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Transport Network Optimization for Wood Pellets from Brazil to Europe

by

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Abstract

As biomass trade starts to emerge in the international arena, this market starts to gradually take its form. Many rules to standardize the biomass market are relatively new or still absent. New opportunities but also new challenges emerge with the increased presence of biomass in the global trade market. Biomass is the oldest source of energy in the world and also the only energy source that can provide energy in a continuous base. Apart from that, Biomass is one of the energy sources that has made the gradual decrease of world's dependency on coal and petroleum possible. Despite the strong advantage of being a clean energy source and able to increase security of energy supply, its peculiar characteristics makes the gradual swap from fossil fuel to biomass a difficult task. Its low-density, expensive densification process and costly transport logistics makes biomass supply expensive. Governmental incentives and schemes supporting the use of biomass is so far the most efficient way to make this commodity competitive.

The main objective of this thesis is to find the most cost efficient transport network of the proposed route. Apart from that, this thesis also aims to set a hierarchical framework for the transport network of wood pellets from Brazil to Europe. Brazil, the origin country is expected to become a frontrunner in the wood pellet business. All the necessary conditions to become a major producer of wood pellets are present in Brazil: Climate, land availability, availability and low cost of its working force and conversion technologies. The final destination, Northwest Europe is a region that has become one of the main wood pellet consumers in the world. For the Port of Amsterdam, the ambition to become one of the main hubs of Biomass, stimulates initiatives to investigate the real prospects of Brazilian pellets export to Europe.

Despite all technology improvements, densification costs for wood pellets still represents a big share of pellets final price. This thesis revealed that approximately 53% of final pellet costs in Brazil is represented by production cost. The other 47% is determined by logistic costs. Production costs are identified to be around $76/ton, Road transport in Brazil $20/ton, Brazilian Port costs $5/ton, Ocean maritime costs $35/ton, European Port costs $5.5/ton and Barge for pellets distribution into Europe $3/ton. These figures were calculated taking into consideration a handymax ship carrying 47.000 tons of pellets.

On the logistics side, road transport and ocean transport costs have been found as the two main components helping to increase pellets final price. Coastal location of pelletizing plants is a determining factor of supply chain profitability. Moreover, all the Transport Networks proposed face trade offs as a form to become more cost efficient in transporting wood pellets to Europe. By improving one aspect of the network, another aspect worsens. The average cost for ready to burn and delivered wood pellets in the Brazil-Europe route were found to be ranging from $142-173/ton. Finally, from all Transport Networks introduced Multiport Network was accessed as the most cost efficient network.

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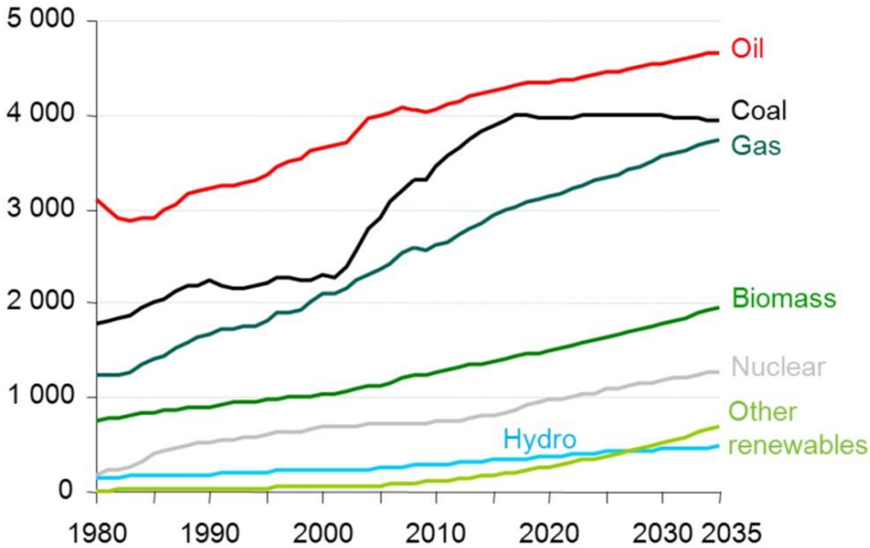
Chapter 1- Introduction

1.1 Background and Problem Scope

In the face of insecurity of oil supply the international community have been forced to adapt to the use of sustainable energy sources. Events as the first and second oil crisis have woken up international community for the problem of oil dependency and pushed for the diversification of energy sources. Further, the problem is aggravated by the increased oil price instability caused mainly by political unrest in oil producing countries. Added to the uncertainty of oil supplies, the emergence of environment concerns translated into national, regional and international policies has contributed to a gradual swap from conventional sources of energy to sustainable ones. The combination of these factors has resulted in the emergence and growth of bioenergy trade (Schlamadinger, 2004).

In order to diversify energy supply and as an attempt to switch consumption to more environmental friendly alternatives, other sources of energy have been gradually arisen. Wind, solar, hydro and biomass are some of the popular sources of renewable energy nowadays.

Figure1- Energy Commodities World Consumption and Forecast



Source: IEA WEO, 2010

Statistical indicators have shown a gradual growth of renewable source within the energy mix. Oil and coal will remain as the main source of energy in the short term. Nevertheless, the growth of these commodities starts to slightly slow down, while consumption of biomass and other renewable sources tends to rise (Figure 1).

Since 2000 the market for renewables has grown increasingly and the forecast is of continuous growth. Solar, wind and biomass energy are clean-energy source created as a form to not only decrease dependency on the dominant sources of energy, but also to decrease green house gases emissions. Biomass is CO2 neutral once the carbon emitted by wood combustion is compensated by the photosynthesis done by these trees during its lifecycle. The five basic categories of biomass are virgin wood, energy crop, agricultural residues, co-products, municipal waste and industrial waste.

