30% and 50% [1, 79]. For example, the average productivity of eucalyptus reaches (2016) 35.7 m^3/ha/year and the average productivity of pines and other species reaches 30.5 and 15.0 m^3/ha/year respectively [78];
- The rotation (period between planting and harvesting of trees) is the shortest in the world.

Brazil is also the major world producer (measured as the volume of wood produced per unit area per year) of wood from planted forest and the wood is the best biomass to produce pellet, according to ENplus. Considering the current area of planted forests and the national AAI, it is estimated[32] an average production of sustainable wood in Brazil of around 288.7 Mm^3 per year. In addition, Brazil has a large amount of wood waste annually generated: almost 80 Mt generated in 2016 of which, 30 Mt was forestry residues and 50 Mt was wood for energy (it is almost equivalent to 967,467 PJ).

The best way to export wood from Brazil is in form of pellet because it is a fuel with a higher PCI compared with PCI of natural wood (4,600 kcal/kg), with a low moisture content (7-10%) and easy to be transported and stored because of its low volume. As a consequence, its transport costs are low and so pellet correspond to a viable alternative in reducing the costs of large thermal energy consumers, which are not close to the storage point. In addition, there are other reasons linked to the importer country (in this study it is the EU28), which are explained below.

Starting from the year 2010, an exponential increase in the demand for pellets has taken place as an alternative for satisfying mainly residential heating, since internal conflicts (Russia interrupts the supply of gas through the pipeline in Ukraine and therefore the transport to Europe) have threatened European energy security. Furthermore, in 2010, various policies were launched to reduce dependence on fossil fuels and to reduce emissions of greenhouse effect gases. Pellet consumption continued to increase, also due to the Fukushima disaster in 2011, which led to the decommission of some nuclear power plants in Europe. Because of climate change and energy security, in many European countries there are taxes on fuels derived from the oil used for heating and for this reason it is of increased interest to meet the demand for heating with alternative fuels. Also in the thermoelectric sector, there is the trend to replace completely or partially fossil fuels with alternative fuels to reduce CO_2 emissions. For example, there are countries in the EU that have not been able to achieve emission reduction targets because of the use of coal as fuel in thermoelectric plants (since 2009, for example, Germany has been producing eucalypt for pellets in Madagascar, after obtaining little reduction in the internal energy mix with intermittent renewable sources such as solar and wind [19, 80, 81]).

In this scenario the European pellet market has grown, and it tends to grow even more, both in electricity generation and in the residential heating sector. Today the EU28 is the biggest producer and consumer of wood pellet. In Figure 24 the production and consumption trends are shown, starting from 2009 to 2016.

[31] AAI: it is the volume by which the forest grows per unit area over a 12 month period.

[32] This estimative represents the supply of wood available in the period from the planting age to the optimum cutting point. The total production cycle could change depending on the species. The commercial spacing used is 3m x 3m (meters between planting lines), and may vary depending on the final destination of the forest production.

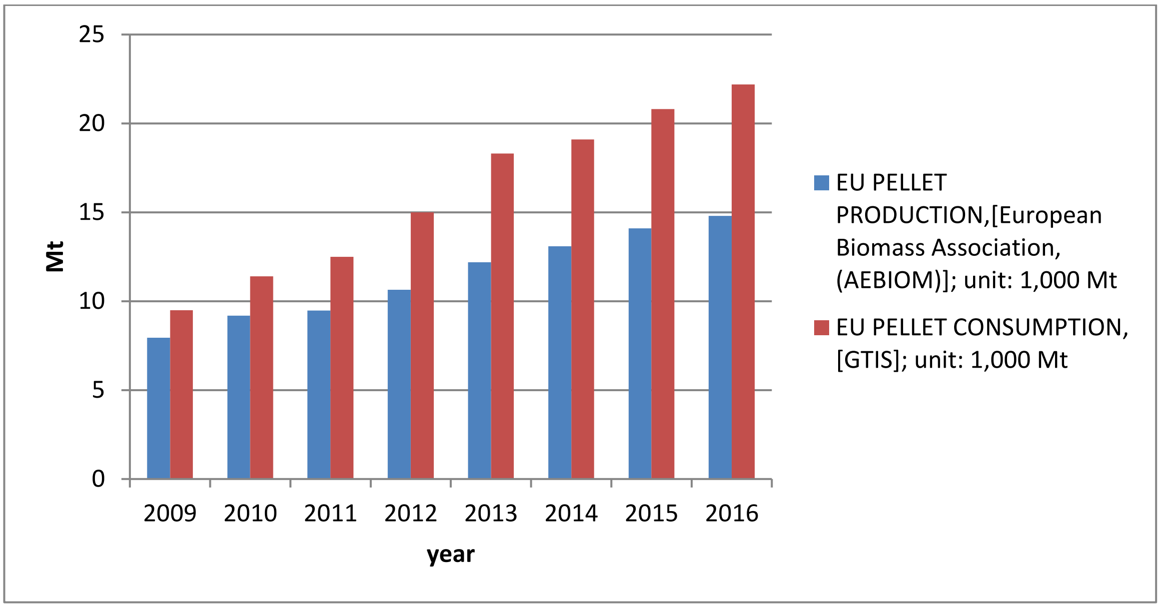

Figure 24: EU pellet production and consumption; 2009-2015 [82].

The production grew from almost 8 Mt in 2009, to almost 14.8 in 2016. Concerning the total consumption (both residential and industrial ones), it passes from 9.5 to 22.2 Mt during the same period. It is evident how the demand is always higher than the internal production. According to the EU Biofuels Annual (2017), EU wood pellet production is not expected to be able to keep up with the demand from both the residential heating market and for power generation. The gap between production and consumption is actually mainly covered by the biomass import from Canada and USA, but a lot of studies demonstrate that Brazil is a good potential exporter of wood pellet to satisfy the growing European demand, [1, 14, 15, 33, 83, 84, 85, 86].

The EU Biofuels Annual [5] says also that the major raw material for pellets has traditionally been sawdust and by products from sawmills but there is a big interest in diversifying the raw material. Additional feedstock could come from forest residues, wood waste and agricultural residues; however, the internal feedstock is not sufficient for supplying the full demand. This is another reason why Brazil could be an excellent exporter of pellets for Europe.

However, the actual situation in Brazil is very far from its real potential. In 2016, for example, there were only 13 pellet production plants in operation and their total production was almost 75,000 t/year [87, 33]. These plants have a production capacity of about 209,750 t/y, so their current production reaches only 35% of this capacity. In Figures 25 and 26 the Brazilian pellet plants and their geographical location are described.

Industry Number	City / State	Production capacity[1] (ktonnes·y⁻¹)	Used agroforestry Biomass	Equipment technology	Operation starting year	Industry current situation
1	Quedas Iguaçú/PR	6.00	*Pinus*	National	2014	Producing
2	Lins/SP	24.00	*Pinus*	National	2010	Producing
3	Telêmaco Borba/PR	9.00	*Pinus*	National	2004	Producing
4	Vale Real/RS	6.00	*Pinus*	National	2014	Producing
5	Benedito Novo/SC	4.50	*Pinus*	National	2007	Producing
6	São JB Vista/SP	2.40	*Pinus*	National	2014	Producing
7	Concórdia/SC	12.00	*Pinus*	Imported	2014	Producing
8	Rio Negrinho/SC	24.00	*Pinus*	Imported	2008	Producing
9	Porto Feliz/SP	6.00	*Pinus*	National	2004	Producing
10	Farroupilha/RS	3.75	*Pinus*	Imported	2010	Producing
11	Itapeva/SP	3.00	*Pinus*	Imported	2012	Producing
12	Piên/PR	42.00	*Pinus*	Imported	2012	Producing
13	Telêmaco Borba/PR	7.50	*Pinus/Eucalyptus*	National	2014	Producing
14	Sengés/PR	12.00	*Pinus*	Imported	2008	Ready to produce
15	Itaju/SP	7.50	*Pinus*	National	2008	Ready to produce
16	Jaú/SP	24.00	*Sugarcane bagasse*	Imported	2015	Ready to produce
17	Maringá/PR	0.00	*Pinus*	National	2008	Disabled
18	Bandeirantes/PR	0.00	*Pinus*	National	2010	Disabled
19	Tunas/PR	0.00	*Pinus*	Imported	2009	Disabled
20	Recife/PE	-	*Elephant grass*	Imported	2016	Under construction
21	São J. Ausentes/RS	-	*Pinus*	Imported	2016	Under construction
22	Rio dos Cedros/SC	-	*Pinus*	National	2016	Under construction
23	Rio Grande/RS	-	*Black wattle*	Imported	2016	Under construction

N°	City/S	Capacity (t/yr)	Produc. (t/yr)	current.	Biomass	Since (yr)
1	Telêmaco Borba/PR	7.000	4.800	On	pinus	2004
2	Porto Feliz/SP	12.000	4.800	On	pinus	2004
3	Benedito Novo/SC	9.000	4.800	On	pinus	2007
4	Maringá/PR	22.500	0	Off	pinus	2008
5	Itaju/SP	22.500	0	Stand by	pinus	2008
6	Rio Negrinho/SC	60.000	30.000	On	pinus	2008
7	Sengés/PR	30.000	0	Stand by	pinus	2008
8	Tunas/PR	24.000	0	Off	pinus	2009
9	Bandeirantes/PR	37.500	0	Off	pinus	2010
10	Farroupilha/RS	3.750	2.400	On	pinus	2010
11	Lins/SP	30.000	2.000	On	pinus	2010
12	Piên/PR	45.000	6.000	On	pinus	2012
13	Itapeva/SP	3.000	2.400	On	pinus	2012
14	S.J. Boa Vista/SP	3.000	2.000	On	pinus	2014
15	Quedas Iguaçú/PR	6.000	5.000	On	pinus	2014
16	Telêmaco Borba/PR	7.000	5.000	On	pinus/eucaliptus	2014
17	Vale Real/RS	3.000	1.800	On	pinus	2014
18	Concórdia/SC	12.000	4.000	On	pinus	2014
19	Recife/PE	60.000	0	Stand by	elephant grass	2015
20	Jaú/SP	175.000	0	Stand by	cane bagasse	2015
21	S.J. Ausentes/RS	100.000	0	Stand by	pinus	2016
22	Rio Grande/RS	80.000	0	Stand by	wattle	2016
23	Rio dos Cedros/SC	9.000	0	Stand by	pinus	2016
Total		209.750	75.000			

Figure 25: On the left all the pellet plants in Brazil in 2014 [87]; on the right all the pellet plants in Brazil in 2016, [2, 33].

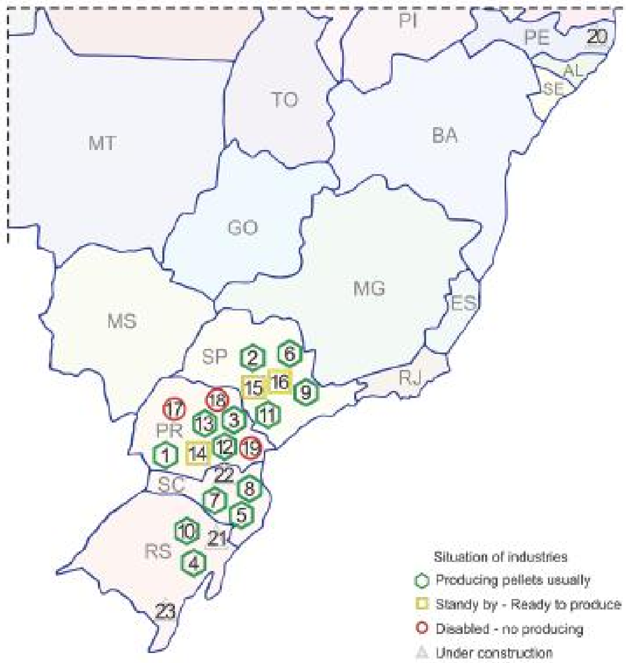

Figure 26: Location of the pellet plants in Brazil in2014 [87]. NB: the numbers refers to the figure 22 of the left side.

Almost all industries (81%) are located in the southern states of the country (Paraná, Santa Catarina, Rio Grande do Sul), and the rest in the center state of São Paulo[33].

[33] It hosts the largest concentration of pine and eucalyptus plantations of Brazil and also generates around 73 % of the waste from the wood processing industries.

The exportation is done only by 3 producing companies (the only ones that obtained the A1 ENplus[34]), which export pine (15,000 t/y, i.e. the 33% of the total production in 2016) since it is, for the moment, the only one that meets the international standards of quality. However, its production cost is too high to be competitive in the international trade and for this reason not developed. It is expansive because the factories are small, with low production efficiency (a standard equipment produce from 0.5 to 4.0 t/h) and consequently with high production costs [87]. In general, the production is mainly destined to domestic market [33]. This low production can be justified by a poor domestic demand, due to the lack of knowledge considering benefits and advantages in the use of pellets, and also because the pellet market is still unstable. The low production is also linked to the use of residual biomass (wood waste[35]) as feedstock for the pelletizing industries, which does not allow a large-scale production. The pellet from agricultural residues would be much cheaper but it has a lot of drawback in comparison with the pellet from forests: lower energy content and higher rates of sulfur, nitrogen, chlorine and silica, which after combustion act as corrosive and mutagenic abrasives [88]. The only feedstock to produce enough quantity of pellet to be exported can be obtained with planted forests (using lignocellulosic biomass residues or/and plantations for energy use). In the Table 12 are reported the quantities of residual wood from planted forests of Pinus and Eucalyptus in Brazil.

Residues [**Mt**]	Rio Grande do Sul	Santa Caterina	Parana´	Sao Paulo	Minas Gerais	Espirito Santo	Bahia
Eucalyptus & Pinus	1.2	2.98	4.74	3.43	1.87	0.46	1.25

Table 12: Brazilian residual wood from planted forests [85].

The most of these residues are left in the field for its regeneration and only a small part is used to produce electricity. According to [2] and since the country is well developed in forestry and has got a large amount of degraded areas that can be utilized to cultivate eucalypt, a promising solution for the marketing of Brazilian pellet to third countries (Europe in particular), would be to use short rotation eucalyptus from planted energy forests, as raw material to produce pellet. With the increase of the number of plants per hectare (assuming variable spacing of 3x0.5, 3x1 and 3x1.5 meters), a larger biomass production occurs in a smaller area: in this way, it would possible to reach, with the same productive cost as traditional planted forests, yields of 45-55 tons of dry mass per hectare in cycles of 1 years (twice the productivity per hectare of traditional planting[36]), and meet to the export demand [17, 89, 90]. Although these are experimental data, they are in line with the large production potential of Brazil [17, 89, 90].

Just to give a comparison with the other countries of South America, in the table 13 there are some data relative to the actual (2016) production and export of pellet [91].

[34] The ENplus certification scheme defines three different classes of pellet quality, based on the classes provided for in ISO 17225-2 and identified as follows: (1) ENplus A1; (2) ENplus A2; (3) ENplus B. In the point 2 of the appendix there are only the pellet properties of interest to the study and the relative threshold values of the different parameters for the different quality classes.

[35] Quantity of wood waste generated in Brazil in 10^3t/year : 27,750 from wood industry(90.7%); 1,930 from urban áreas (6.3%), 923 from construction sectors (3%) [STCP,2011; SAE,2011].

[36] The production of traditional planted eucalyptus florests is, with a spacing of 3x2 and 3x3 meters of planting between plants, with a productive cycle of 5 - 7 years, and considering an average AAI (national - 41 m^3 / ha / year), around 25 tons of dry mass per hectare per year. Under these conditions, wood productivity is able to meet only the national demand of the woody sector (cellulose, panels, etc.) and it is in most cases economically unviable for energy use.

Country	BRAZIL	ARGENTINA	CHILE	COLOMBIA	MEXICO
Pellet produced (**t**)	75,000	6,000	30,000	0	4,000
Pellet exported (**t**)	15,000(33% della produz. tot.)	3,440	2,565	0	1,513
Wood residues (**m³**)	17,194,000	305,000	1,916,000	566,000	Not Found

Table 13: Central and South America pellet production, pellet export and wood residues production [91].

It is evident how Brazil has well-established forestry and agricultural sectors, with large technical potential for pellets production from planted forests, wood residues and agricultural residues. However today, it produces pellets mainly for the internal demand, while the share of pellet exported is still unimportant compared with its potential.

An obstacle for the Brazilian pellet exportation is the lack of Brazilian sustainability standards, that must be put in place to safeguard the environment, and to meet desired social and economic criteria. In fact, short rotation eucalyptus represents a promising scenario (in price and productivity), but at the same time it contains rates of chlorine and ash up to five times higher than allowed by international standards[37]. However, a process allowing the removal of chlorine and other inorganic rates present in eucalyptus wood has recently been patented. With it, it is possible to produce pellets that are in line with the European sustainability standards. So, short rotation eucalyptus energy forests can be one solution for the penetration of Brazilian pellet in the international market [22].

Another issue is the logistic costs (precarious railroads, expensive freight, ports adaptable but not adapted yet) [63] and a set of bureaucratic and economic difficulties that make investments in pellet more difficult, making the international trade difficult too. Although the country is believed to have the potential to become a future global leader in the production and distribution of pellet, in reality it is a big challenge.

The price of pellet could vary a lot because linked to the quality of the pellet (feedstock), port (CIF[38]) or (FOB), type of market to be reached (for residential or industrial use) and others. According with the report from Argus Biomass Markets (2016), it can vary in a range from 97 to 200 US$/t and the spot average price in 2016 was (CIF) US$/t 127.17 (based on the ports of Amsterdam-Rotterdam-Antwerp, ARA) and 150 (FOB) US$/t.

According with [22], in Brazil the production cost of wood pellets of a standard factory is around R$/t 380.00, from which 50% is absorbed by capital investment and O&M (production costs) and 50% by the acquisition of residual biomass (raw material cost). The price of pellet in the internal market is in the range of 450.00-600.00 R$/t (FOB) [22]. Another source [92] underlines that Brazilian pellet cost production per ton is between R$ 290 and R$ 380 and it is sold at prices ranging from R$/t 490-650 (FOB). The cost of producing pellets in Brazil results lower to the selling price of pellets in Europe. However, the current pellet production efficiency is low and therefore the cost could become even lower if this efficiency had improved. In addition to this, according to a study done by FIESP (Federation of Industries of the State of São Paulo), the cost of Brazilian electricity (which is used in pellet production process) is high when compared with other countries (like USA), and there is not adequate logistical structure which becomes an increase in costs.

[37] The international standards considered in this work are the European ones. That values are avaible in the certification called ENplus, (see the annex).
[38] CIF: in CIF contracts, the insurance and other costs are assumed by the seller, with liability and costs associated with successful transit paid by the seller up until the goods are received by the buyer.