Biomass as source of energy starts to become more competitive as a result from government incentives towards green energy. Despite the fact that such regulations tend to increase biomass competitiveness, biomass is still an uncertain market. Added to that, due to its wide ranges of types and considering biomass as a relatively new commodity being internationally traded, there is still a lack of a standardized code (harmonized code) able to cluster all biomass products in a compact group. Apart from this problem, sanitary barriers, lack of global sustainability criteria and absence of global standardization are some of the main challenges faced by biomass global trade.

Kyoto Protocol has been able to create a framework, which limits the emissions of green house gases in the atmosphere by its signatory's members. Regionally the so-called 20/20/20 target created by the European Commission has demanded climate and energy targets to be reached by European members until 2020. Apart from green energy provider, biomass has been referred as possible solution for problems as population and urbanization increase, as they are not finite sources as coal or petroleum. Therefore, many governmental incentives to increase demand of biomass as renewable energy such as mandates, feed-in tariffs, trading of green certificates, cap-and-trade systems, subsidies and taxes have been adopted by some nations (Schlamadinger et al, 2004).

Countries with adequate conditions for biomass production have great opportunity to trade their biomass globally. Besides Canada and USA, Brazil is expected to play an important role in the global trade of biomass. Brazil counts with favorable conditions for the production of biomass: climate, rainfall, land availability, availability and low cost of its working force and finally biomass conversion technologies (Walter et al, 2012). Nowadays Brazil generates 157 million cubic meters or 38.6 million tons of forest residues per year (Oliveira, 2012).

As biomass demand increases internationally, high logistics costs end up by hampering potential trade gains. A wide range of literatures have discussed the importance of transport cost and transport infrastructure (Limao et al.,1999; Sanchez et al., 2003; Ximena et al., 2004; Martínez-Zarzoso et al., 2009, Haddad, et al., 2010). As defended by Goldman Sachs, "Infrastructure is a key determinant of economic growth potential."

Transport infrastructure bottlenecks are in many cases the main reason for low levels of international trade practiced by a country. Furthermore, Ximenas (2004) showed in her studies that an increase in transport costs from the 24% to 74% means a 25% decrease in bilateral trade. Further, Sanchez revealed the correlation between inefficiencies in port infrastructure and high transport costs.

1.2 Objectives and Relevance of the topic

Even tough many studies address logistics and supply chain matters and particular facility location problems, few studies have been conducted in terms of developing a solid biomass transport network not limited to location problems. As biomass use tends to grow rapidly and due to the limitation of various countries in the production of self-sufficient sources of energy, countries will be forced to import even bigger amounts of biomass. Europe's forest resources directed to energy use are nearly fully utilized (Heinimo et al, 2007), whereas in 2011 in Brazil 6.5 million hectares (1.5 times the size of The Netherlands) of planted forests were already in place. Added to that, Brazilian eucalyptus plantation reaches an average productivity of 41m3/hectares per year (ABRAF, 2011). Therefore, Brazil has been showing great potential to become one of Europe mean wood pellets supplier.

Transport network optimization studies have being introduced in others literatures. Alfred Weber (1909) first introduced the location theory in order to minimize distance between warehouse and clients. Since then many other authors focus their studies on warehouse location to minimize network cost (Kuehn et al., 1963; Tanse et al 1983; Brandeau et al., 1989; Owen et al., 1998).

Frombo (2009), Eksioglu (2009) and Feng (2010) have presented a model to determine quantities, size and location of power plant and bio-refineries in order to optimize their biomass supply chain. Junginger (2010) in his paper called Opportunities and Barriers for international Bioenergy trade recognized the logistics process as one of the main bottleneck faced by countries when exporting their biomass.

As most of forest biomass goods are formed by low-density parts (chips, briquettes, pellets) freight transportation over a certain distance can add excessive costs to final good price, transforming it in a very unprofitable business. Recently several authors have applied in their studies mathematical models to study biomass' supply chain and logistics issues, showing the increase cost of logistics when concern to biomass trade (Wang et al, 2007; Huang et al, 2008; Rentilezas et al., 2009; Fuzhan et al., 2009; Van Dyken et al, 2010; Wan Yan et al, 2010; Mobini et al, 2011).

This thesis will initially present a detailed analysis of the costs involved in the transport of Brazilian biomass to Europe, followed by the introduction of Transport Network options. In order to be able to optimize the transport costs of wood pellets into Europe, each supply chain component is to be individually assessed. A framework is to be developed by identifying concrete opportunities to improve trade costs through minimizing the total logistics costs for the network, and finally achieving a highly cost-efficient network. This thesis will focus on the study of the wood pellets in particular, considering Brazilian wood pellets production potentialities and due to wood pellets representative trade into Europe.

UK, Netherlands, Belgium, Germany, Italy, Scandinavian and Spain are foreseen as the main European consumers of biomass until 2020. It is looking at the perspective of European consumption of Brazilian wood pellets that the Port of Amsterdam, a frontrunner in the energy segment leads the initiative towards Brazilian Biomass trade as a potential booming market. Following this idea, Brazil a imminent strong player in the field of biomass and the Port of Amsterdam the forth biggest port in Europe have a good opportunity to strength its relation and take advantage of the biomass trade into Europe. This thesis will approach in a broader sense the opportunities and challenges of the Brazilian pellets export into Northwest Europe.

1.3 Research Question

In light of the possible issues hampering the Brazilian exports of wood pellets to Europe and Port of Amsterdam's ambition plan to become a vital biomass hub in Europe, this thesis main objective is to answer the following research question:

What are the main transport network options of Brazilian wood pellets into Europe and how to design a transport network to optimize logistics costs for this route?

Adding to that, in order to set the basis for this research and be able to answer the above research question the following sub-questions are proposed:

1. What are the prospects for the Brazilian wood pellets market in Europe?
2. What are the main challenges to biomass international trade?
3. Which are the main drivers of pellets supply chain cost components?
4. Which are the main costs in the Brazil-Europe pellets transport network?
5. Can logistics costs in this route be reduced by the introduction of maritime concepts as Hub-and-Spoke and Multiport networks?