The present average price for wood pellet of the largest EU wood pellet producers (Germany and Austria) is 245 Euro per ton[39] [93]. The pellet price in Switzerland is always slightly higher (around 310 Euro/t) [62]. In the table 14 there are the actual pellet prices in EU and in Brazil.

Country	Average pellet price (internal market)	Averge pellet cost production
Brazil	122-165 Euro/t[40] (450-650 R$/t [92])	95 Euro/t[41] (380 R$/t [22, 92])
EU	240-310 Euro/t [93]	

Table 14: Comparison in price and cost of pellet between EU28 and Brazil.

5.2.1 THE BRAZILIAN WOOD SUSTAINABILITY

It is challenging to illustrate the sustainability of the Brazilian wood for energy. It depends both on the type of feedstock utilized and on the final biomass produced. Between the different type of lignocellulosic waste and natural wood, the wood pellet is more efficient and less polluting than others when utilized to produce thermal energy. Its lower heating value (LHV) is almost 18 MJ/kg and that is higher, for example, than the chip wood (13 MJ/kg); moreover, its manufacturing and transport is very simple and relatively cheap. So, it is a good option to substitute fossil fuel in the thermoelectric power generation for residential, industrial and commercial sectors. It represents as well a very interesting opportunity for Brazil international market because the country boasts a large wood feedstock able to provide both internal energy consumption (according to [32], the internal thermal demand of the commercial and industrial sector could consume about 21 Mt of pellet per year in substitution of fossil fuels, resulting in 35% of savings), and exportation. According to ABIPEL [33], in 2015 the pellet production in Brazil was of 75,000 t and the internal consumption was of 60,000 t; and according to different studies, like Poyry management consulting's studies [14, 15, 34], Brazil is one of the countries in the world with a highest wood biomass potential. Considering the eucalypt wood as a feedstock, there are some debates about its environmental impact but according to many authors [2] it can be considered sustainable since it is able to grow in degraded areas and it is very efficient when water supply and water are concerned.

[39] It is included the Value Added Tax (VAT) per ton of pellets.
[40] Currency change (from brazilian Real to Euro) of 2017.
[41] Currency change (from brazilian Real to Euro) of 2017.

6. SCENARIOS

After a deep preliminary literature study, the most important points of which have been presented in the previous chapters, it is possible to talk about scenarios of biomass trade from Brazil to Europe.

This chapter describes four scenarios that have been designated to assess the role of the aforementioned trade and the results obtained through model runs. The utilized model was REACCESS which is composed by the union of the TIAM, PET and RECOR models (all described in 1.3.2.1 paragraph).

The four scenarios are the following:

- BASE;
- BIO BRAZIL 2;
- ADV;
- BIO BRAZIL 3.

The BASE scenario, as the name suggests, was done to evaluate the initial condition of the whole energy system as it was in the model before the implementation of the new corridors. No external constraints have been imposed and neither processes nor commodities have been added.

The BIO BRAZIL 2 scenario results from the implementation of the following biomass corridors (five in total) in the BASE scenario:

- pellet corridor from Santos port (San Paolo, SP) to Rotterdam port (NL);

- pellet corridor from Paranagua' (Parana', PA) port to Rotterdam port (NL);

- pellet corridor from Salvador (Bahia, BA) port to Rotterdam port (NL);

- ethanol corridor from Paranagua' (Parana', PA) to Rotterdam (NL);

- ethanol corridor from Paranagua' (Parana', PA) to Marseille (FR).

The ADV scenario was obtained with the imposition of the Italian Decree (DM 2 March 2018: on the use of advanced biofuels in transport) to the BASE scenario. The Decree was imposed to all European countries and not only to Italy, with the aim to see what would happen to the European energy system if all European countries adopte that Decree.

Finally, the BIO BRAZIL 3 scenario was designed. It includes the constraint on the advanced biofuels (DM 2 March 2018), the five biomass corridors already implemented in the BIO BRAZIL 2 scenario and the following two new corridors:

- ethanol corridor from Itaqui' (Maranhao, MA) to Rotterdam port (NL);

- ethanol corridor from Itaqui' (Maranhao, MA) to Marseille port (FR).

6.1 BASE RUN

The first results were obtained doing the BASE run of REACCESS model. It means without any constraint, such as policies or other imposed limits. The base year is 2005 and the data years (in which the user gives the input data) are 2009, 2010, 2015, 2020, 2025, 2030, 2040. The initial Reference Energy System (RES) include all energy systems of EU28 and ROW[42] and includes all corridors that link the ROW with the EU and the ones that link the ROW with itself. The TIAM model not considers the energy system of Brazil as a single country but it considers the energy system of the entire Central and South America (CSA). However, the CSA biomass trade in the model is operated only by Brazil excluding a portion of biodiesel traded by Argentina.

The brown lines in Figure 27 are the corridors that represent all biomass imports from the ROW to EU and also from the ROW to the ROW.

Figure 27: All biomass corridors of REACCESS model at the beginning. Source: Dynamic WebGIS Application.

Among these corridors, the Brazil-Europe corridor (which represents all biomass energy fluxes from Brazil to Europe) is also present. The fluxes of biomass from Brazil to EU are represented in the model as a series of different sea routes. The model initially includes two different sea routes (see Figure 28.a and 28.b):

- from Santos port (San Paolo) to Rotterdam port, (Figure 28.a);
- from Santos port (San Paolo) to Marseille port, (Figure 28.b).

The choice of the arriving European ports was taken for reasons related to logistics, such as avoiding high transport costs [94]. Moreover, Rotterdam, that is the biggest European port, serves the Northern part of EU and Marseille, that is the France's largest commercial port, serves the Southern part of the EU. At the same way, the starting port (Santos) is the most important of Brazil.

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[42] ROW: Rest Of World. It includes the following countries: Africa, Australia-New Zealand, Canada, Central and South America, China, India, Japan, Mexico, Middle East, other developing countries of Asia, South Korea, United States, Russia, Central Asia and Other Europe.

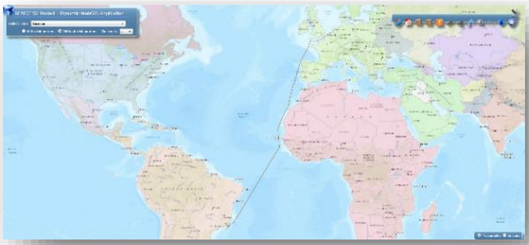


Figure 28.a: Santos-Rotterdam biomass trade. **Figure 28.b: Santos-Marseille biomass trade.**

The only biomass shipped in these two routes are biodiesel and ethanol, while pellet trade is not present in the BASE scenario. As mentioned above, a part of biodiesel is exported from Argentina so the biomass corridors of the BASE scenario are the following:

-ethanol from Santos (Brazil- BR) to Rotterdam;

-ethanol from Santos (BR) to Marseille;

-ethaol from Mar de la Plata (Argentina) to Rotterdam;

-biodiesel from Santos (BR) to Rotterdam;

-biodiesel from Santos(BR) to Marseille;

-biodiesel from Mar de la plata (Argentina) to Rotterdam.

Before biodiesel and ethanol are exported to the EU, they are produced by CSA. The process of production is present in TIAM (because the producer region is part of the ROW) and it is composed by a series of technologies described with economical, energy and technological parameters. Each technology is linked with the others by commodities (fluxes of energy) that are characterized by economical values and energy quantities.

In Figure 29 there is the simplified RES which describes the production chain of the ethanol and biodiesel as well as is present in TIAM. All the acronyms are explained in point 3 of the Appendix.

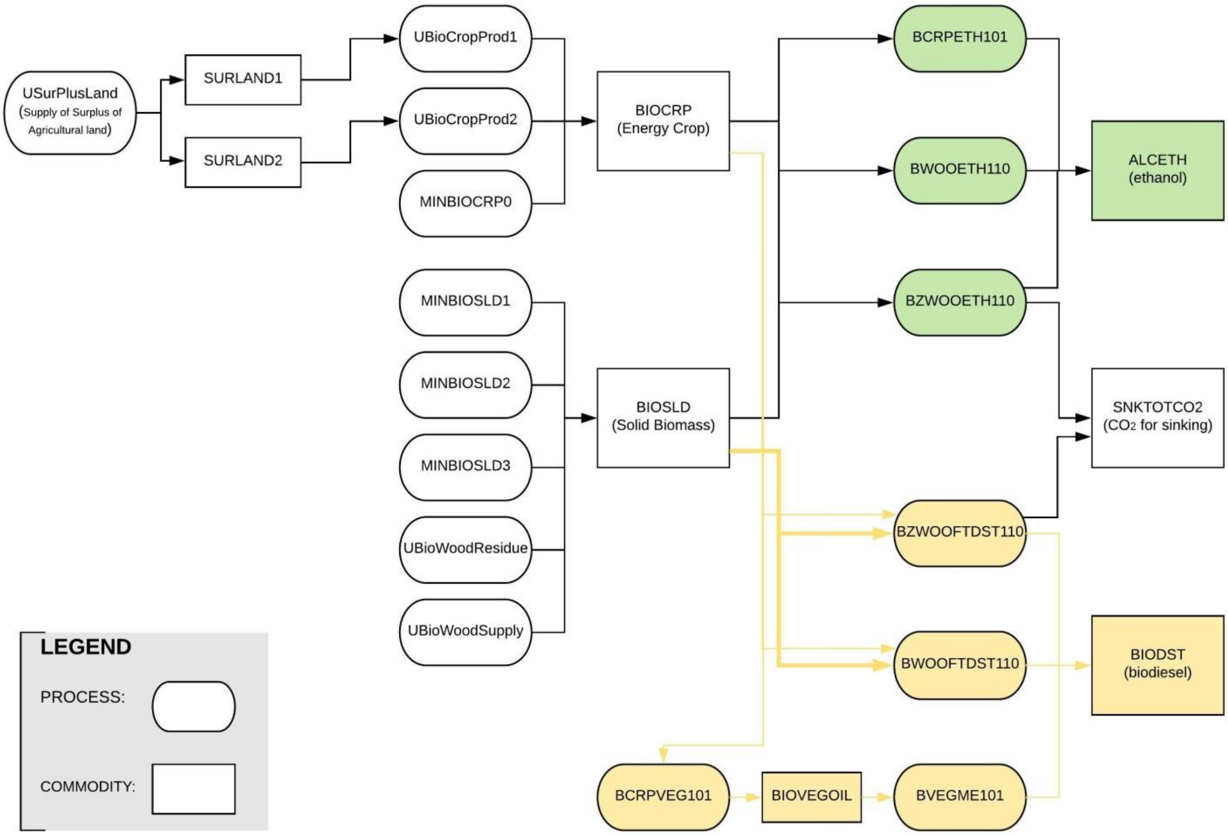


Figure 29: ethanol and biodiesel production chain in TIAM.

The previous representation is only a qualitative description to understand the production process of ethanol and biodiesel in the TIAM model; all connction-lines represent a commodity flow quantity that enter in/go out from a technology (process). Moreover, each process is characterized by different attributes like: activity (ACT); capacity (CAP); activity cost (ACT_COST); capacity cost (CAP_COST); new capacity (NCAP); efficiency (ACT_EFF); and so on[43]. In particular the mining process have an activity equal to zero in all regions and during the all period (from 2005 to 2040).

The commodity named "SNKTOTCO2" is not an energy flow but it represents the CO_2 emission for sinking. It then goes to the various CO_2 removal technologies which are not illustred here.

Doing the BASE run of REACCESS, it was possible to calculate, among others, the evolution in time of the things listed below which will be compared with the results of the subsequent runs:

- the BASE-biomass (ethanol and biodiesel only, because pellet corridors are not present in the BASE scenario) balance (production, consumption, import/export);

- all commodities fluxes involved in ethanol and biodiesel production;

- ships capacity, ship activity, ship consumption;

- transport demand;

[43] In the annex there is the list of all these attributes with their own TIAM´s code and description.

- CO_2 emissions.

All these results were calculated by the model for each milestone year and the most relevant are shown and explained in the chapter 6.2.

6.2 RESULTS FROM THE BASE RUN OF REACCESS MODEL (BASE scenario)

Considering the whole Central and South America (CSA) biomass export to EU, six different ships (listed in paragraph 6.1) exist in the model. However, the results of the all runs done show that biodiesel is exported by Argentina and by Brazil but the ethanol export is operated only by Brazil.

The export of ethanol begins in 2015. Of the total ship capacity available in 2015 for the ethanol export, only the 26% is used. This percentage grows until 2025 arriving at 92% and then it falls again. The following Figure 30 represents it:

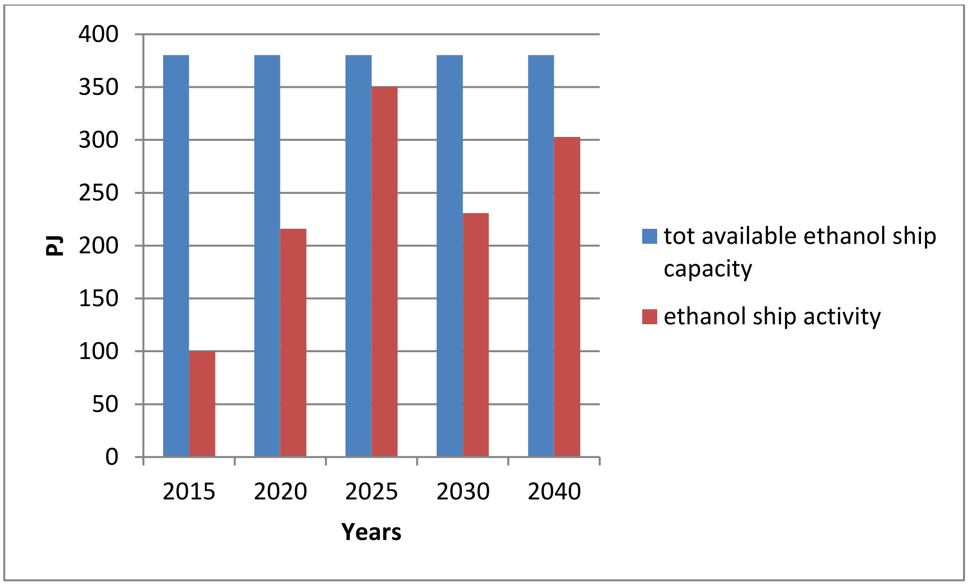


Figure 30: Comparison between the ethanol ship capacity and the ethanol ship activity in the base Scenario.

The red columns represent the ship activity in PJ, while the blue columns represent the ship capacity available for the ethanol export.

Another result is that the all biodiesel produced in CSA is also exported to EU, while it is not the same for ethanol as the following graph (Figure 31) shows.

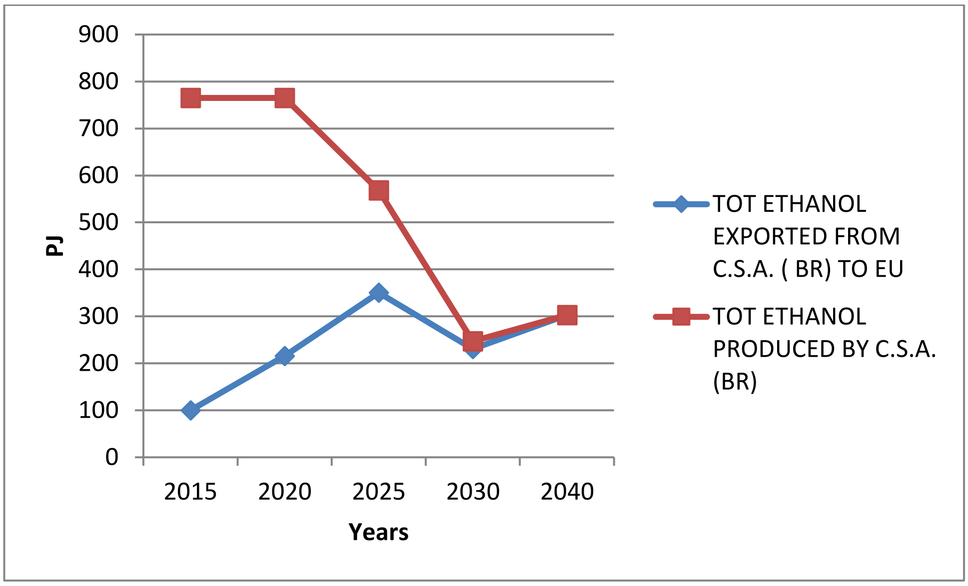


Figure 31: ethanol produced and exported from CSA to EU; Results from base run.

Figure 31 shows an increment in the CSA ethanol production from 2015 to 2020; that is followed by a decrease until 2030. In fact, in 2030 the production is equal to the export while for all the previous years the production is always higher compared with the exported quantities.

Figure 32 shows the share of ethanol destined to Rotterdam port and the one destined to Marseille port.

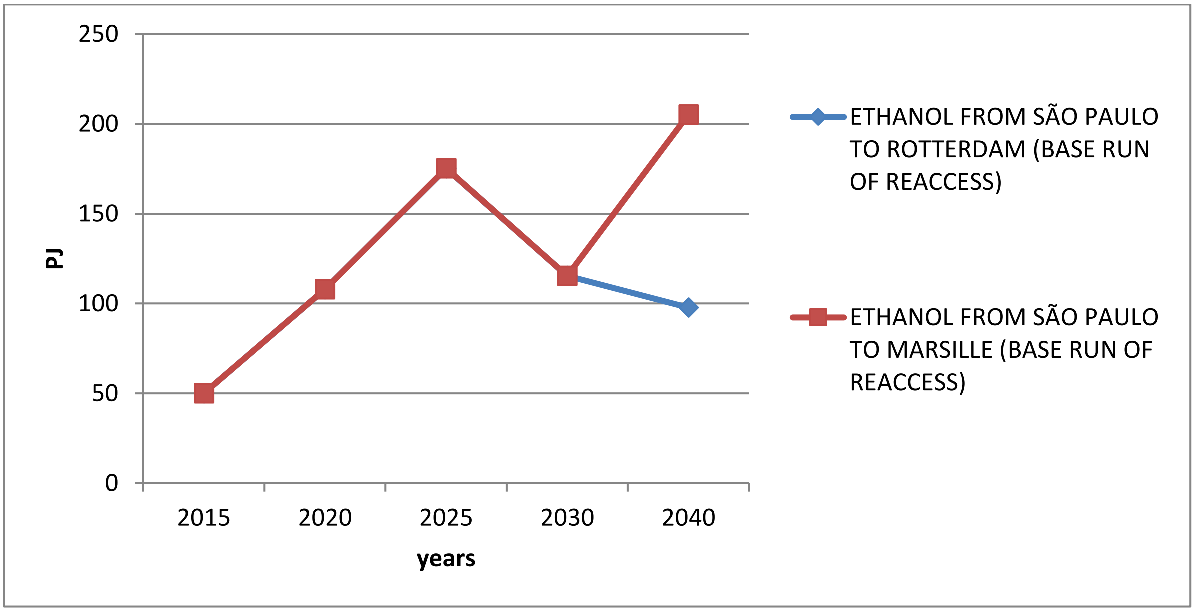


Figure 32: share of ethanol exported from CSA to Rotterdam and to Marseille; results of the base run.

The two shares are the same for all years except in 2040 where the ethanol exported to Marseille is the double with respect to the one exported to Rotterdam.

As the diagram of production chain show (Figure 29), both ethanol and biodiesel are produced from two different resources (commodities): energy crop (BIOCRP) and solid biomass (BIOSLD). The share of BIOSLD used for ethanol production is null (no 2G ethanol is produced), but not the all BIOSLD is used to produce biodiesel because a part of it is used for other processes, such as gasification (methane production from biomass), and conversion from solid biomass (BIOSLD) to solid biomass for end use (BIOBSL), (see Figure 33).

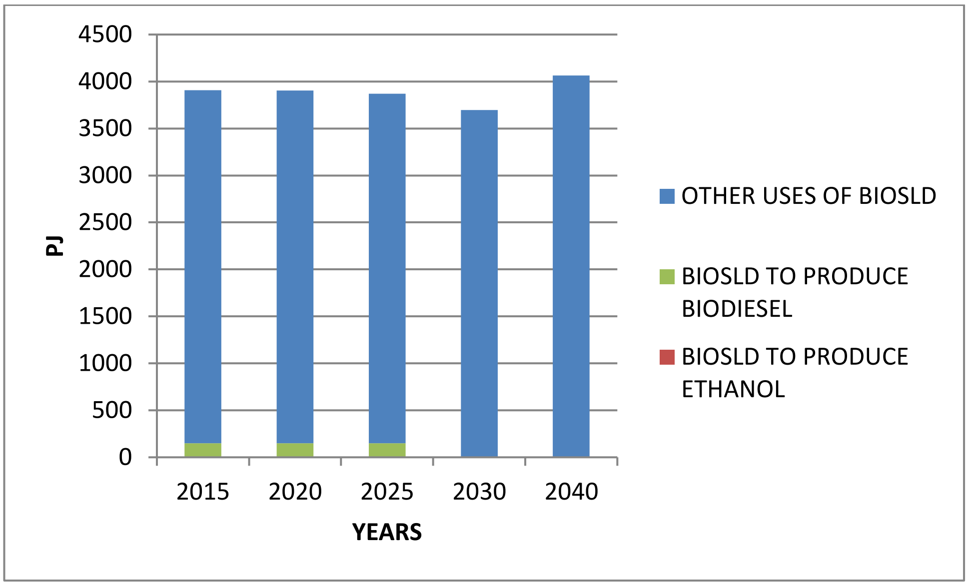


Figure 33: share of solid biomass use; results of the base run.

The share of BIOCRP used for the ethanol production is bigger than the one used for biodiesel production up to 2020. In 2025 the BIOCRP used to produce ethanol is of almost 45% and in 2030 it drops sharply to almost 15% up to 2040 (see Figure 34).

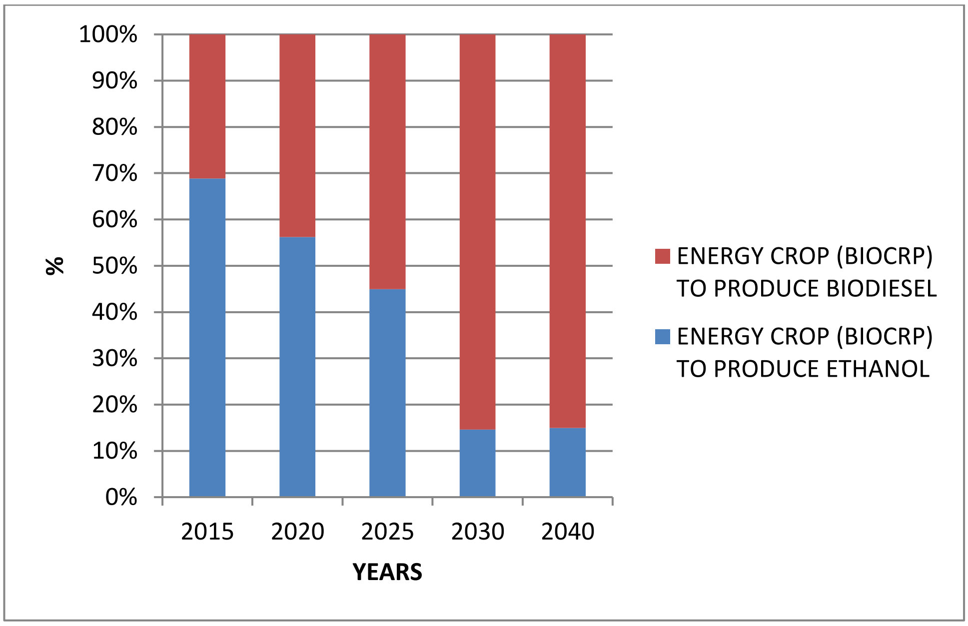


Figure 34: Energy crop use; result of the base run.

As far as the CO_2 emissions concerned, we can see in the following graph (Figure 35) that they gradually increase from 1.7 $GtCO_2$ in 2005, to 2.4 $GtCO_2$ in 2040, without peaks or falls.

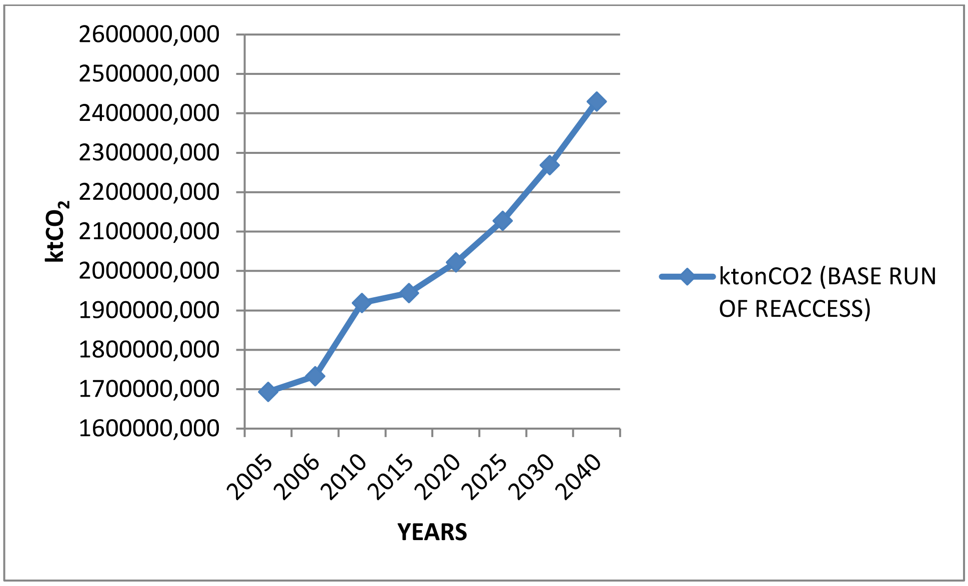


Figure 35: CO2 emissions of the total CSA energy system; result from BASE run.

The represented emission trend refers to the total CO_2 emissions produced by CSA region. These emissions include all the CSA processes of the model.

6.3 INPUT DATA FOR THE SIMULATION OF THE BIOMASS EXPORTATION FROM BRAZIL TO EU ("BIO BRAZIL 2" SCENARIO)

The input given for the creation of the new biomass corridors and the BIO BRAZIL 2 scenario were:

- raw material supply;

- activity (production), capacity and new capacity of the examined biomass production plants along the time (up to 2040);

- production costs, investment cost, fixed and variable costs;

- environmental policies (imposed constraints on attributes);

- other technical data (logistical data, transport costs, efficiencies, ships characteristics, etc).

To create a corridor it is important to clearly define the technologies, energy and economy that are part of it. To do this it is necessary give the input data listed above describing the corridor as a trade process. The trade process starts in this case from a Brazilian port and arrive to an European port transporting biomass (commodity). For each kind of biomass trade exists a different process with its own characteristics and its parameters.

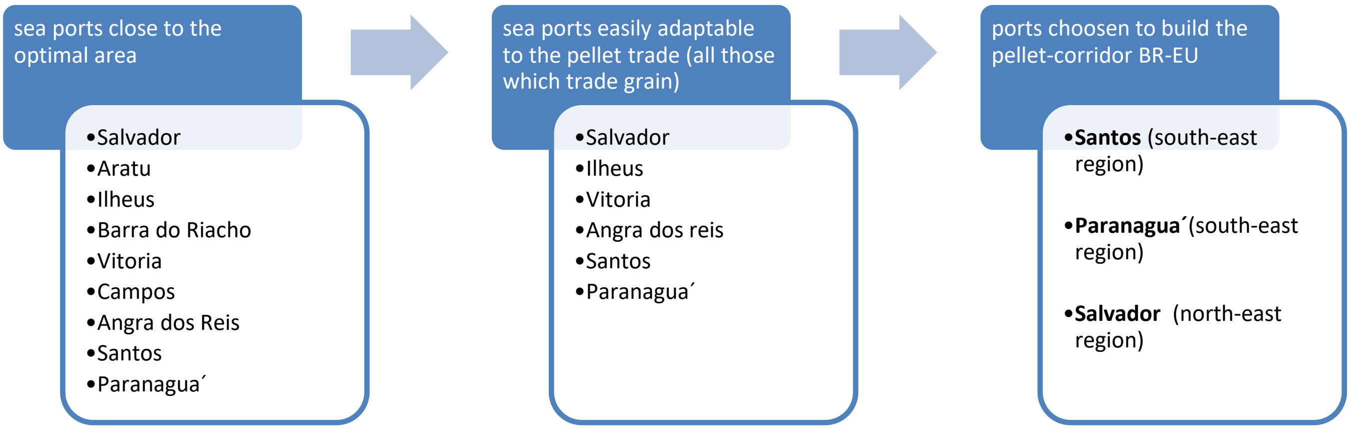
For the choice of the input data a deep research and hypotheses have been made. These considerations are explained in the paragraphs 6.3.1, 6.3.2, 6.3.3, 6.3.4.

6.3.1 TECHNICAL DATA AND ASSUMPTIONS

6.3.1.1 PELLET

The potential export route was designed in relation to the actual Brazilian pellet production, to its domestic use and the estimated percentage that will be destined to the exportation. Considering these values it is possible to make an estimation of the ship load and to choose the Brazilian and European ports suitable for this type of trade.

According with Escobar [2], the Brazilian ports that fall within the optimal area for the export of pellets are all situated between Salvador and Paranagua'. This is due to the fact that are the nearest (not further than 150 km) to the optimal area[44], in which it is possible the plantation of energy forests for the sustainable pellet production. However, the choice was then restricted to the port that are more easily adaptable to the pellet trade, that are those equipped with containers for the grain trade. This is because for the moment there are no ports specifically adapted for pellet production; nevertheless, the pellet trade is currently possible through the aforementioned existing ports. Finally, only the two major ports of the South-east and one of the north-east were chosen, because the potential flow of exported pellets would only depend on them. The higher production came from the South-East regions so were chosen two ports. For northern regions that produce less only one port was chosen. The next graph represents the path followed for the choice of the export ports.



The choice of the Europen port was obvious and easy to take. It was choosen the atual major EU port in which already pellet trade occurs (with the North America mainly): the Rotterdam sea port.

After the choice of the ports, the distance in km was calculated using a distance simulator [108]. The ship characteristics (ship fuel type, O&M, consumption, lifetime, etc) were choosen on the base of the other cargo vessel ships already present in the model.

Other technical data refer to the technologies for transforming the raw material to primary energy and from primary to secondary. In the case of Brazilian pellet, the resources are the land available for the plantation of energy forests and the woody, agriculture and forestry residues. The first is transformed into energy crops

[44] To have an idea of the optimal area, an image is available in the appendix. It was taken from [2].

and then into pellet. The seconds, into pellet directly. All these data (i.e. efficiency of land conversion into energy crop; production capacity) were taken from scientific studies and statistics, (mainly from [2, 33, 91]).

In particular, it is interesting to explain the choice of the efficiency to convert land to energy crop. The value used to calculate the wood production was 45 ton of dry wood/ha/y. This value could appear higher than the actual average productivity for a traditional Eucalyptus planted forest, (it is only 25 ton of wood/ha/y in Brazil and only 2.5 t/ha/y in Sweden). However, if it is considered a short rotation Eucalyptus energy forest, the number of plants per hectare increases and the aforementioned yield is achieved with the same cost of a traditional Eucalyptus cultivation [17, 89].

With regards to the pelletization technology in Brazil, it is not widespread yet. As explained in the chapter 5.2, only about 25-30% of the actual total production capacity is exploited. So, for the exstimation of the production capacity in 2020, 2030, 2040, 2050, it was taken into account the potential pellet production. According with Escobar [2], it is estimated to be almost 40 Mt in 2030 and 124 Mt in 2050. Consequentely, it was considerd a production capacity of the same order in the same years.

6.3.1.2 ETHANOL

The export routes considered are not all already existing in RECOR. The 2 ones that were added are: from Paranagua´ Brazilian port to Rotterdam and to Marseilles ports, (with a total of 2 new differents commercial routes). The addition of these new sea routes was done because the actual ethanol export from Brazil to the rest of world is operated mainly by Santos and Paranagua’ ports. Both ports were already described in the chapter 5.1. While the destination ports are the two presents in the model that serve the northen (Rotterdam port) and the south-west (Marsille port) EU as already explained in the introduction of chapter 6. The calculation of distance in km was estimated using the same distance simulator used for pellet´s routes [108]. The ship´s characteristics are choosen on the base of the others tanker ships already present in the model.

Other technological data refer to the ethanol chain from the raw material to the final use. As raw material it was considered the sugarcane crops (BIOCRP) and also the lignocellulosic residues (like sugarcane bagasse for example). The first one is used to generate a 1G ethanol and the yield to convert land to energy crop is about 6,200 litres of ethanol per hectare (i.e. 73 ton of sugarcane per hectare); the second one is used to produce 2G ethanol. In chapter 6.2.3.2. it was seen that the production of 2G ethanol is still poorly developed; its production cost is still high mainly because of the difficult in the production process and in the trasportation of raw material from the field to the production plant. However, in 2014 a 2G etanol plant started to produce ethanol from sugarcane´s bagasse and another one started in 2015 too. Today Brazil counted a total 2G ethanol plant capacity of 127,000 m^3/y [11]. While the actual production capacity of 1G etanol is of 39,650,000 m^3/y [11], the future production capacity was calculated on the base of ten-year Brazilian energy plan. It is forecasted a capacity of almost 42,500,000 m^3 of ethanol in 2020 and 45,500,000 m^3 in 2030. The 2G production capacity in the future was considered the same of the actual one despite having many chances of growth. This choice was made to avoid overestimating the production capacity since the development of 2G ethanol production could be very slow, [11, 95]. So, it is considered the worst case in term of total production capacity in the future.

6.3.2 ENERGY DATA AND ASSUMPTIONS

6.3.2.1 PELLET

The main sources for the research of the pellet energy quantities were ABIPEL [33], BEN [41] and FAO [91]; these quantities are the production, domestic consumption and export of pellet from 2005 until now. The estimation of the future pellet production is on the base of [2, 96]. Moreover, it was estimated the percentage of pellet that will be exported in the future (2020, 2030, 2040). This estimation was done on the base of the world pellet request. In particular the 3 major regions in the world were taken into account, regions that nowadays and much more in the future are likely to need importation of pellet. In increasing order, they are: EU, Japan and Korea, and China, [14, 15, 34, 54]. The potential external request considered was the sum of the deficit of pellet of these 3 regions, estimated in 2020 with the data of the biofuels annual world report. Then, the rest of Brazilian pellet produced is considered to be destined to internal consumption. In Figure 59 (chapter 7) is shown and explained that the Brazilian potential pellet production meets and exceeds the estimated external and internal demand.

6.3.2.2 ETHANOL

The energy data refers to UNICA source [4], as regards the amount of land available and used for the production of sugar cane. The ANP source was used to obtain the production, export, import and then domestic use data of the 1G ethanol. As regards the 2G ethanol production data, it was used the "demoplants2020" platform. All the 2G ethanol produced was exported, since the production costs are still too high for it to be profitable on the national market [41].

The production projections are made considering that the ethanol production is destined to grow: studies have shown that in the upcoming years, ethanol yield per hectare of sugarcane (which presently is almost 6,200 l/ha) may increase until 9000 l/ha, thanks to the increase in sugarcane yield, in TAR, in fermentation efficiency and in sugar extraction [12, 95]. The production in 2020 and in 2025 is of 35,000,000 and 43,000,000 m^3 rispectively on the base of energy brazilian plan [44].

Similarly, to the hypothesis done for the projection of the 2G production capacity, also the projection of the 2G ethanol production was considered the same as today. This assumption was made on the base of the last Brazilian Biofuel annual [11].

The export projection is almost 2,700,000 m^3 in 2030, according to the energy brazilian plan [44]; then the export in 2020 was considered an intermediate value between that of 2016 and that of 2030.

6.3.3 ECONOMIC DATA AND ASSUMPTIONS

6.3.3.1 PELLET

The economic values were calculated on the base of average values found in literature. That are the investment production cost, that it is necessary if we want to increase the production to meet the demand. It is an average 40 US$ per ton installed, considering a good equipment to produce pellet [96]. This value could swing depending on the country in which the equipment is installed. For example, in Brazil it could be a little bit more expansive, like 200 R$/t (almost 60US$/t) [96].

The variable and fixed O&M costs, linked to pellet production plant, that have not been modified in the model.

It was estimated the transportation cost too. The transportation, firstly from crop land to production plant and then from the plant to the export port, is a fundamental aspect to establish the feasibility and the introduction in the market of a new source of energy. The viable distance from the crop to the port is 150 km [2]. Considering the pellet transported by truck (it is the best choice of transport due to logistic reasons) [97] and not by train, the cost of transport is almost 3 R$/km for a load of 27 tons (it is a suitable freight for pellet). It means almost 0.11 R$/km/ton [98]. So, considering the production cost estimated in paragraph 5.2 and adding it to the transport cost just calculated, the total cost up to the export port result almost 396.5 R$/ton. Then it must be added the shipping cost from Brazil to Europe (i.e. Rotterdam port) to obtain the pellet price at Rotterdam port.

The transport cost for shipping is endogenous to the model: 0.121 Euro/TJ/km [94]. Considering an average distance of 10,000 km from Brazil port to Eu port, the total shipping cost of pellet is almost 21.80 Euro/ton (considering a LHV of 18 MJ/kg). It is almost equivalent to 87 R$/ton (actual currency change,2018).