1.4 Methodology

In order to optimize pellets trade from Brazil into Europe, a twofold analyses will be deployed in this thesis. Firstly, an extensive literature review of previous works, interviews and market information will form the analytical methodology of this thesis. In a second moment a quantitative approach will be introduced. From the data collected the author proposes a model formulation for pellets transport network design in this route. A framework for transport network optimization is to be developed in order to assess the most cost-beneficial network to be adopted.

1.5 Structure

This thesis consists of five chapters. In Chapter 1, a summary of the background, problem scope, objectives and relevance of the topic, research question and methodology is presented. In Chapter 2 a short introduction of the Biomass market, types of biomass and explanation of the reasons biomass is back in vogue is done. In Chapter 3 an overview about the main topics concerned to wood pellets market is showed in order to set the basis for the detailed study of the pellets transport network: main market players, trade patterns, transportation, index and trade challenges. Chapter 4 introduces the Brazilian wood pellets scenario. The challenges and opportunities to export are also introduced. Chapters 5 focus on the main methodology to be implemented in this thesis. First, each component of the supply chain is in detail presented together with the main costs drivers of each component. After that, the author introduces a called "Base Case" to introduce specific costs in this route for a particular case. In the Transport network Design Options several possible transport networks from Brazil to Europe is showed in order to be able to select the most cost efficient one through real costs calculations and finally create a framework for Transport Network. The methodology objective is to minimize the total logistics costs for the network by creating a criterion to be considered when exporting the Brazilian biomass to Northwest Europe. Finally, a case study of a potential Brazilian pellets exporter is also introduced. Chapter 6 presents thesis key findings and results. Moreover, limitation to the research and suggestions for future research is also presented.

Chapter 2- Biomass Market

2.1 Introduction to Biomass

Biomass includes all decomposed matter from plants or animals capable to generate energy, fuel or heat in a sustainable way. The term was first use in the field of ecology to describe the mass of living organisms (Vossos, 2012). During their life cycle plants capture carbon dioxide through photosynthesis, what is accumulated in their system in form of energy. Animals as well accumulate energy in their organisms by ingestion of plants. Part of the energy captured by plants is released during combustion what can generate energy.

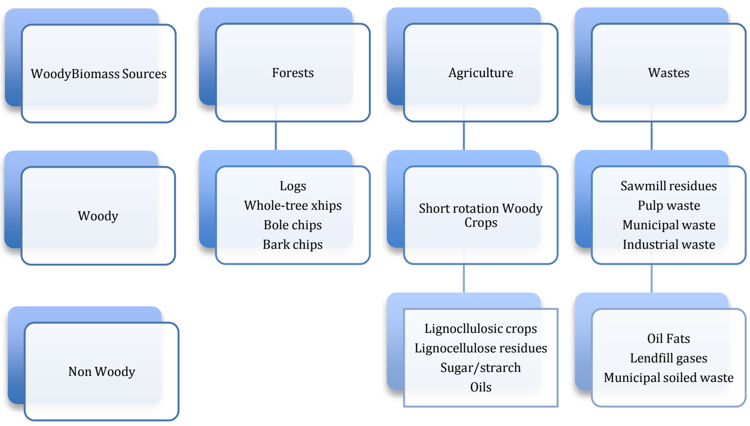
Being of biological origin and mostly with high water content, biomass needs to be transformed into a homogeneous, compact and dry content in order to facilitate its transportation and combustion. Crops and agricultural residues are mostly transformed into chips, pellets, briquettes or direct into biofuels.

Biomass has been traditionally used for heating and cooking, nevertheless its popular use is in the generation of energy and as vehicles fuel. The biomass that generates electricity for industrial, commercial or residential purpose can be either combusted alone or co-fired with natural gas, coal or other fuels. Combined heat and Power system (CHP) is an efficient energy system, being able to produce electricity and heat. The heat waste generated by electricity generation is used for heating in spite of being released into the environment.

For electricity generation biomass feedstock is normally burned in boilers producing high-pressure steam able to run the turbines connected to the electric generators (Bioenergy Network, 2012). To convert biomass into gas or liquid fuels normally used in the transport sector, the biomass goes through conversion process, such as fermentation, gasification, torrefaction, pyrolysis or transesterification.

Biomass originates from three main sources: agriculture, forest and wastes, which can be woody and non-woody. The five basic categories of biomass are virgin wood, energy crop, agricultural residues, co-products, municipal waste and industrial waste (William, 2010) (figure 2).

Figure 2- Sources of Biomass



Source: Williams, 2010

2.2 Main Biomass Types

2.2.1 Forest Biomass

Forest biomass mainly originates from dedicated forest crops (energy crops) or from sawmill residues. The most common forms of woody biomass are wood pellets, briquettes and chips. Wood pellets are most of the times produced from dry sawdust, which is then compressed under high pressure. Pellets for industrial use are usually in a 10-12 mm size and with a lower than 10% energy content. Its ash content varies as per standard requirement and is a signal of high energetic content. These requirements assure the high quality of pellets: clean, dry and free of contaminants materials.

Wood briquettes are very similar to wood pellets, however briquettes are larges than pellets. Briquettes are generally 60-150mm of length and 50-100mm of diameter. They are considered of better quality material than wood logs. However, its voluminous characteristics and therefore low-density makes transportation over long distances very complex and expensive. Briquette size makes it a less attractive biomass for long distances international trade.

Wood chips can be made from wood residues, sawing residues, short rotation forestry and forest in general. Its dimension is 20-50mm with an average of 25% moist content. The main challenges for this type of biomass are caused by its big volume of approximately 200kg/m3 (Cox, 2003). Storage, handling and transportation are the main difficulties face by chips. Wood pellets require three times less space for storage as chips with the same energy content. They should be stored under cover with good airflow and maximum stacking height of 9 meters. The European standard, CEN/TC 335, have been working on the creation of a standard for chips trade in order to guarantee minimal moisture content and absence of fines for efficient burning (Biomass Energy Center, 2008).