Summing the shipping value to all the others pellet costs described above, the cost of pellet at Rotterdam port will be almost of 483 R$/ton (about 121 Euro/ton). This calculation agrees with literature according to which pellet price is of 127 US$/t (CIF) and 150 US$/t (FOB) at Rotterdam port [99]. The cost of pellet at Rotterdam port was not used in the model because it is endogenous in the model, but it is interesting to highlight that the value found in the literature is consistent with the one of the model. In addition to this, this value can be used to calculate the Brazilian pellet price arrived at Rotterdam port and compare it with the European pellet price.

6.3.3.2 ETHANOL

It was considered, according to the ten-years energy plan [44], a unit investment cost for the construction of a new ethanol production plant[45] of almost 344 R$ per ton of sugarcane; then, the total investment estimated in 2020 was of 3,435 US$[46] and of 3,536 US$ in 2030.

The unit cost of the ethanol destined to export was calculated (as explained in the chapter 5.1 and as showing in chapter 7.1), year after year, using the UNICA database [4]. Then, to obtain the value of ethanol at the European port, it must be added the cost of freight from Brazil to Europe. As for pellets, the cost of Brazilian ethanol arrived at European port is not an input to the model because that value is endogenous in the model but it is interesting to highlight it for example to compare the price of Brazilian ethanol at the European port with the one of European ethanol.

Considering the route Santos-Rotterdam, the cost of freight results in a range between 23.6 and 31.4 US$/ton[47] [72]. So, considering the total ethanol exported in 2017, its price at Rotterdam port would be in the range of 0.649 and 0.655 US$/l. This value was obtained only summing the value of ethanol exported from Brazil with the value of freight in US$/l considering an ethanol density of 800 kg/m^3. This calculation is underestimated because sometimes there are port taxes that are not included in the estimation done by

[45] Considering a plant that can produce both sugar and ethanol; a plant that can produce only ethanol has a lower cost of investment for the construction: 310.6 R$/tsugarcane.
[46] Currency change: 3.413 R$/US$, [68].
[47] W100 Santos -Rotterdam 15.7 US$/ton; WS mercado pra navio Handy size WS 150-200. This means that the cost of fright is: 15.7x(1.5 – 2.0) = 23.6 – 31.4 US$/t.

[72]; moreover, there are also some minor insurance costs, inspection, losses, overstay that were not considered.

The same calculation can be done considering, instead of the total exported ethanol in 2017, the volume exported per Brazilian region. These volume quantities are available in the UNICA database with their own value of export in US$ (FOB) (the profit margin is included). So, the only calculation that was done was dividing the value of exported ethanol that is in US$(FOB) by its own volume in liter to have a unit cost in US$/liter (FOB). Then, adding it to the cost of freight in US$/liter from the Brazilian port to the European port.

The results are reported in the conclusions (see 7.1 chapter) where the cost of sea transport was calculed for three different routes (those useful for the analysis): Santos – Rotterdam; Paranagua´ - Rotterdam; Itaqui´ - Rotterdam. The calculated shipping costs (see chapter 7.1) resulted underestimated with respect to those used in the model, which are the following:

- 0.212 Euro/TJ/Km for Ethanol [94] (57.24 Euro/ton, considering a LHV=27 MJ/kg);

- 0.152 Euro/TJ/Km for Biodiesel [94] (56.24 Euro/ton, considering a LHV=37 MJ/kg).

The variable and fixed O&M costs linked to ethanol production plant have not been modified in the model.

6.3.4 INPUT DATA FOR BRAZILIAN BIODIESEL

Together with the other input data, useful for the simulation, other data related to the Brazilian biodiesel production chain were also searched and included. This has been done for completeness as the model already presents the biodiesel corridor from CSA to Europe as shown previously. In fact, thanks to further research, it was found that the pre-existing values in the model differed very much from the actual values, so an update was deemed appropriate. It should also be noted that biodiesel is an important biofuel in the Brazilian energy mix, although it is used essentially for internal use as already explained in the previous paragraphs.

Here the biodiesel data updates are briefly explained.

In Brazil the feedstock used for the production of biodiesel is of different types, but the predominant is the soy oil (80.79%, [ANP,2015]), followed by animal fat (15.82%, [ANP, 2015]). In the production chain of the model are present two ways of biodiesel production: the transesterification of vegetable oil (BVEGME101) and the biodiesel production from woody biomass (BWOOFTDST110 or BZWOOFTDST110: with or without carbon capture CCS respectively). Consequently, the percentage of biodiesel produced by animal fat was excluded and it was taking into account only the share from soy. The third share from other feedstock (3.39% [ANP,2015]) was not considered because negligible.

The production and the production capacity data of soy, soy oil and its derived biodiesel from 2015 to 2030, were found in a document realized by three brazilian associations (ABIOVE, APROBIO and UBRABIO), which shows the brazilian biodiesel projections compared with the actual situation [101]. The values were considered reliable after a consultation with specialists in the sector; in addition of this, they match with the ones of the ANP database and with the ones of Biofuel brazilian annual [11]. It was the same for the data referred to the new capacity investment cost in 2020, 2025 and 2030. Fixed and variable O&M costs and efficiency in process trasformation (from SURLAND to BIOCROP) are the ones given by the model.

To convert the data from quantity per year to energy per year were considered the following lower heating values (LHV): 6,778 kJ per kg of soy [102]; 33,995 kJ per liter (=8,125 kcal/liter) of soy oil (BIOVEGOIL) [103]; 33,137 MJ per m^3 (9,000 kcal/kg) of biodiesel (BIODST) [41]. The density of soy oil considered was 920 kg/m^3 [11]. The biodiesel density considered was 880 kg/m^3 [11].

The surplus of agricultural land (SURLAND), that is the start commodity of the production chain for both ethanol and biodiesel produced by energy crop, has been differentiated in SURLAND1 and in SURLAND2. The first one refers to hectares of sugarcane, and second one refers to hectares of soy.

6.4 RESULTS FROM BIO BRAZIL 2 SCENARIO

Thanks to the input data just described in paragraph 6.3, the so called Bio Brazil 2 Scenario was modelled. Then, through a run done after the first BASE run, some interesting results were obtained.

In this chapter the main results are described and compared with the BASE scenario results.

The BIO BRAZIL 2 scenario includes the implementation of new five biomass corridors already listed in the introduction of chapter 6 and now shown in Figure 36.

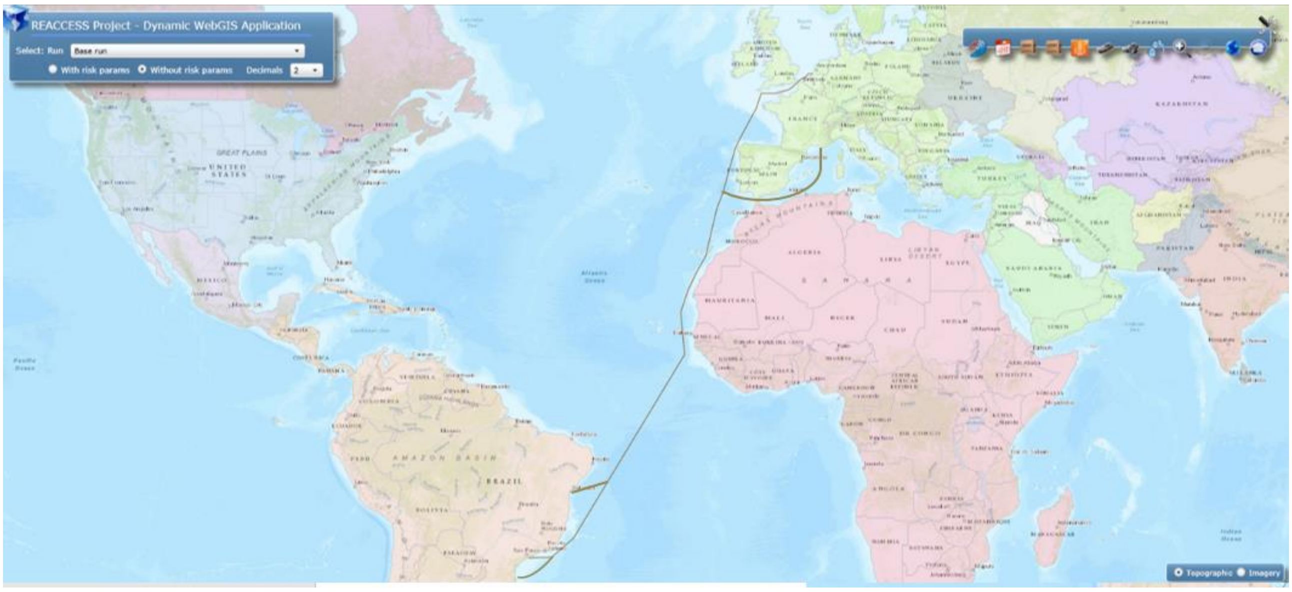


Figure 36: Biomass Corridors from Brazil to EU of the BIO BRAZIL 2 scenario.

The map shows the biomass routes present in BIO BRAZIL 2 scenario. These include a total of eleven ships: the 6 already present in the BASE scenario plus the 5 new ships implemented (all listed in the introduction of chapter 6).

The ship activity is shown in figures 38, 39 and 40 in PJ. These pictures describe three types of biomass trade: ethanol, biodiesel and wood pellet.

The import of pellet from Brazil to EU was null in the BASE scenario but it appears in BIO BRAZIL 2 scenario. This means the model chose the pellet corridors created.

The following Figure 37 illustrate the conversion process (UBIOBSL100) which transform the solid biomass (BIOSLD) from raw material to energy source for end use (BIOBSL, which is pellet), which is present in TIAM model. In the same Figure is also shown the trade of pellet from Brazil to EU through the three different ships that have been added in RECOR model (from Santos to Rotterdam; from Paranagua' to Rotterdam and from Salvador to Rotterdam).

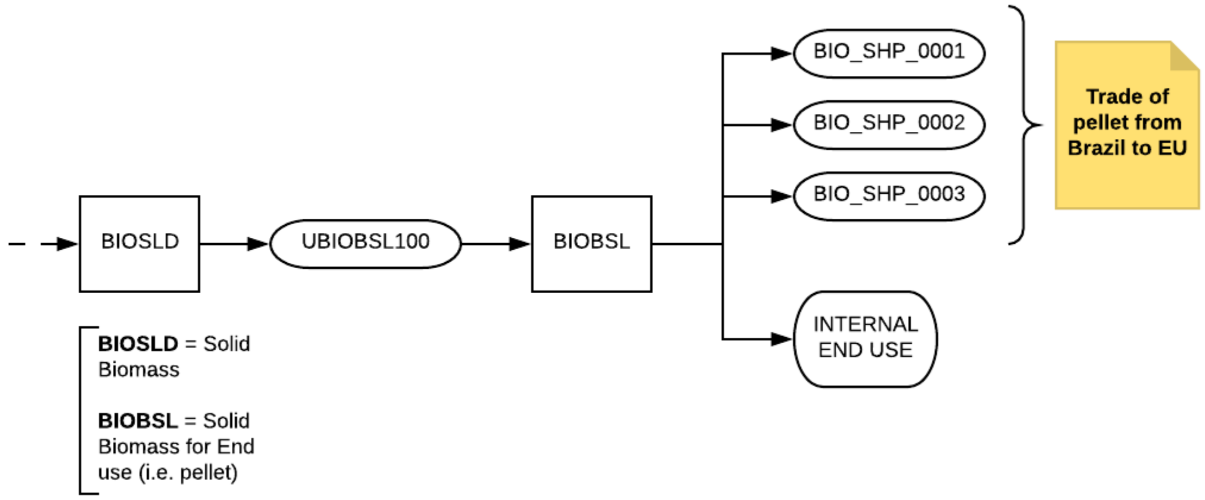


Figure 37: Solid Biomass chain from production to trade_BIO BRAZIL 2 Scenario.

The BIOBSL production exceeds the export. Figure 38 shows that in the BIO BRAZIL 2 scenario the production of pellet starts to be higher than the one of the BASE scenario in 2015. In the same year Brazil starts to export pellet to EU end this exportation grow up in a linear way up to reach 856 PJ in 2040.

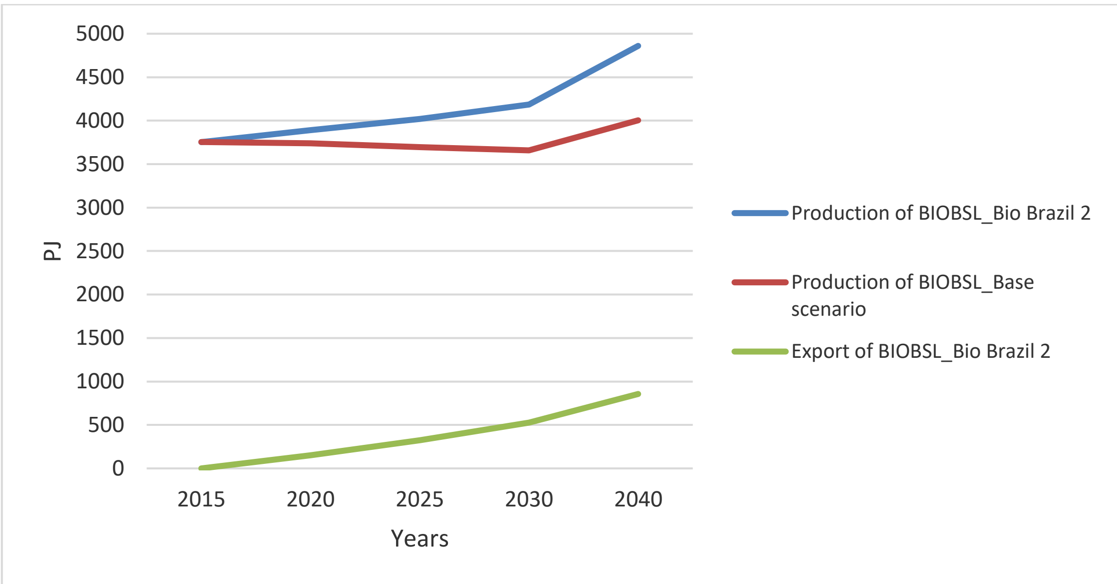


Figure 38: Trend of the production and exportation of Brazilian pellet (BIOBSL).

The growth can be justified by the increasing need of EU to buy pellet and the fact that the new scenario provides three available routes of pellet (all starting from Brazil) that did not exist in the BASE scenario. Moreover, since these routes are chosen by the model, it means that they are convenient in term of costs with respect to the others from the ROW. So, it happens that EU continues to import BIOBSL from Canada and Russia with the same total quantities in both scenarios but in BIO BRAZIL 2 scenario the corridor Brazil-EU appears.

The quantity of pellet shipped is equally distributed between the three Brazilian ports and so into the three different ships. This trend is surely linked with the available quantity of pellet at the Brazilian ports. The fact that it is equally distributed is due to the fact that the model cannot distinguish the region in which the production is higher and where is lower. The model only considers the cost and so the preferred route should be the shortest route. However, it does not exactly occur in this case because when new process is introduced, the growth/decay values can influence the choice of the model. These values have the function of modulate the variations of the activity of a process along the time horizon to avoid sudden changes from one year to another in order to generate a trend which is as realistic as possible.

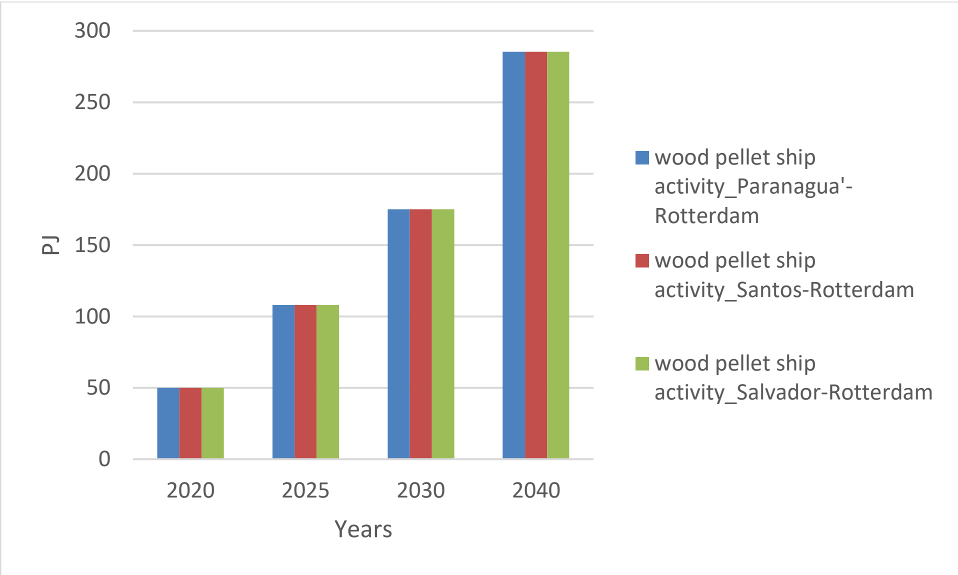


Figure 39: Pellet ship activity of BIO BRAZIL 2 Scenario.

The only ship activity that remains the same in both scenarios is the one of biodiesel trade. The trend is growing along the time almost in a linear way. At each year the model prefers the cheaper route (from Brazil to Marseille) with respect to the others (see figure 40).

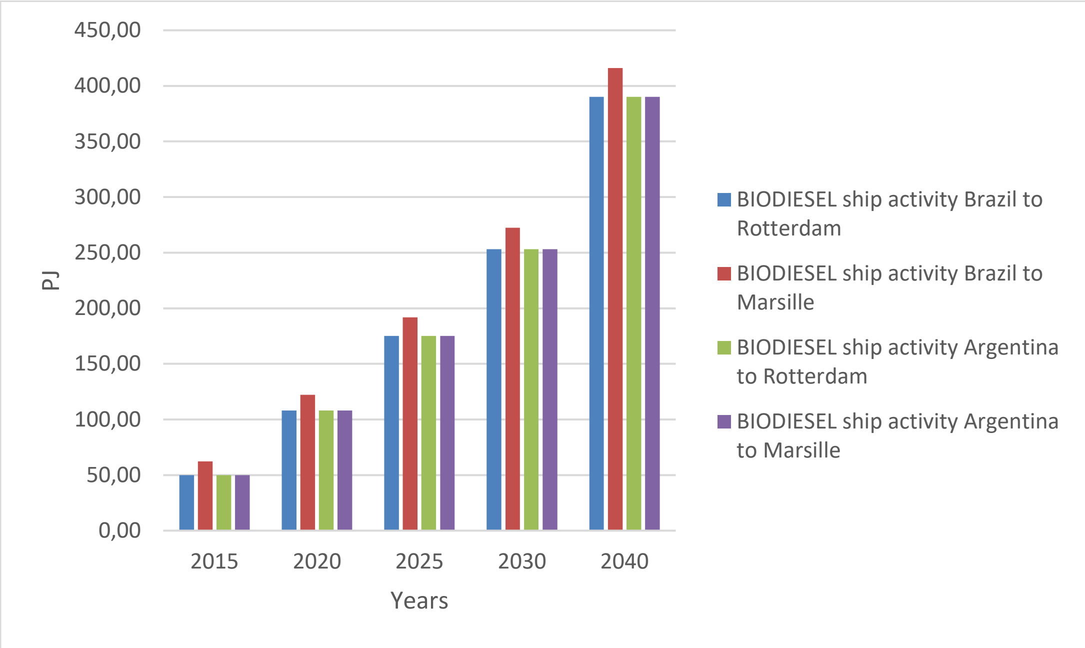


Figure 40: Biodiesel ship activity of BIO BRAZIL 2 Scenario (that is the same of that of the BASE Scenario).

The fact that the importation of CSA biodiesel to EU in BIO BRAZIL 2 scenario remains the same of the one of the BASE scenario is due to the fact that the demand for biodiesel from Europe remains the same but the production of biodiesel in CSA decreases from one scenario to another (see figure 42). So, it is justified that export not increased and it also did not decrease to satisfy the EU demand.

The ethanol ship activity begins in 2015 and its trend is not stable along the time (see figure 41). This unstable trend is due to the fact that the introduction of new process (in this case the two ships: from Paranagua' to Marsille and from Paranagua to Rotterdam) is modelled by some values of growth/decay that have the function of modulate the variations of a process along the time horizon to avoid sudden changes from one year to another to reproduce a trend as close as possible to reality.

The quantity of ethanol exported is not equally distributed into the different ships. For example, we can see in figure 41 a high peak in 2040 for the tanker that transports ethanol from Paranagua' to Marsille port. This peak is unexpected because, even if only slightly, the route Paranagua' -Marseille is the second cheapest route. The cheapest route is from Santos (San Paolo) to Marseille. However, Santos is also the only Brazilian port present in TIAM (before introducing new corridors) whose capacity has to be able to export all the rest of energy sources (in addition to biodiesel) to the ROW. So, it is not always chosen by the model, like in this case, despite being the cheapest.

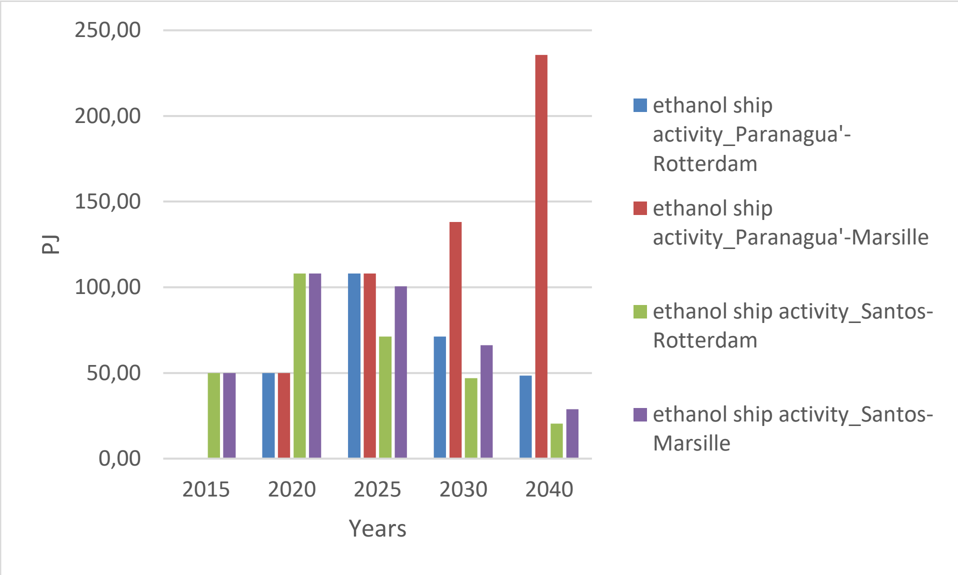


Figure 41: Ethanol ship activity of BIO BRAZIL 2 Scenario.

If we compare the total quantity of ethanol imported from CSA in the BIO BRAZIL 2 scenario with respect to that imported in the BASE scenario, we can note that in the first case it is higher. The exact quantities are showed in Table 15 (PJ).

2005	2006	2010	2015	2020	2025	2030	2040
total alceth_ship activity(PJ)_**base**							
0,00	0,00	0,00	100,00	215,93	350,32	230,89	302,80
total alceth_ship activity(PJ)_**bio brazil 2**							
0,00	0,00	0,00	100,00	315,93	387,62	322,46	333,28

Table 15: comparison between the ethanol imported from CSA in the base run and in bio brazil 2 scenario.

The higher quantity of ethanol imported by EU from Brazil in the Bio Brazil 2 scenario (1459,29 PJ VS. 1199,94 PJ) can be justified by an increment in ethanol availability at lower cost, if compared with the ethanol from the other countries of the world. Moreover, there is a country that is exporting less ethanol in EU than in the BASE scenario. This country is Africa (see Table 16). The following table shows this phenomena in term of numbers where:

- delta_BR is the increase of ethanol imported from BR, with respect to the one of the BASE scenario;
- delta_AFR is the decrease of ethanol imported from AFR, with respect to the one of the BASE scenario;
- delta_tot is the total increment of ethanol imported from the ROW with respect to the one of the base scenario.

YEARS	2020	2025	2030	2040
DELTA_BR [PJ]	100,00	37,30	91,57	30,48
DELTA_AFR [PJ]	-24,28	-26,23	-17,29	-7,51
(DELTA_BR/DELTA_TOT) [-]	1,321	3,371	1,233	1,327

(DELTA_AFR/DELTA_TOT) [-]	-0,321	-2,371	-0,233	-0,327

Table 16:Comparison between ethanol imported by EU in the base scenario and in the bio brazil 2 scenario in PJ. Increase in BR share and decrease in AFR share.

The previous Table 16 highlights that in the BIO BRAZIL 2 scenario the model increases the import of ethanol from Brazil at the expense of the one coming from Africa. In the table were showed only the years starting from 2020 because until that year the exportation is the same between the two scenarios.

The production of CSA biofuels is represented in figure 42. Biodiesel production grow up from 2005 to 2040 without falls. The ethanol production is not increasing along the whole timeline but it is higher than the biodiesel one except in 2030 where the ethanol production goes down and became lower than the biodiesel one. The same occurs in the BASE scenario but before 2030, exactly between 2020 and 2025. The decrease in production is due to a decrease in energy crop (BIOCRP) availability because the model prefers to use it to produce biodiesel instead of ethanol (it is showed in figures 43 and 44).

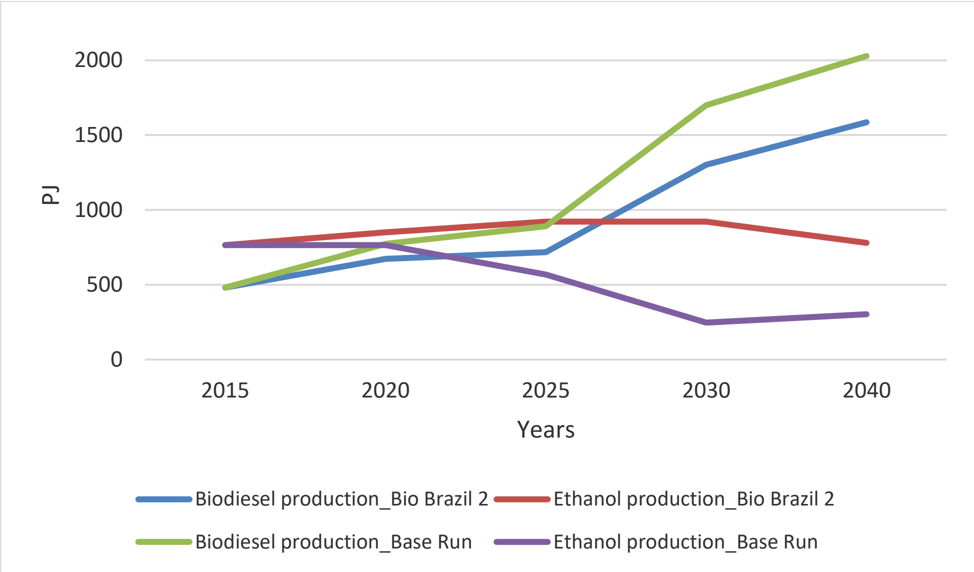


Figure 42: CSA Biofuels production, BIO BRAZIL 2 Scenario.

In figure 43 and 44 the use of energy crop (BIOCRP) in the BIO BRAZIL 2 scenario and in BASE scenario respectively is showed, differentiating the part used for the biodiesel production and the part used for the ethanol production. In Figure 34 is represented the same thing but referring to the BASE scenario in terms of percentage.

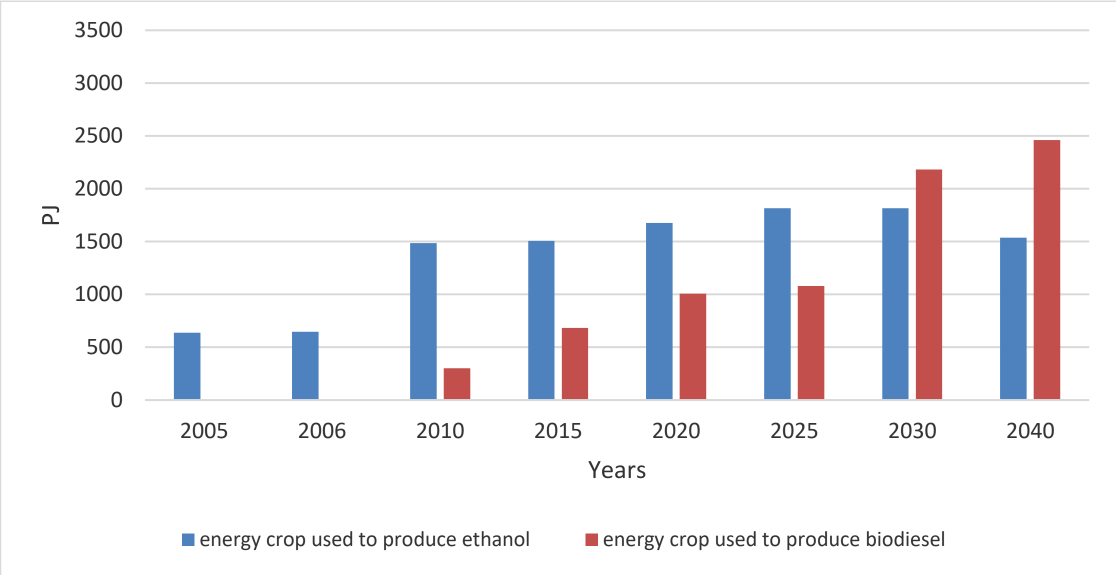


Figure 43: Energy Crop used to produce biofuel in CSA, BIO BRAZIL 2 Scenario.

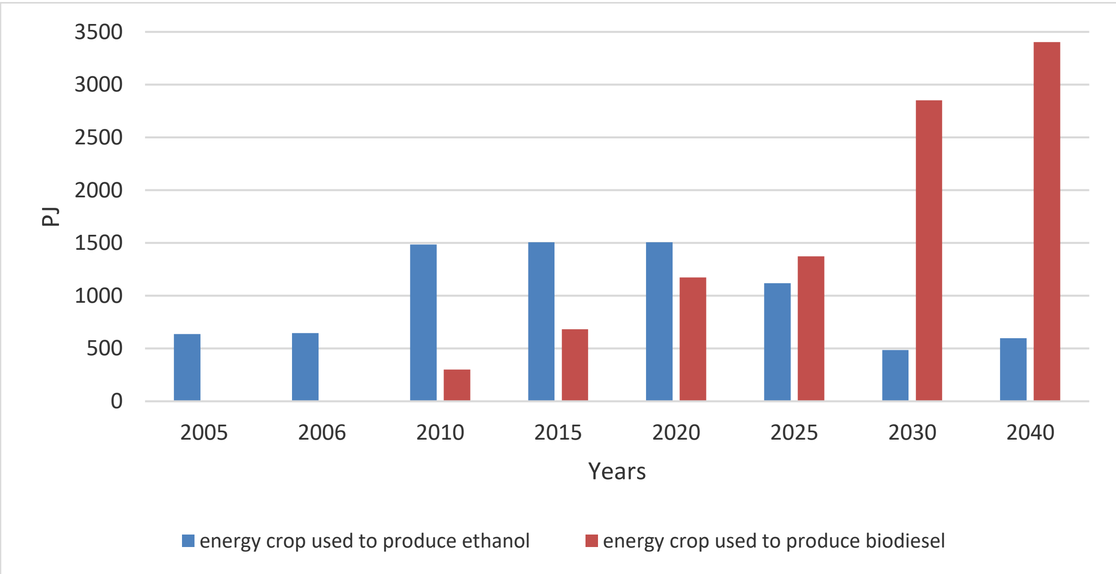


Figure 44: Energy Crop used to produce biofuel in CSA, BASE Scenario.

In figures 44 is evident that until 2020 the share of BIOCRP used to produce ethanol is higher but after this year the opposite happens. This phenomenon obviously influences the production quantities as it was explained above.

Concerning the solid biomass (BIOSLD) used to produce biofuels, the share used to produce ethanol is null (Figure 45). It means that the model chooses not to produce 2G ethanol in Brazil. Moreover, the BIOSLD is not entirely used to produce biodiesel but also for other process such as gasification (methane production from biomass), and conversion from BIOSLD to BIOBSL. Figures 45 and 46 show the BIOSLD utilization for the two different scenarios.

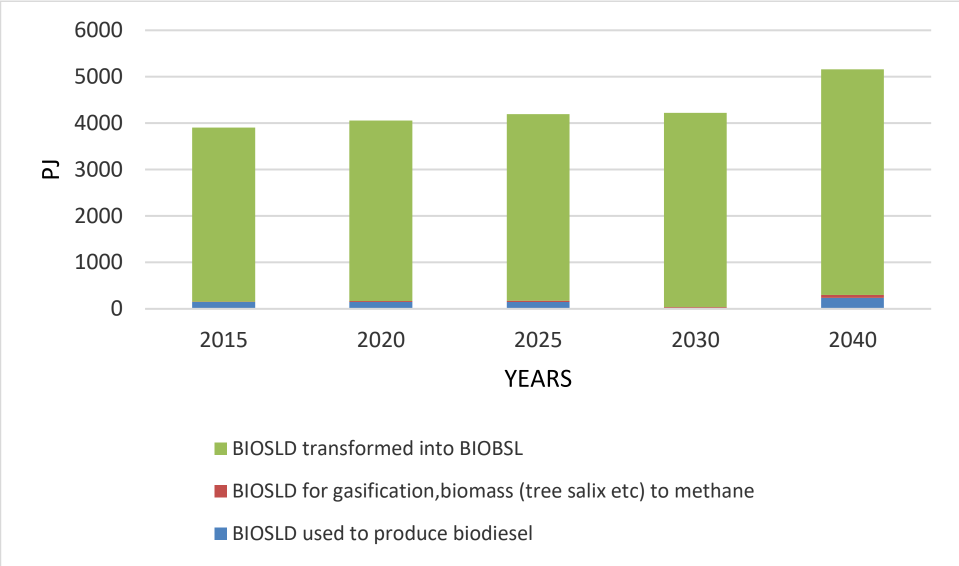


Figure 45: CSA solid biomass use, BIO BRAZIL 2 Scenario.

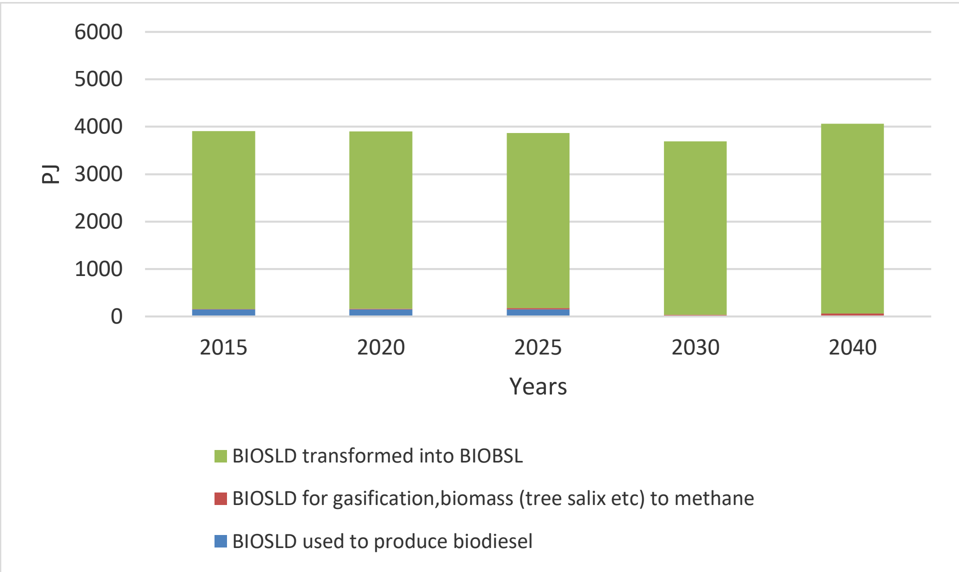


Figure 46: CSA solid biomass use, BASE Scenario.

Comparing the previous 45 and 46 histograms, the only thing that changes is the quantity of BIOSLD used to produce BIOBSL; that is a little bit higher for the BIO BRAZIL 2 scenario than for the BASE scenario, starting from 2020 up to 2040. This can be justified by the fact that Brazil starts to export pellet in BIO BRAZIL 2 scenario so also the production increase. The rest of quantities remains the same along the whole time horizon.

Finally, in Table 17 the CO_2 emissions (in ktonCO$_2$) generated by the CSA energy system in Bio Brazil 2 scenario and in Base scenario are showed where:

- Delta CO2 = (total CSA CO2 emission of REACCESS_BASE) – (total CSA CO2 emission of REACCESS_BIO BRAZIL 2)
- Total CO2_BASE is the total CSA CO2 emission of REACCESS_BASE.

Comparing the two, it is possible to see that emissions vary very little between one scenario and another. In addition to this is possible to see in the third line of the table that in 2020 and in 2025, the higher emissions occur in the BASE scenario; while in 2030 and 2040, the higher emissions occur for the Bio Brazil 2 scenario. The higher discrepancy occurs in 2040 with an absolute value of percentage difference of 0,0012%.