2.2.2 Agriculture Biomass

Agricultural crops are normally non-wood material, however as in the case of fast growing tree species, wood can also be an agriculture crop (Williams, 2010). Agricultural crops can be dedicated or not to the bioenergy market. The non-dedicated crops are the ones planted for other purposes than bioenergy, nevertheless the waste generated from these crops can also be use for bioenergy. The most common source of dedicated agricultural bioethanol source is corn, wheat and sugar cane, while vegetable oils is the main source for biodiesel.

The majority of the plant matter is cellulose, hemicellulose and lignin, which are made up of chains of sugars. Bioenergy is generated by the break of these chains into fermentable sugar. Sugar, starches, non-woody lignocellulosic and woody lignocellulosic are the four types of agricultural crop components which can generate bioenergy (Williams, 2010).

The main issue surrounding agriculture crops as source of bioenergy production is the long lasting discussion over fuel vs. food. On the one hand, conventional crops can be the source of food, feed and bioenergy and on the other hand it is about the allocation of earth. The allocation of earth goes to the production of the good which receives superior financially compensation from markets. In 2007, agricultural commodity prices raise immensely causing food shortage in developing countries.

This issue ended up by focusing on the use of food crops for the production of bioenergy by the international community. Several factors could be used to explain the food crisis in 2007: high oil prices, developed countries subsidies to agricultural prices, growing population with an increasing demand for food and fuel and use of lands originally used to food production to the ethanol market (Williams, 2010).

2.2.2.1 Biofuel

Biofuels are derived from biomass. Biofuel is normally produced from plant sugars, starches, vegetable oils or lignocellulose material fermentation and it is the main alternative for gasoline and diesel. Like other types of biomass, biofuel has also been the focus of international community. Energy security and government subsidies have triggered biofuel global trade. In 2002, global biofuel used in transportation reached 0.33 EJ and it has been in continuous growth (Heinimo et al, 2007).

Bioethanol and biodiesel are the two main types of biofuels. Bioethanol is made from fermentation of feedstock such as corn, wheat, sugarcane, sugar beet and other crops, while biodiesel is made from animal fats or vegetable oils. Both can be used in its pure form for engine fuel, however they are commonly used as a fuel additive to reduce engine carbon dioxide emissions. In 2008, global ethanol production was 67 billion liters. Brazil and USA are the world's largest ethanol producers, producing together 91% of 2008's global production. In 2008, USA and Brazil generated an output of 34 billion liters and 27 billion liters respectively. European Union is the main producer of biodiesel, responsible for 53% of world's biodiesel production in 2010 (Junginger et al, 2010).

2.2.3 Municipal Waste

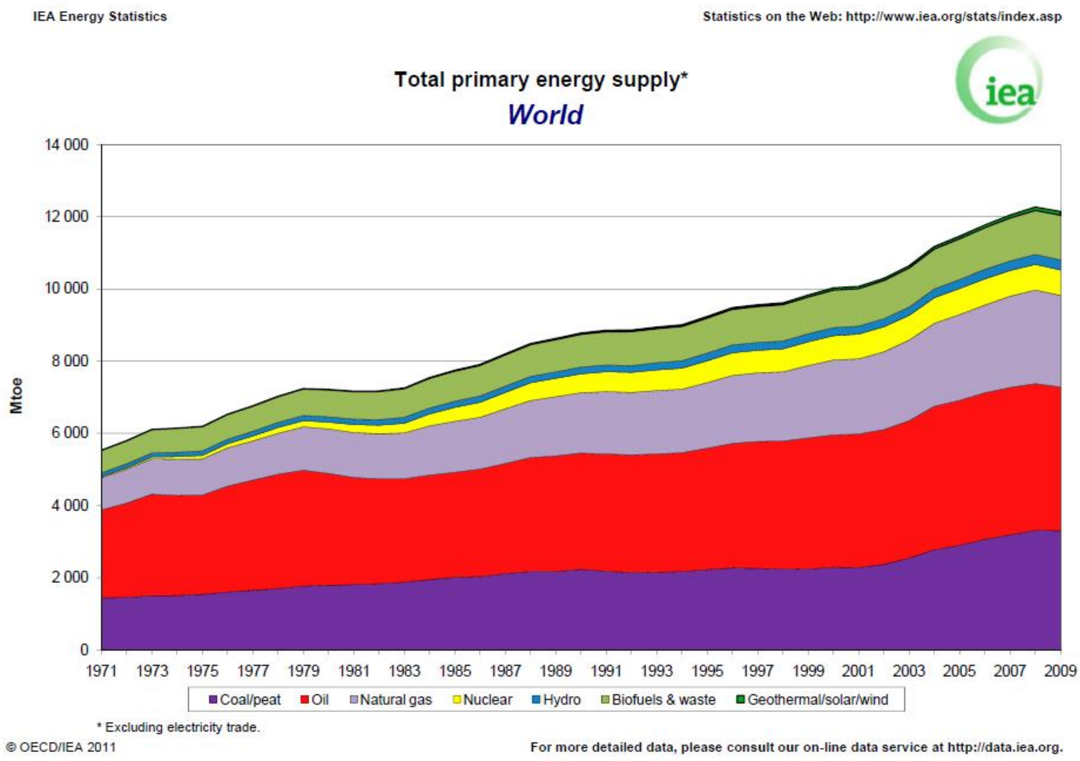
Waste biomass can come in a liquid or a solid format. A big share of waste biomass is solid. For instance, plastic, which is mostly made from petroleum is a huge source of energy. Power plant systems fueled by garbage is an expensive business and therefore less competitive than coal firing. However, combustion of waste brings several advantages. Apart from being less pollutant than coal, it also makes use of an energy source that otherwise would be lost. Combustion of garbage also contributes to solve the problem of landfills disposal.

2.3 Biomass back in vogue

Some forms of biomass have been used by mankind since man discovered fire, further environmental concerns is hardly a new topic. Until the 19th century biomass energy accounted for 70% of global consumption of energy, while nowadays its use is reduced to a minor 10% of world's energy consumption. Nevertheless, renewable energy is expected to reach until 80% of global demand by 2050 (Cocchi et al., 2011).

Biomass consumption started to slow down in the 19th century mainly in developed countries, as biomass continues to be an important source of energy in rural and small communities in developing countries. Cooking and heating were the main use of biomass in that period because lack of incentives to make usage of biomass for energy production competitive. Currently, a new biomass trend seems to emerge in the international field, however with strong orientation towards energy production (figure 3).

Figure 3- World Energy Production



Source: IEA, 2011

Since the two-world oil crisis the use of biomass and biofuels for energy production rose considerably. Some countries have been famous for their forerunner conduct. This is the case of Brazil and Sweden. Brazil's strong commitment to the developing of sugarcane ethanol industry settled its example toward the early use of renewable energy for fuel. In 1975, the country introduced the Pro-alcool scheme, which introduced a minimum percentage of 25% of ethanol to be blended with gasoline for flex-fuel cars (Moraes, 2010). Since the oil shock Sweden have also leaded the path towards diversification of energy. The fact that a big part of Sweden's total area is covered with forests, allowed the country to become one of the world's largest wood pellets producer.

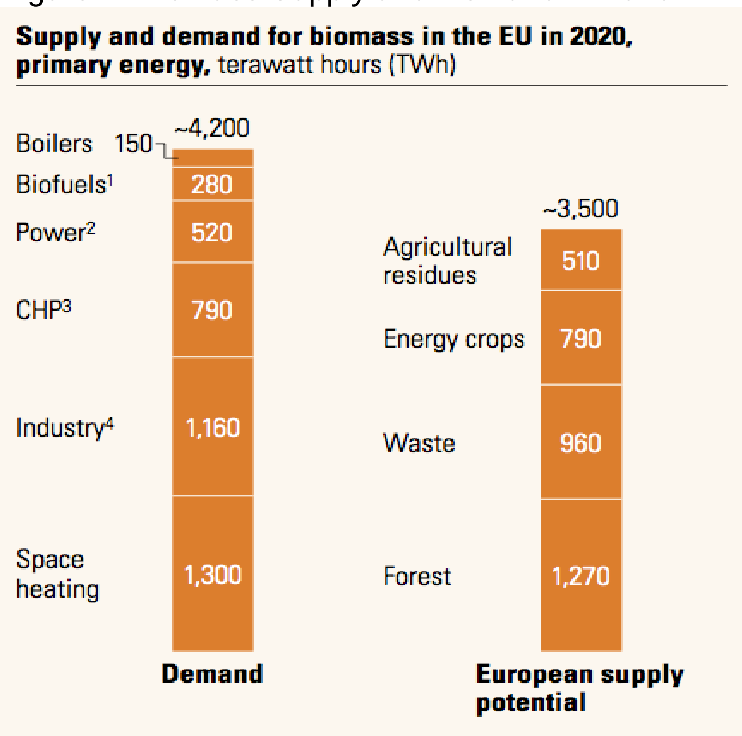
Additionally, despite old concerns about environmental issues (green movements trace back to the 19th century) for many years political issues and privileges for big oil companies prevented biomass development. Only after the Second World War the cost of environmental negligence started to become clear and a green mentality become more evident within countries.

In 1997 the ratification of Kyoto Protocol inserted a more pragmatic reasoning on the international agenda. Signatory countries have committed themselves to greenhouse gas emission reductions. European Union has accorded on an 8% reduction, while some countries, as Greece and Spain have not committed to any reduction. As countries are bound to achieve these targets, national rules tends to strongly enforce compliance of companies to these norms. Co-firing techniques become available and power plants co-firing practices start to become more common (IEA Newsroom, 2012).

Nowadays, there is a huge expectation that biomass will become one of the main sources of energy in the world. In 2020 renewable electricity will be responsible for approximately 30% of EU electricity production, while biofuel consumption for fuel for road transportation is expected to rise to 10% (Heinimo et al, 2007). The IEA's projection to 2030 is that demand for global energy will reach 16,5 billions tep (the petroleum ton equivalent), what also supports the intensification of bioenergy consumption (Green World, 2011).

McKinsey research in 2008 showed a complete report for biomass' demand in different sectors in Europe. A total of 4.200 TWh (or 861 million tons) was foreseen as European total consumption of biomass for 2020 (figure 4).

Figure 4- Biomass Supply and Demand in 2020



[1]Excluding ~220 TWh food crops for 1st generation biofuels.
[2]Cofiring and condensing biomass.
[3]Combined heat and power plants.
[4]Forest/pulp and paper ~1,100 TWh; other industries 60 TWh.

Source: McKinsey, 2008

As biomass becomes more popular in Europe, regional supply of biomass has been increasing but not in the same speed as demand. Therefore, consumption of biomass imported from outside Europe is expected to increase enormously.

Chapter 3- Wood Pellets

3.1 Introduction

Wood pellets are usually made of dry and untreated wood waste pressurized into pellets (Junginger et al, 2007). Pellets are originally produced as a by-product of other industries as Paper and Pulp or Timber industries. The sawdust, shavings or ground chips generated during production by these industries now have a new purpose and that is to feed the furnace of big power plants and Combined Heat and Power Plants. Nowadays, with the rising environment concerns and policies supporting it, dedicated pellet plants for wood pellet production have been introduced to the market.

Wood pellet is a form of biomass, which is a biological material derived from organisms. Plant biomass is a vegetable derived material composed of organic molecules and carbon. The carbon present in plants is absorbed by the plant during photosynthesis through its life. The electricity generated in Biopower plants is coming from biomass combustion. Pellets are directly burned in biopower boilers generating high-pressure steam, which finally runs electricity generators (Bioenergy Network, 2012).

The advantages of wood pellets as a source of renewable energy has gradually been recognized by the international community. Its main advantage as of any kind of biomass is its carbon neutral characteristic. Unlike coal, the carbon emitted by wood combustion is compensated by the photosynthesis done by these trees during their lifecycle. Another advantage is the administration of waste. The wood waste directed to the production of energy is used instead of thrown away. Third, on the contrary of other renewable sources as wind and solar sources, biomass and wood pellets are a continuous source of power and not intermittent in nature. Another good advantage is that when compared with other renewable energy sources, biomass has a lower capital investment. Finally, the easy availability in most parts of the world makes pellets an easy to find source of energy (Green World, 2011).