Scenario	**2020**	**2025**	**2030**	**2040**
REACCESS_BASE [ktonCO2]	2022241	2127956	2268621	2430406
REACCESS_BIO BRAZIL 2 [ktonCO2]	2022240	2127951	2268630	2430436
(DeltaCO2)/(total CO2_BASE) [%]	0,0000	0,0003	-0,0004	-0,0012

Table 17: CO2 Emissions of the whole CSA energy system in KtonCO2; comparison between the BASE and the Bio Brazil 2 scenarios.

6.5 INPUT DATA AND HYPOTHESIS FOR THE SIMULATION OF ALTERNATIVE SCENARIOS ("ADV" and "BIO BRAZIL 3" SCENARIOS)

After the analysis of BIO BRAZIL 2 scenario, two other sea routes were introduced in the model, which are dedicated only to the export of ethanol. These are the listed below and are shown in figure 47:

from Itaquì port to Rotterdam port;

from Itaquì port to Marseille port.

Figure 47: ethanol corridors Itaquì-EU.

The choice of adding the Itaquì port for ethanol exportation is already discussed in chapter 5.1. So, the so called BIO BRAZIL 3 scenario is done with the aim to analyse the effect of the introduction of these new sea route on the whole energy system.

The costs of these two new trades result lower with respect to the ones already present in the model because the distance of these routes is lower if compared with the others routes already modelled. So, we expect that the model prefers them at the expense of the other ones.

The distance was calculated with the same distance simulator used for the other routes [108] and all the ship's characteristics (such as costs and fuel) are the same of the others too.

In addition to including the two new corridors listed above and those introduced in BIO BRAZIL 2 scenario (in point 4 of appendix all the corridors of the scenario are listed), the BIO BRAZIL 3 scenario also considers the effects of the imposition of the Italian Decree (DM 2 March 2018) extended to all European countries. This Decree is composed by the following targets, setted for 2020:

- the minimum biofuels contribution to transport must be of 9%;
- the minimum of advanced biofuel contribution to transport must be of 0,9% of the sum (gasoline + diesel);
- the 75% of this 0,9% must be bio-methane;
- the 25% of this 0.9% must be advanced biofuels;
- after 2020 the advanced biofuels must be equal or higher than 1,85%.

The first important consideration emerges after the calculation of the biofuels share over the total EU transport energy consumption of the BASE scenario: the 9% of biofuels contribution results already reached in 2020 (see Figure 48). It occurs thanks to the CO_2 emissions limit just included in the BASE scenario.

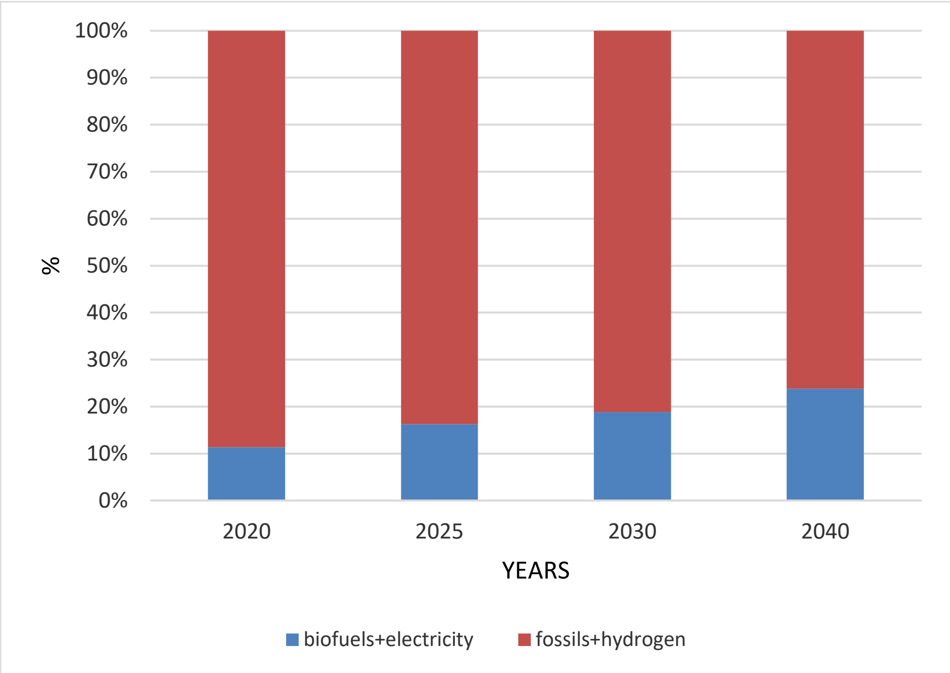


Figure 48: EU energy transport demand: percentage of fossil VS biofuels and electricity.

So, it was possible to impose all the others limits, on the use of advanced biofuels, to the EU energy mix used to satisfy the EU transport demand of the BASE scenario. Considering these values as input, another run was done and another scenario (the ADV) was created. Finally, were added all the new corridors (new with respect to the BASE scenario) to the ADV scenario and another run was done with the consequence creation of the BIO BRAZIL 3 scenario.

The main results of the ADV and BIO BRAZIL 3 scenarios are described in the paragraphs 6.6 and 6.7.

6.6 THE ADV SCENARIO RESULTS

Figure 49 shows the effects of the Italian Decree imposition for two representative years: 2020 and 2040. The green part represents the share of biofuels used in transport and it is, as expected, the higher share of renewable transport fuels. This occurs for both scenarios and for both the representative years.

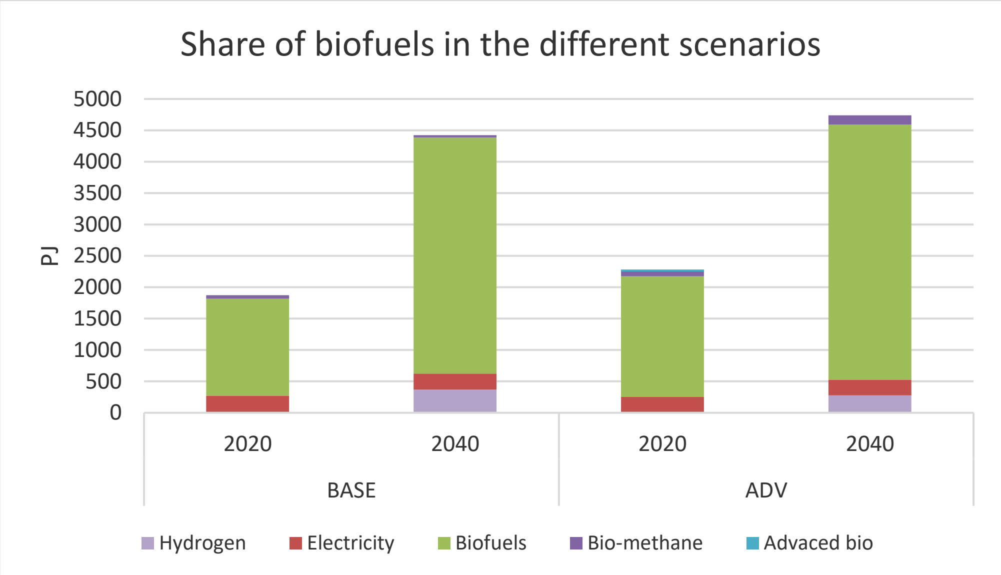


Figure 49: Share of renewable fuels used to satisfy the transport demand in EU; comparison between the BASE scenario and the ADV scenario.

In the previous bar graph, it is not so evident the share of advanced biofuels. It is justified by the fact that the percentage imposed on the total is low. If we eliminate the share of biofuels and electricity it is visible the difference between the BASE and the ADV scenario, in which the advanced biofuels are chosen by the model (because imposed) at the expense of others fuel such as hydrogen (see figure 50).

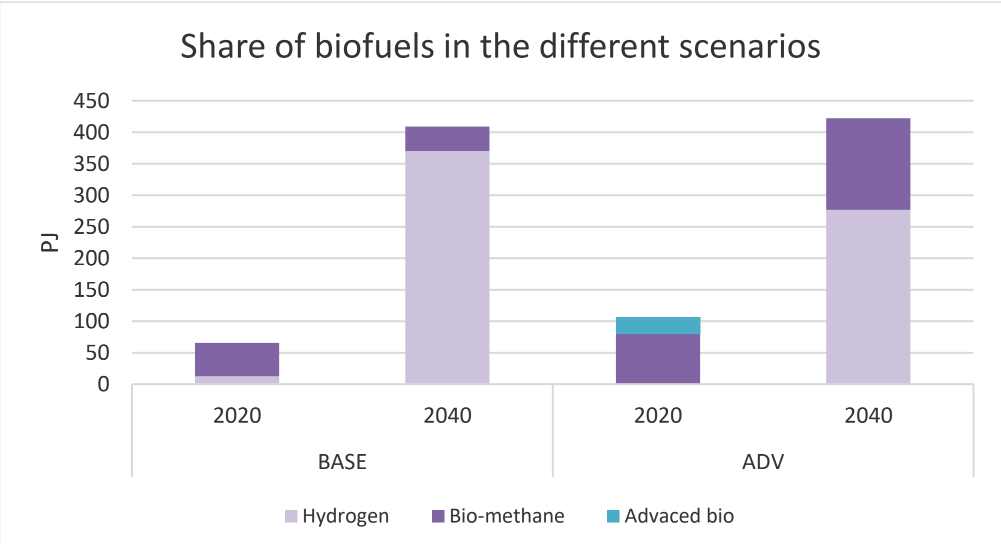


Figure 50: Share of hydrogen, bio-methane, advanced biofuels on the total fuels consumed to satisfy the EU transport demand.

In figure 50 it was eliminated the share of 1G biofuels and the share of electricity. In this way it is easier to appreciate the growth of the 2G (advanced) biofuels in the ADV scenario with respect to the BASE scenario.

However, it is important to note that if the 2G biofuels are not imposed, they may not be chosen by the model because too much expansive.

Other effects of the imposed targets are evident on the biofuels import from CSA. Figure 51 shows the trend of the ethanol and biodiesel trade from CSA to EU.

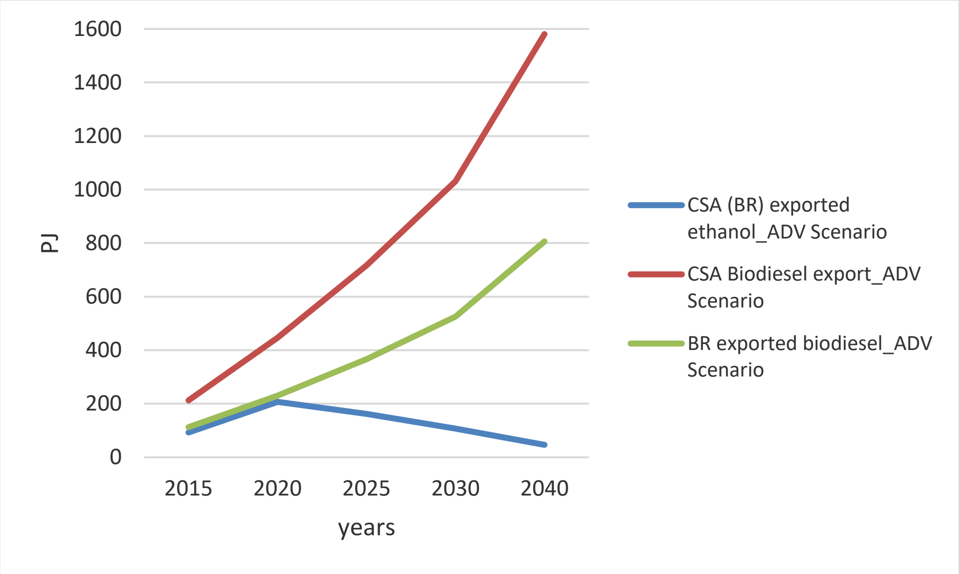


Figure 51: Biofuels exported from CSA to EU _ ADV scenario.

The import of biodiesel remains almost the same in quantity in comparison with the BASE scenario (the difference is only of about 6 PJ in 2040). It is shown in Figure 52.

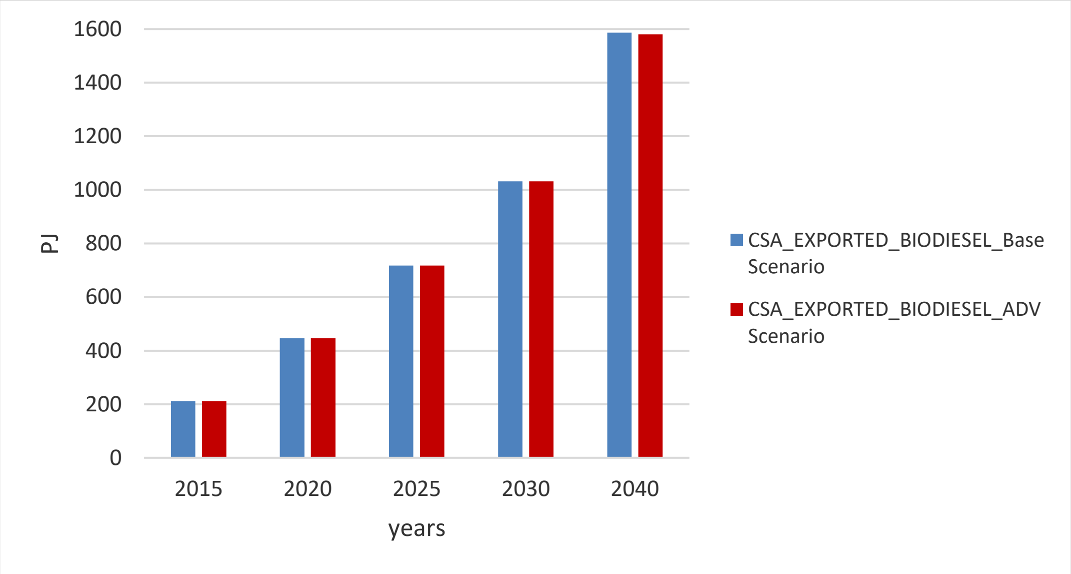


Figure 52: Biodiesel ship activity_comparison between the BASE and the ADV scenario.

It is not the same for the ethanol trade: it grows up until reaching 200 PJ in 2020 and then rapidly goes down to reach 47 PJ in 2040. Considering the total ethanol exportation, it results of only 615 PJ in the ADV scenario against the 1200 PJ of the BASE scenario.

The phenomenon is more visible in figure 53, where the blue bars represent the BASE scenario ethanol ship activity (export from CSA to EU) and the red bars represent the ethanol ADV scenario ship activity along the time.

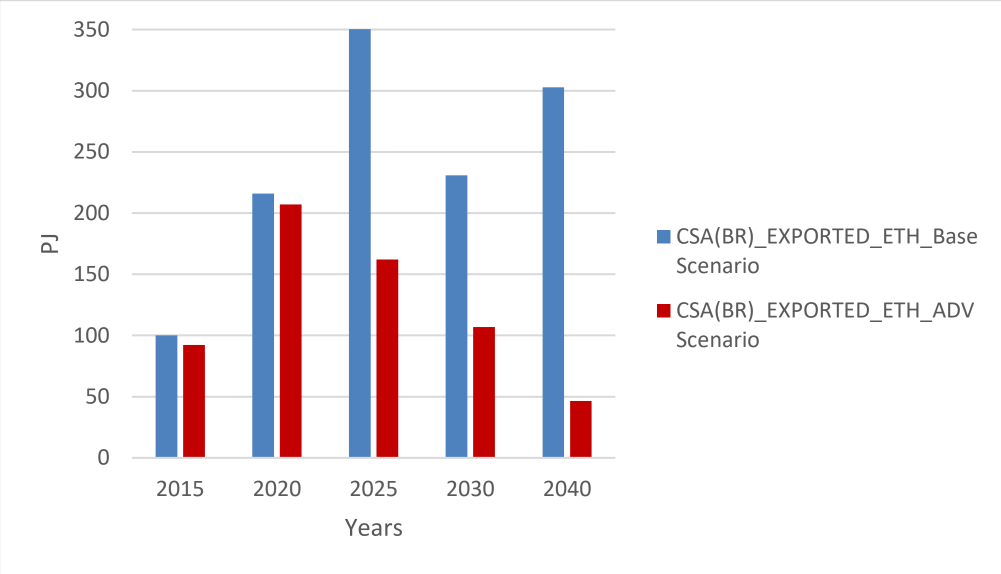


Figure 53: ethanol ship activity_comparison between the BASE and the ADV scenario.

We can expect that in future a decrease of 1G biofuels import will occur because the demand in EU became lower (as the table 18 shows starting from 2040) in favour of the introduction of the 2G biofuels.

In the ADV scenario the decrease in ethanol import starts in 2020 and it is much bigger than the one in biodiesel import (only 6 PJ in 2040). It can be justified because between the European transport technologies present in the model, the ones that use ethanol are very less than the ones that use biodiesel. In fact, the consumption of ethanol for transport in EU in the BASE scenario is only of 227.8 PJ while the one of biodiesel is of 1246.6 PJ. Also in the ADV scenario the consumption of ethanol for transport in EU is lower than the one of biodiesel. For example, in 2020, the ethanol consumed is of 266.2 PJ against 1324.2 PJ of biodiesel consumed (see Table 18).

EUROPEAN ETHANOL AND BIODIESEL DEMAND FOR TRANSPORT (PJ)			
2020_BASE		**2020_ADV**	
Biodiesel	1246.6	Biodiesel	1324.2
Ethanol	227.8	Ethanol	266.2
2040_BASE		**2040_ADV**	
Biodiesel	3398.5	Biodiesel	3372.4
Ethanol	297.6	Ethanol	283.2

Table 18: EU transport demand; BASE vs ADV scenario.

The previous table also shows that the discrepancy between the EU consumption in transport of biodiesel and ethanol grows up to 2040.

6.7 BIO BRAZIL 3 SCENARIO RESULTS

As explained in the paragraph 6.5, after the analysis of the ADV scenario were introduced in it all the seven new biomass corridors[48]. The fact that the quantity of exported ethanol has already decreased in the ADV scenario leads to think that it will decrease this time too because the same Decree is imposed and the same European transport technologies are present in the model.

As for the addition of new ships, we expect that the ships that will be chosen by the model for the trade are the ones already introduced because of its lower distance from EU with respect to the others.

Figure 54 shows the resulted trends of the three different types of biomass exported from Brazil to EU in the BIO BRAZIL 3 scenario compared with the ones of BASE scenario.

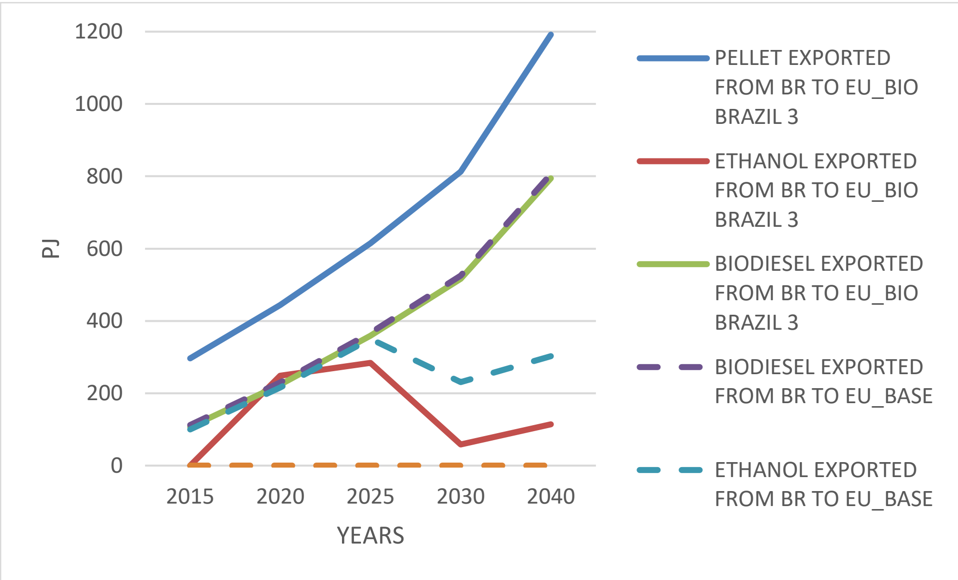


Figure 54: Pellet, ethanol and biodiesel trade from BR to EU; comparison between BIO BRAZIL 3 and BASE scenario.

The decrease of the ethanol had been foreseen. The reasons are the same already explained in chapter 6.5 in fact, even if with different numbers, the same things happen:

- with the imposition of the Decree the demand of 1G biofuels in EU becomes lower in the future so the import of 1G biofuels is expected to decrease.
- The export of ethanol decreases much more than the almost imperceptible decrease in biodiesel because the European transport technologies present in the model are always the same so the ones that use ethanol are again very less than the ones that use biodiesel and the demand of ethanol for transport in EU results much lower than the one of biodiesel.

Another thing that can be highlighted is the fact that EU ethanol import is only from Brazil, while biodiesel import is also from Argentina, USA and ODA. Consequently, could occur that the biodiesel import decrease is distributed on all these regions while the ethanol import decrease occurs only for Brazilian corridors.

[48] All the seven corridors are listed in the point 4 of the appendix.

Another relevant result was the inactivity of the following three ships:

- from Santos to Rotterdam (pellet);
- from Santos to Rotterdam (ethanol);
- from Santos to Marseille (ethanol).

This was not expected because the more expansive routes are the ones from Paranaguà port. However, Santos and Paranagua' are very near so the difference between the two routes is a few kilometres. In addition to this, the inactivity of the three ships listed above can be justified with logistic reasons as the fact that Rotterdam port is the main of EU and so its capacity is limited to be able to receive all the energy and materials imports from all part of the world. At the same way Santos is the only Brazilian port present in the model (before the addition of the new routes) and so, it has to be able to export all the other sources of energy, in addition to biomass, from Brazil to the ROW.

For the same reason, of the two ships leaving from the nearest port (Itaquì), only the one that arrive to Marseille is really used to export. While the one that arrive to Rotterdam port is used very little.

If we compare the ship activities of the BIO BRAZIL 3 scenario with respect to the ones of the BIO BRAZIL 2 scenario, we can observe that:

- ethanol export from BR decrease a lot with respect to the one of the Bio Brazil 2 scenario;
- pellet export from BR increase a lot with respect to the one of the Bio Brazil 2 scenario;
- biodiesel export from CSA (BR and Argentina) remains almost the same with respect to the one of the Bio Brazil 2 scenario.

This is visible in the following three Figures (55, 56, 57).

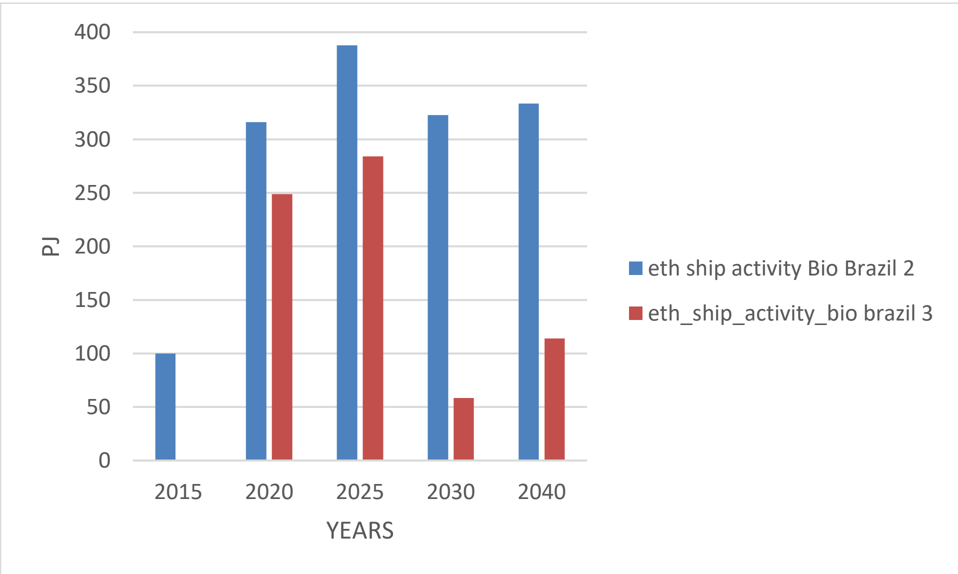


Figure 55: ethanol ship activity: comparison between bio brazil 2 and bio brazil 3 scenarios.

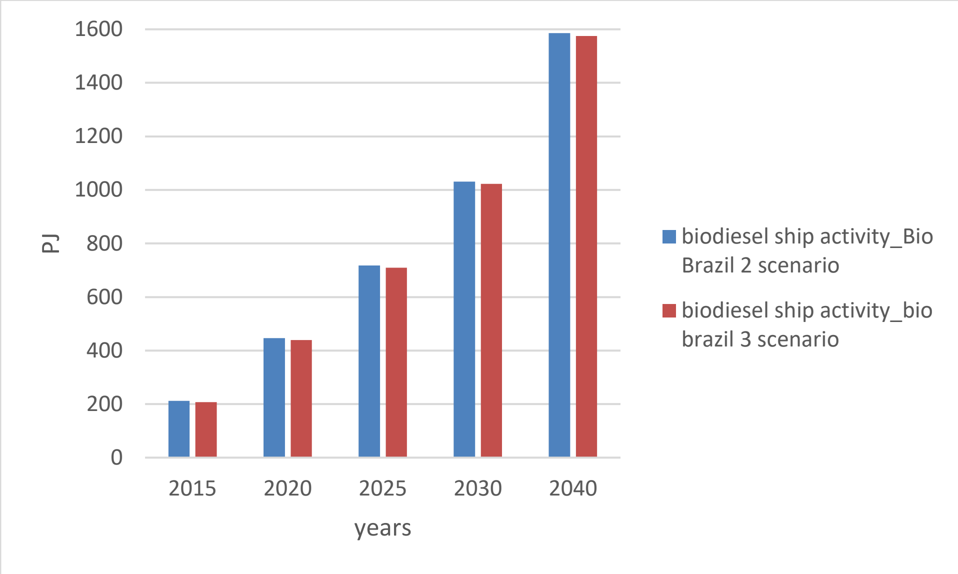


Figure 56: biodiesel ship activity: comparison between bio brazil 2 and bio brazil 3 scenarios.

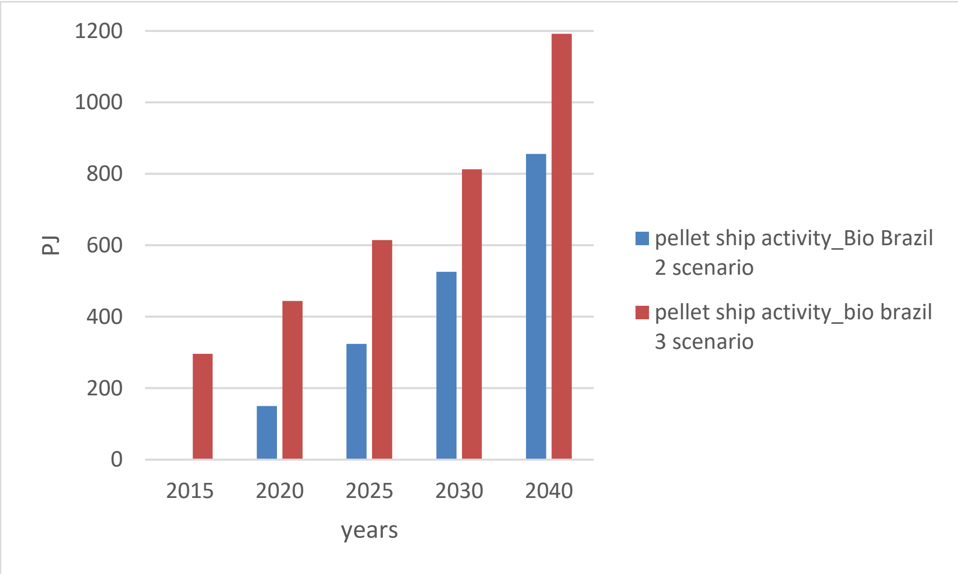


Figure 57: Pellet ship activity: comparison between bio brazil 2 and bio brazil 3 scenarios.

The activity trends of ethanol and biodiesel have already been widely discussed.

Last but not least, the fact that solid biomass import increases a lot from 2006 to 2040 and it also increase passing from the bio brazil 2 scenario to the bio brazil 3 scenario: it is a potential trade that can be taken into account because convenient as also literature suggests.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY

The analysis made in this study starts from the common interest of Brazil and European Union in exporting and importing types of energy alternative to the fossil one. In particular it was studied the possibility of ethanol and pellet trade between the two regions.

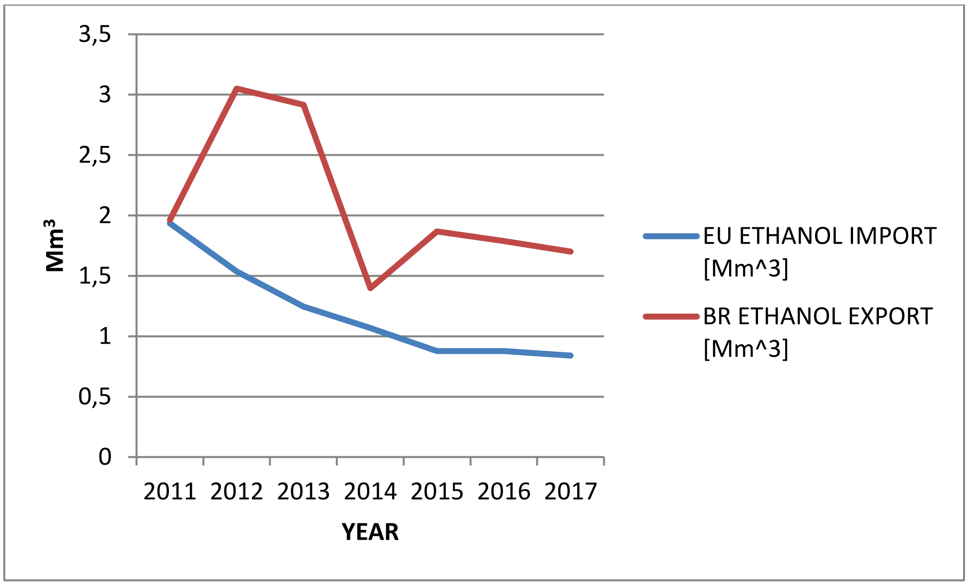


Figure 58: EU ethanol import & BR ethanol export.

Figure 58 shows the quantity of ethanol exported by Brazil to the rest of the world in the last seven years (red line) and the quantity of ethanol imported by EU in the same period (blue line). The ethanol available in Brazil has been sufficient to satisfy the European demand.

Figure 59 represents the potential of pellet exportation for Brazil (red line). It is expected to start in 2020 in which it has a big and fast growth. For the moment the production is limited to the internal market because it is still too low, but the growth is really possible. This growth surely requires investment of the whole sector, like in transport, infrastructures and export port; but if there is a suitable buyer who is interested in the import of this kind of biomass, Brazilian pellet companies are more motivated to invest. It is possible to arrive to produce 40.77 Mt of pellet in 2030 and so it was estimated an export availability of almost 20 Mt in the same year; the export of pellet can reach a quantity of almost 57 Mt in 2040. All these values came from some considerations explained in the paragraph 6.2.2.1.

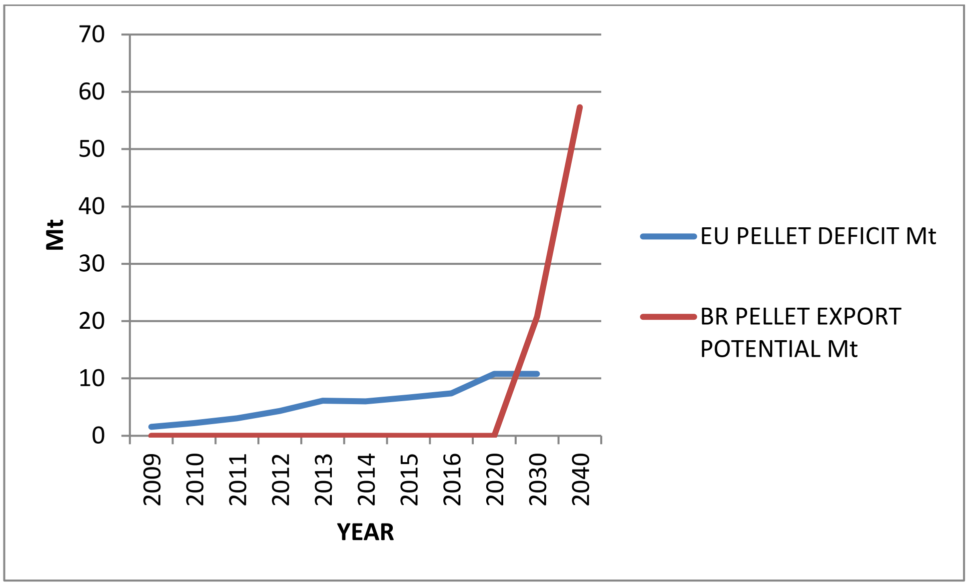


Figure 59: EU deficit of pellet & BR export pellet potential.

In the same graph (figure 59), the blue line represents the EU deficit of pellet from 2009 to 2030. EU results a suitable buyer since the quality of pellet that can be produced in Brazil meet all the characteristics required by the Enplus certification. Moreover, the European deficit of pellet is growing: it passed from 1.6 Mt in 2009 to 7.4 Mt in 2016 and it will continue to grow (in 2020 it is estimated to be 10.8 Mt [5]).

7.1.1 THE POSSIBILITY OF GROWTH OF THE BRAZILIAN ETHANOL´S PENETRATION IN THE EUROPEAN MARKET

From this study also emerges a potential of growth for the export of ethanol from Brazil to EU as it is totally competitive in the European market. Figure 60 shows on the Y axis the unit cost [US$/liters] of ethanol calculated at the port of Rotterdam starting from the Santos port, and on the X axis the quantity of ethanol [litres] exported by Brazil in 2016/17.

This representation was made for each ethanol production region. In this way it is possible to see from which region of Brazil it is more convenient to export to Rotterdam.

The values are approximate because the cost calculated does not include some port taxes and some minor insurance costs, inspection, losses, overstay that were considered negligible.

The cost at the port of Rotterdam essentially includes the cost of production and the cost of transportation up to Rotterdam. The cost of ethanol is available in the UNICA database which provides the value of ethanol per region of production without taxes (PIS, COFINS, ICMS). The cost of shipping was calculated with the Worldscale platform estimation [72].

The quantities of exportable ethanol per region also derive from the UNICA database.

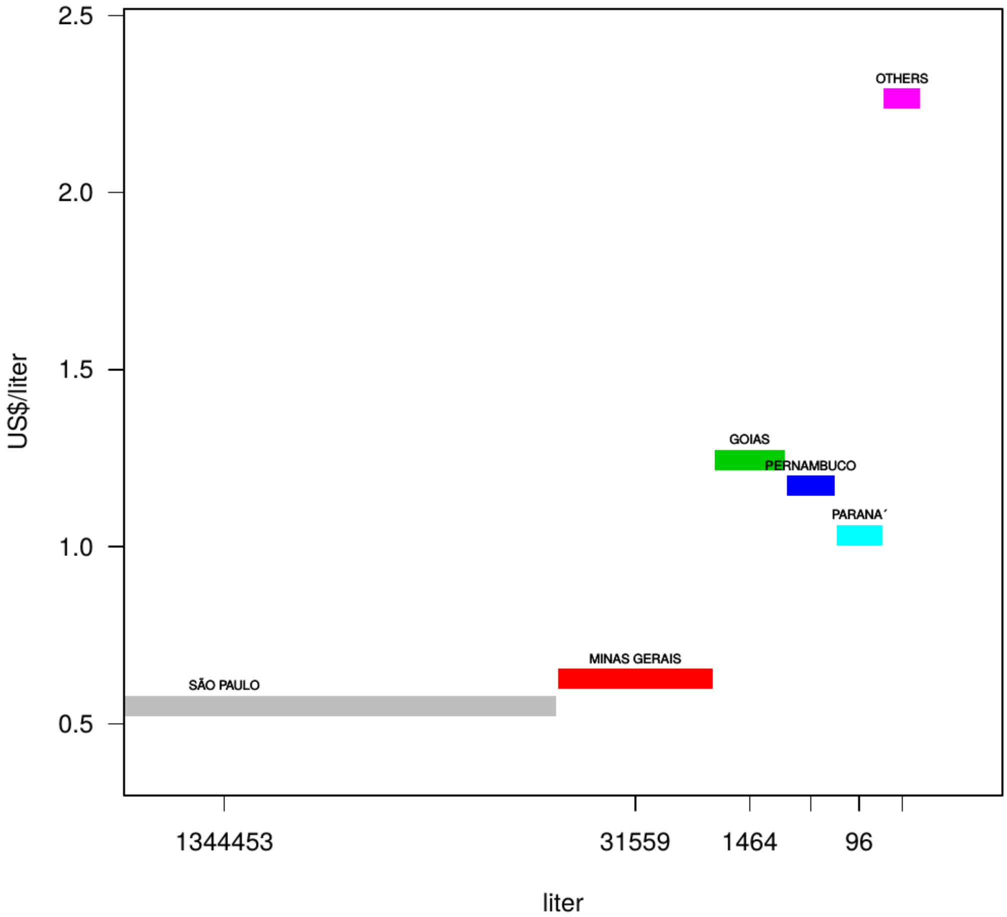


Figure 60: Ethanol export per Brazilian state of production [litre] VS its price at Rotterdam port starting from Santos port [US$/litre].[Done by the author using data from [72, 4]].