3.2 Main Market Players

Wood pellets foremost market players include main producers and main consumers of biomass. Sweden, Canada and the USA are the world's largest producers of wood pellets. In 2006, European annual production of wood pellets accounted for 4,5000,000 tons. In the same year, pellets consumption in Europe reached around 5,500,000 tons (IEA Bioenergy Task 40, 2007). Austria, Italy, Germany, Estonia, Latvia, Russia, Poland and Denmark are other EU members with good potential for wood pellet production.

USA

USA is considered to be one of the main potential wood pellet exporters. There is a particularly rapid increase in wood pellet production in the southern region of the country. This could be explained by the incentives given by American government to green energy sources. However, these incentives are much more focused on production of biomass for electricity generation domestically then on biomass produced for export purposes. A second reason of the rapid growth of the pellet production in the US could be the fact that pellet production is a good manner to direct its non-economic wood sources to wood pellets as a by product. Nevertheless, the main reason for the USA's constant increase in the number of pellet plants dedicated to export are the new policies emerging in European countries to ensure Europe to meet their 2020 renewable energy targets (McLellan, 2012).

Nowadays there are over sixty wood pellet plants within the USA. Currently, US wood pellet production capacity is 4.9 million ton (McLellan, 2012), while 4 million ton is expected to be southern USA's capacity for direct export. Two of the world's largest wood pellet plants are located in the USA. Georgia Biomass and Enviva Biomass are two strong American pellet producers each with a output capacity of around 750,000 tonnes per annum (tpa).

Finally, big European power plants as RWE, E.ON and Electrabel have started the vertical integration by investing in their suppliers in order to secure their pellets supply. The German utility RWE have currently invested 120 million euros in Georgia's Biomass plant in the south of US. E.On and Electrabel have both signed long term contracts with Enviva Biomass to supply respectively 240,000 tpa and 480,000 tpa wood pellets (McLellan, 2012).

Transatlantic wood pellets trade originated in the USA is currently a growing business. The challenge to make pellets at a price that can compensate the long and pricy transatlantic journey has so far been successful.

Canada

Despite Canada's vast plantations of pine forest and current strong pellet export, Canada has some constraints regarding the development of its pellets industry. Until 2006, Canada had around 23 pellet plants, accounting for the production of 1,400,000 tones wood pellets per year (IEA Bioenergy Task 40, 2007). Canada's forests are concentrated in the western part of the country what meanss longer distances to the European markets then from the eastern part of the country. Western Canada is responsible for exporting over half a million ton of wood pellets per year. Added to that, the high amounts of pellets originated from Canada can be explained by the low performance of Canadian timber industry. In the past, over 8.5 million hectares of forest directed to the timber industry were affected by a pest, what has created the perfect opportunity for the export of Canadian pellets to Europe (IEA Task 40, 2007).

Another aspect of the Canadian pellet industry is that Canada itself consumes pellets nationally due to the country's national plan towards sustainable economic growth. Canada has formally rectified the Kyoto Protocol in 2002. Canada have announced its target for reducing green gas emissions until 2012 to be of 6% lower than 1990's figure. Nevertheless, pellets in Canada are mainly used for heating and its consumption was still below 150,000 tons in 2006 (IEA Task 40, 2007).

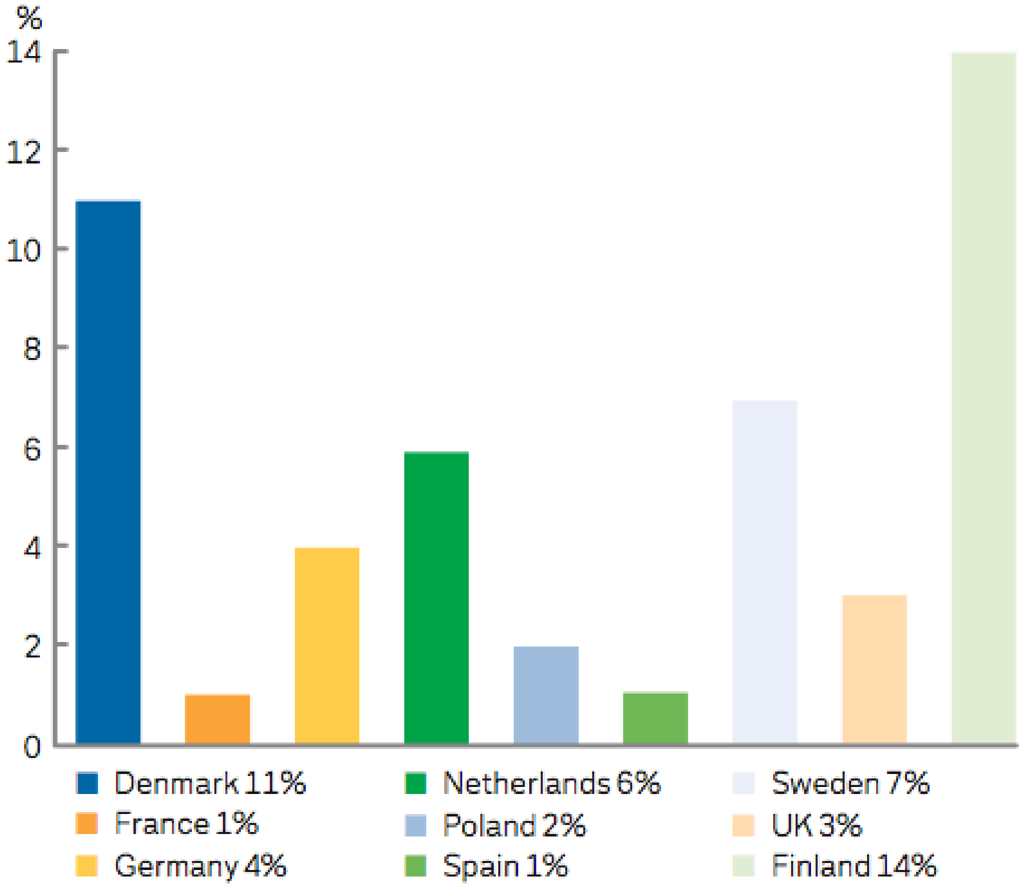
Sweden

Sweden is a good example of how national subsidies for pellet production can stimulate the industry. Since 1992, when the Swedish government presented a tax on the use of fossil fuel, the country has seen a rapid growth in pellet production. In 2003 the Swedish government introduced a green energy certificate system. The implementation made production costs of pellets decrease so much so that pellets became more competitive than fossil fuels. Following the changes of the green energy rules, Stockholm Energy, Sweden's major utility, decided to invest in a large-scale pellet plant for its own production.