Crop year: 2016/17	ETHANOL COST AT ROTTERDAM PORT (from Santos port)					
	SÃO PAULO	MINAS GERAIS	GOIAS	PERNAMBUCO	PARANA´	OTHERS (it not included the MATOPIBA area)
US$/l(min)	0.548	0.624	1.242	1.169	1.029	2.262
US$/l(max)	0.555	0.630	1.248	1.175	1.036	2.268

Table 19: ethanol price at Rotterdam port (from Santos port).

In Table 19 the detailed cost values of Figure 60 are reported.

San Paolo emerges as the most favourable region for export to Europe. Considering that ethanol in Europe has values close to US$ 0.8 per litre [76] (E85 is sold at 0.89-1.01 US$/l [76]), the Minas Gerais region is also competitive. It should be emphasised that these two regions (the Centro-Sul region representing the 91% of production [66]) and in particular San Paolo, constitute the largest percentage of ethanol production in Brazil; therefore also in terms of quantity the market results favourable.

As it was seen in the chapter 5.1, an investment is planned in another suitable area available for sugar cane production: the MATOPIBA area. It was calculated that the potential ethanol production from that area is 22,765,000 m^3. Considering an increase in efficiency production from 6,375 to 9,000 liter of ethanol per hectare, it could reach 32,138,000 m^3. Another scenario of production was done by the MME [44]. It refers to the whole Brazilian soil and foresees a production of 35,000,000 m^3 in 2020 and of 43,000,000 m^3 in 2025.

Considering the scenario of MATOPIBA region it is possible to develop a new route of trade from Itaqui' (Saint Louis, MA) port (since it would be the nearest port to that area of production) to Rotterdam. In this way the distance to reach Europe would be less than the one starting from Santos port (almost 5 days less [104]) and consequently the cost of transport lower.

In the table 20 is reported the calculated value of maritime transport from Itaqui' to Rotterdam port and the one from Santos port to Rotterdam port:

Cost of maritime freight (ethanol)	Min [US$/l]	Max [US$/l]
Santos - Rotterdam	0.019	0.025
Itaqui´ - Rotterdam	0.014	0.019

Table 20: comparison between the freight costs of two different sea routes; Worldscale estimation [72].

Consequently, considering that the potential production quantities in MATOPIBA are high if compared with the actual exportation quantities, surely the cost of production would be almost similar to the one of São Paulo. So, the value of ethanol at Rotterdam port starting from Itaquì would be similar or lower than the ones starting from Santos port. Additionaly, it would result totally competitive with the European ethanol too.

It is interesting to remember the fast development of 2G ethanol production in Brazil. It started in 2014 and it is a sector very promising for the future. For this reason the main ethanol producers are investing a lot to improve the efficiency of this new technology [105]. This is interesting considering the needs of the EU to consume as much as possible 2G biofuels, to meet the stipulated environmental policies. The production cost of 2G ethanol are obviously higher than the ones of 1G ethanol, but is forecasted a reduction in Brazil, which will result in the sale of absolutely competitive 2G. The cooperation between Brazil and Europe is already existing. For example in 2016 a project called BECOOL between Italy and Brazil on the development of 2G biofuels, was born. Pillars of BECOOL are the creation of innovative cropping systems and crop residues, the improvement in the biomass logistics and the optimization in conversion processes of advanced biofuels for the transport sector. BECOOL is in cooperation with a project called BIOVALUE developed in Brazil; this cooperation will permit opportunities of new jobs and growth through the development of a sustainable biofuels.

7.1.2 THE POSSIBILITY OF THE BRAZILIAN PELLET´S PENETRATION IN THE EUROPEAN MARKET

Considering the cost estimations about pellet in Brazil and in Europe, results similar to those of ethanol in term of competitiveness are obtained. As seen in this study, the cost of pellet at the export port could be calculated summing to the production cost, the cost of transport to the port by truck considering a distance of 150 km. This calculation gives an approximated value of 397 R$ per ton (almost 110 US$/ton considering the actual (2018) currency change). The value at Rotterdam port will be slightly higher as it was calculated in the paragraph 6.2.3.1, (like for example 127 CIF or 150 FOB US$/ton [99]).

The lowest actual price of pellet in the European market is almost 245 Euro/ton (almost 293 US$/ton considering the actual (2018) currency change). It means that the Brazilian pellet would be totally competitive. However, it is necessary to overcome the barriers (precarious railroads, expensive freight, ports adaptable but not adapted yet, low production efficiency [63]) that hinder the export of this product from Brazil. This is not a simple process but to be aware of the gain that would be obtained if this type of trade were completed, surely helps speeding up the mechanisms of expansion of this trade.

Another issue that one has to consider is the competitiveness with the other countries that already export pellets to Europe. The most important European pellet trade is with the USA and Canada. In 2015 the USA exported 4.64 Mton of pellet to EU; in the same year Canada exported 1.29 Mt of its own pellet in Europe. According to [106, 107] the cost of Canadian pellet already transported at North Vancouver to be exported was of 104.35 US$/t.

7.1.3 COMPARISON OF SCENARIO RESULTS AND LITERATURE RESULTS

Before commenting on the scenarios results, some considerations must be underlined:

- in literature it is considered that the production is done only by Brazil and its exportation to the rest of world, while the model refers to CSA production and to CSA exportation to the EU only;

- the objective of the scenarios of this study is giving the trends of biomass export from Brazil to EU and giving an idea of potential situations linked to this trade that could occur in future;

- cost of shipping in the model are almost the same of literature ones regarding the pellet but higher regarding ethanol.

The results of the BIO BRAZIL 2 scenario related to biomass exportation differ from those found in literature (see tables 21 and 22). As the table 22 shows, only the values related to the production of ethanol in 2030 are similar because exogenously imposed.

Biomass: **PELLET**	EXPORTATION(PJ)
Year	**2030**
Scenario results	526
Literature values	360

Table 21: Comparison between pellet results of BIO BRAZIL 2 scenario and literature values.

Biomass: **ETHANOL**	PRODUCTION(PJ)	EXPORTATION(PJ)
Year	**2030**	**2030**
Scenario results	922	322
Literature values	920	60

Table 22: Comparison between ethanol results of BIO BRAZIL 2 scenario and literature values.

Values of exported ethanol of Bio Brazil 2 scenario are higher with respect to the ones of the scenario done by MME [44]. In 2030, for example, the MME study [44] foresights an ethanol export of 60 PJ, while the Bio Brazil scenario accounts for 322 PJ in the same year.

Regarding the pellet values, export projections deviate from the literature values. Export values resulted of 526 PJ in 2030, while in literature they are estimated to grow up to 360 PJ in 2030.

7.2 CONCLUSIONS AND RECOMMENDATIONS

In conclusion, even if the scenario values differ from those of literature in quantities, they remain acceptable in terms of trends because reflects the expectations. Moreover, the objective of the study, which was to simulate the biomass trade between two countries and to analyse its trend, is reached. In fact, the creation, updating and implementation of the biomass corridor from Brazil to Europe in REACCESS model was done.

The objective reached coincides substantially with the innovative contribution of the thesis because the new RECOR corridor created was implemented in the model and tested with results that met the expectations and illustrate how the new corridors behave and how the global energy system can react to the introduction of these new corridors.

The most interesting results of the work are resumed below.

The 1G ethanol import in EU is destined to decrease in future and it will happens mainly because of the European restriction on 1G biofuels. This result suggests to EU to start importing or investing in 2G ethanol. Since Brazil is at the forefront in ethanol sector, it can be a good candidate to import from.

In addition to this, it was seen that the imposition of biofuels restriction on the transport energy mix in EU allows to improve sustainability but at the same time it challenges the penetration of other fuels that would help diversify the EU energy mix, such as hydrogen.

An interesting result concerns the import of pellet from Brazil as this is a market that has not yet been developed. From the analysis, Brazil proved to be an interesting alternative to current pellet suppliers. In fact, in the BASE scenario Canada and Russia are the only pellet suppliers but in BIO BRAZIL 2 scenario (and consequently in the other scenarios) also Brazil appears as pellet supplier for EU.

If looking at the scenarios results, biodiesel export from Brazil to EU could appear convenient because its trend is increasing along the time horizon in all scenarios analysed and the quantities exported remains almost the same for all scenario. However, it is good to remember that in literature this trade is considered to be not convenient for Brazil in economic terms. Nevertheless, this can be a motivating result for Brazil which, overcoming the barriers that hinder the export of biodiesel, can consider Europe as a potential buyer.

We can conclude by saying that this scenario analysis was useful because it highlighted some aspects that can be derived from the biomass trade from Brazil to the European Union taking into account the actual environmental policies. Together with them, this study was useful to show the opportunities and challenges linked to this business which is of common interest to both regions.

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ANNEX

1. Picture with the potential area for biomass production for wood pellet.

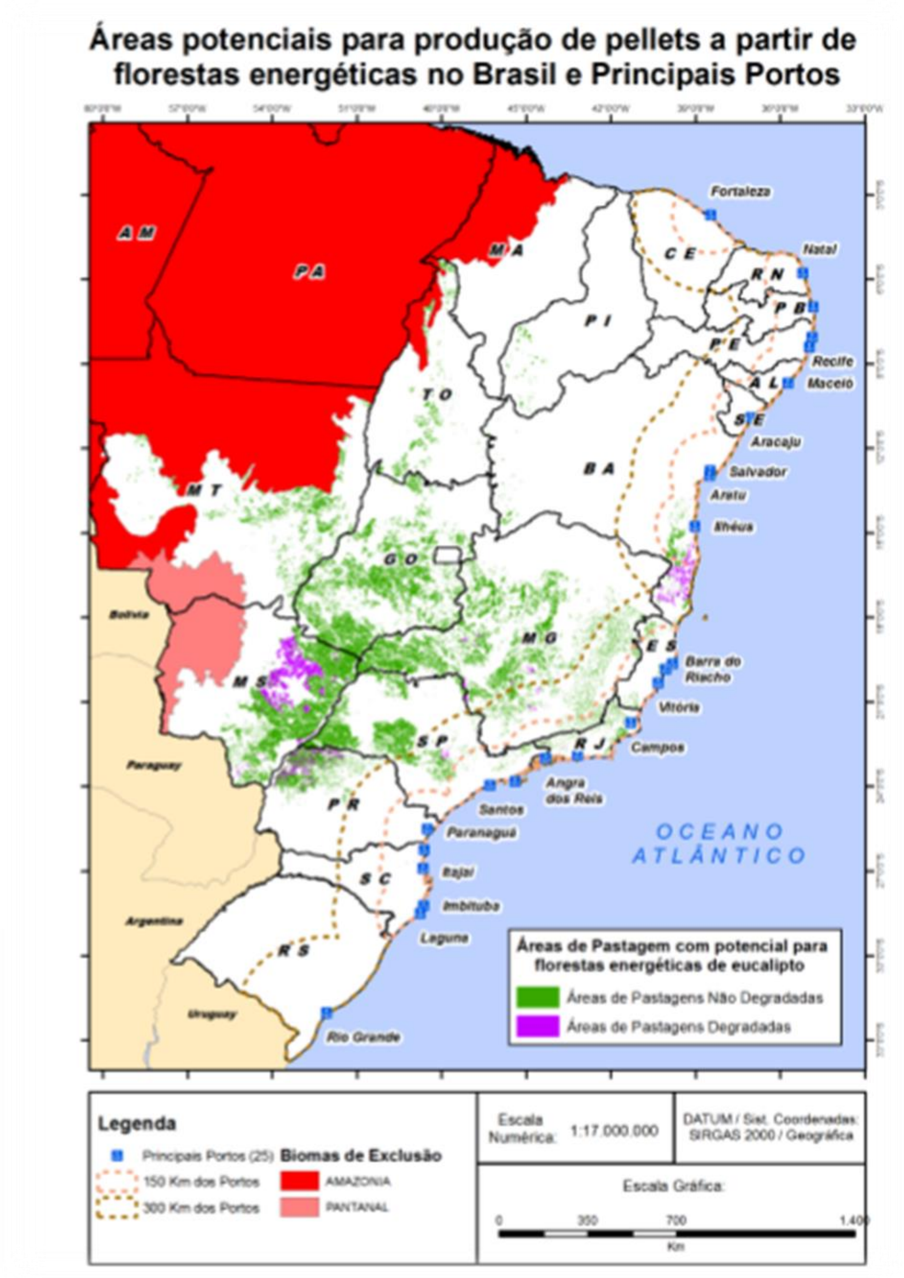

Figure 4: potential areas for eucalyptus short rotation forests and potential ports for pellet export, [2].

2. The whole table with the ENplus and ISO certification is avaible on line: ENplus Handbook, Part 3 - Pellet Quality Requirements, Quality Certification Scheme for Wood Pellets, 2015.
   The following table representes a comparison between the ENplus (pellet for residential use) e the ISO (pellet for industrial use) requirements (only the ones that are on limit because the rest are in line with ENplus and ISO), with the brazilian wood pellet characteristics [38]:

Norma e Padrão do pellets combustível		Unidade	Cloro (Cl)	Enxofre (S)	Teor de cinzas
Uso residencial	*(Enplus)* -A1	w-%	≤ 0,02	≤ 0,04	≤ 0,7
	(Enplus) -A2	w-%		≤ 0,05	≤ 1,2
	(Enplus) -B	w-%	≤ 0,03	≤ 0,05	≤ 2,0
Uso industrial	*(ISO18122)* -I1	w-%	≤ 0,03	≤ 0,05	≤ 1,0
	(ISO18122) -I2	w-%	≤ 0,05		≤ 1,5
	(ISO18122) -I3	w-%	≤ 0,06		≤ 3,0
Pellets de madeira brasileiro	*Pinus ssp.*	w-%	≤ 0,02	≤ 0,04	≤ 0,3
	Eucalyptus ssp.	w-%	0,02 ≥ 0,1	≤ 0,05	≤ 0,5
	short rotation Eucalyptus ssp.	w-%	0,02 ≥ 0,1	≤ 0,05	≤ 2,7

3.

3.a Explication of the acronyms of the ethanol and biodiesel production chain

SURLAND 1= surplus of agricultural land, cost 1

SURLAND 2= surplus of agricultural land, cost 2

UBioCropProd1= energy crop production, cost1

UBioCropProd2= energy crop production, cost2

MINBIOCRP0=crop production

BCRPETH101=production of ethanol from starch and sugar crops

BWOOETH101=production of ethanol from woody biomass

BZWOOETH110=production from woody biomass with CCS

MINBIOSLD1=production of solid biomass- low price

MINBIOSLD2= production of solid biomass- medium price

MINBIOSLD3= production of solid biomass- high price

UBioWoodResidue=Agricultural and forestry residue

UBioWoodSupply=Wood for energy

BZWOOFTDST110=FT- diesel production from woody biomass with production of CO2

BWOOFTDST110=FT-diesel production from woody biomass

BVEGME101=transesterification of vegetable oils

BIOVEGOIL=vegetable oil

BCRPVEG101=vegetable oil extraction from energy crops

3.b The main properties (attributes) with their own TIAM´s code and description:

ACT =ACTIVITY

CAP =CAPACITY

NCAP =NEW CAPACITY

ACT_COST=ACTIVITY COST

NCAP_COST=NEW CAPACITY COST

NCAP_FOM=NEW CAPACITY FIXED COST

NCAP_TLIFE=NEW CAPACITY TECHNICAL LIFE

NCAP_AF=NEWCAPACITY AVAILABILITY FACTOR

ACT_EFF=ACTIVITY EFFICIENCY (it defines the amount of activity that can be produced by one unit of flow of a commodity or commodities on the shadow side of the process. The shadow side of a process is the side opposite to the side of the primary group (PCG). ACT_EFF cannot be used for storage or trade processes, [iea-etsap.org/docs/TIMES-VDA.pdf])

VDA_FLOP=VEDA FLOW PARAMETER (it defines the amount of flow of commodity per unit of process activity, or the sum of the flows of the commodities in the commodity group per unit of process activity, [iea-etsap.org/docs/TIMES-VDA.pdf])

4. The list of ships that transport biomass from **Brazil** to EU already present in RECOR (Base run) are:
   - BIO_SHP_07: ship that transports biodiesel from São Paulo (Santos port) to Rotterdam; 10056 Km
   - BIO_SHP_08: ship that transports biodiesel from São Paulo (Santos port) to Marsille; 9384 Km
   - BIO_SHP_09: ship that transports ethanol from São Paulo (Santos port) to Rotterdam; 10056 Km
   - BIO_SHP_10: ship that transports ethanol from São Paulo (Santos port) to Marsille; 9384 Km

   New ships wrt the Base run (Bio Brazil 2 run):

BIO_SHP_0001	Corr(BIOWPL) Brazil (Santos) to Netherlands (Rotterda) [];10056 Km
BIO_SHP_0002	Corr(BIOWPL) Brazil (Paranagua´) to Netherlands (Rotterda) []; 10030 Km
BIO_SHP_0003	Corr(BIOWPL) Brazil (Salvador) to Netherlands (Rotterda) []; 9190 Km
BIO_SHP_00011	Corr (ALCETH) Brazil (Paranagua´) to Netherlands (Rotterdam) [];10030 Km
BIO_SHP_00012	Corr (ALCETH) Brazil (Paranagua´) to France (Marseille) [Gibraltar]; 9644 Km

   New ships wrt the Base run (Bio Brazil 3 run):

BIO_SHP_0001	Corr(BIOWPL) Brazil (Santos) to Netherlands (Rotterda) [];10056 Km
BIO_SHP_0002	Corr(BIOWPL) Brazil (Paranagua´) to Netherlands (Rotterda) []; 10030 Km
BIO_SHP_0003	Corr(BIOWPL) Brazil (Salvador) to Netherlands (Rotterda) []; 9190 Km
BIO_SHP_00011	Corr (ALCETH) Brazil (Paranagua´) to Netherlands (Rotterdam) [];10030 Km
BIO_SHP_00012	Corr (ALCETH) Brazil (Paranagua´) to France (Marseille) [Gibraltar]; 9644 Km
BIO_SHP_00013	Corr (ALCETH) Brazil (Itaquì) to Netherlands (Rotterdam) [];7647 Km
BIO_SHP_00014	Corr (ALCETH) Brazil (Itaquì) to France (Marseille) [];7206 Km

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