Sweden is currently the largest wood pellets producer in Europe. In 2010, 1,700,000 ton of wood pellets were produced in Sweden. Despite its high production capacity, Sweden's national consumption, which is mainly directed to the heating sector, is very high. While 1,575,000 tons pellets were produced in 2009, the national demand for pellets reached 2,300,000 ton (Svebio, 2011).

Finland, Denmark, Sweden, Netherlands, Belgium and UK are the main consumers of wood pellets for energy in Europe (figure 5). Netherlands and Belgium mainly use pellets in co-firing Utilities, while Denmark, Finland and Sweden's pellets are directed to the Combined Heat and Power Plant (CHP). In other European countries as Germany and Italy pellets are mainly used for cooking and heating.

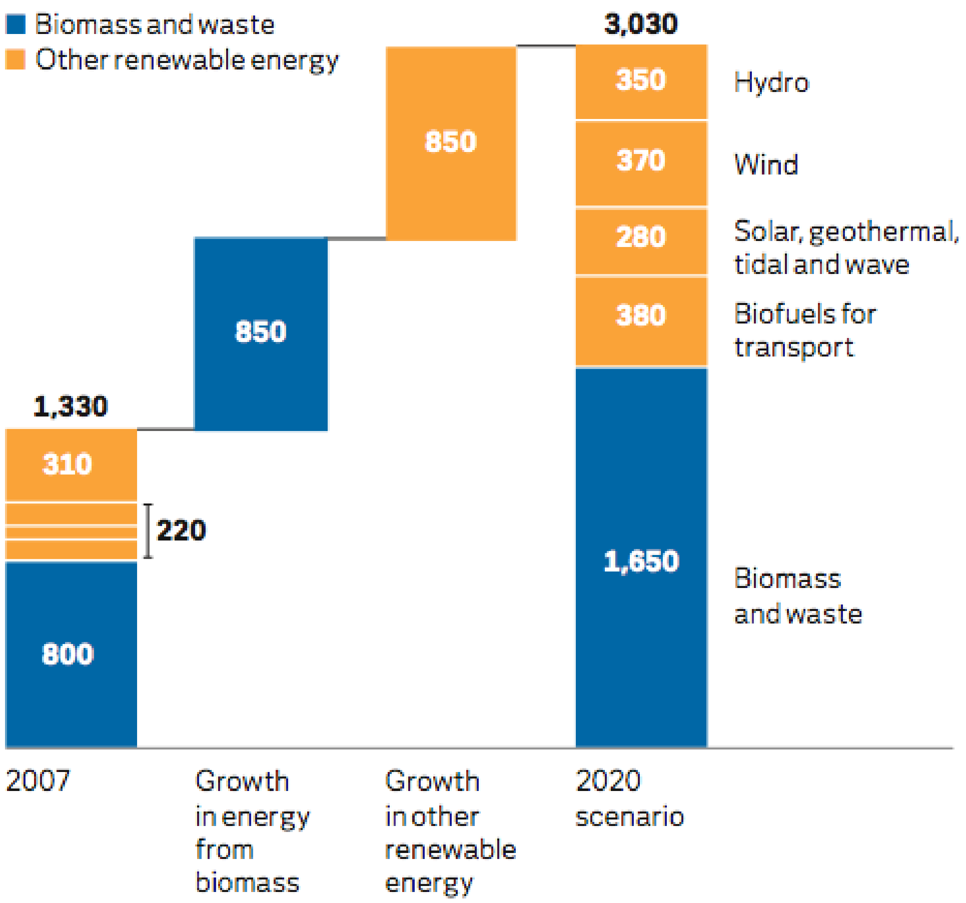
Figure 5- Share of Biomass for Electricity Generation in 2008



Source: IEA Statistics, Electricity Generation 2010

Further, it is foreseen that with the signature of Kyoto Protocol and the implementation of the 20-20-20 target of EU, new potential consumers of wood pellets in Europe tend to emerge. The scenario foreseen for 2020 in Europe can be seen in the below graphic (figure 6). Until 2020 the share of only biomass and waste in EU's energy portfolio will be more than a half, 54,4%.

Figure 6- Biomass' Role in meeting Europe's Renewable Energy Targets

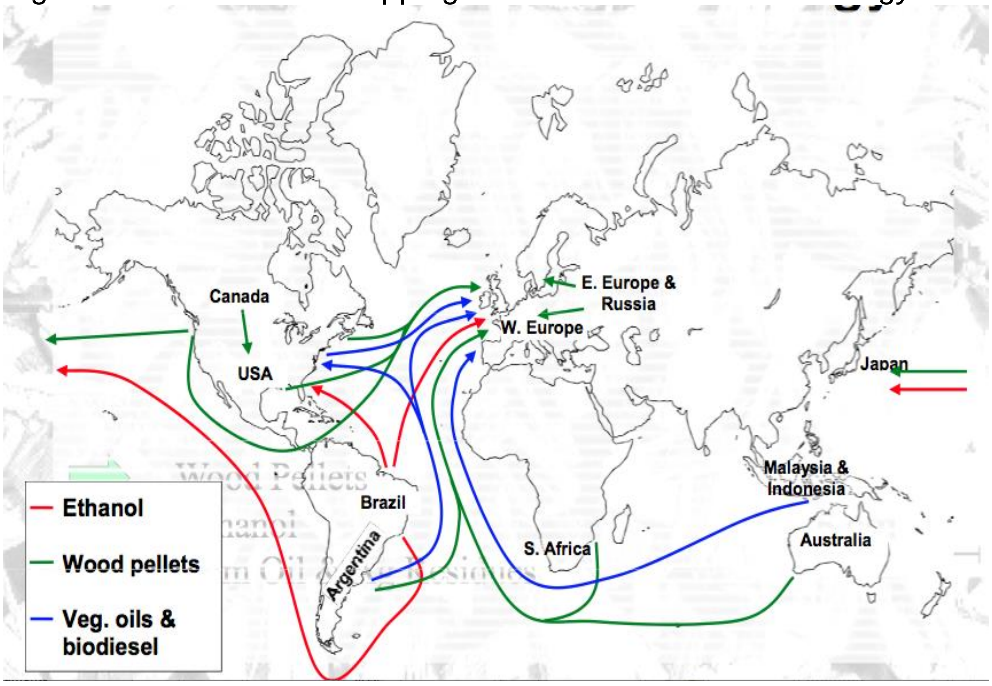


Source: Vattenfall's Report, 2012

3.3 Trade Patterns

The current trade routes for biomass differs as per type of biomass traded. The main trade routes for ethanol, wood pellets and vegetable oils and biodiesel are showed in the figure below (figure 7).

Figure 7- Current Main Shipping Lanes For Biomass For Energy Production



Source: IEA, 2006

The above map displays the main shipping routes for biomass around the world. The main destination for internationally traded wood pellets is the European market. Western Europe import pellets mainly from countries in Eastern Europe, Russia, Canada and USA. Main maritime trunk routes are from North America to Belgium and the Netherlands and from Baltic States and Russia to Scandinavia (Sikkema, 2009).

The two main exporters of pellets are Canada and USA. In 2008, United States pellet production reached 1.8 million tons and in Canada production of pellets in the same year was of 1.4 million tons. Their production capacity in 2008 was nevertheless not fully utilized, 66% and 81% respectively. The main exporters of pellets inside Europe are so far Germany, Austria, Poland, Finland, the Baltic States, Spain and Portugal.

Wood Pellets Main Trade Routes		
	Exporter Country	Importer Country
Extra EU	Canada	Belgium
	Canada	Netherlands
	Russia	Sweden
	USA	Belgium
	USA	Netherlands
Intra EU	Austria	Italy
	Belgium	France
	Estonia	Denmark
	Estonia	Sweden
	Estonia	United Kingdom
	Finland	Sweden
	France	Belgium
	Germany	Denmark
	Germany	Spain
	Germany	Sweden
	Latvia	Denmark
	Latvia	Sweden
	Lithuania	Denmark

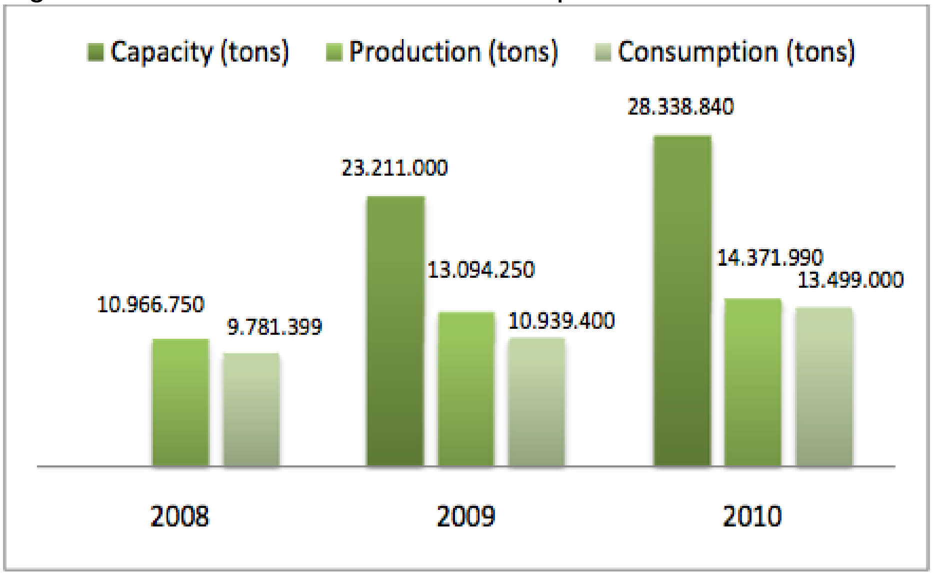
Table 1 – Source: Wood pellets data collection, 2009

In 2008, the total wood pellet consumption in Europe was 8.2 million ton, (Sikkema, 2009). In 2009, 650 pelletizing plants produced over 10 million tons of pellets in Europe, and in the same year consumption within Europe was of 9.8 million ton of pellets (Sikkema et al, 2011). As consumption of pellets in Europe increases, supply of pellets in Europe tends to be completely absorbed by the internal market.

In 2020, European total demand for pellets to electricity generation proposes has been forecasted to reach approximately between 105 to 300 million tons (Sikkema et al, 2011). Regional production of pellets in Europe has been forecasted to be insufficient to fulfill internal demand. Outside Europe, Asia has also started to increase its consumption of pellets. In 2008, Japan started co-firing coal with Canadian pellets. Korea, Japan, India and China are potential emerging consumers of wood pellets. Brazil and USA are expected to become two of the biggest suppliers of wood pellets to Europe and to the world.

Statistics have shown that global trade of wood pellets has been increasing. In 2010 the global capacity of pellets has been significantly raised in order to keep up with world's demand for pellets. This can be explained by several factors. Governmental incentives and possible new regulations towards green energy is the main factors stimulating wood pellets trade growth. From 2008 to 2010, pellets production increased with 24%, while for the same years pellets consumption increased by at least 27% (Figure 8) (Cocchi et al, 2011).

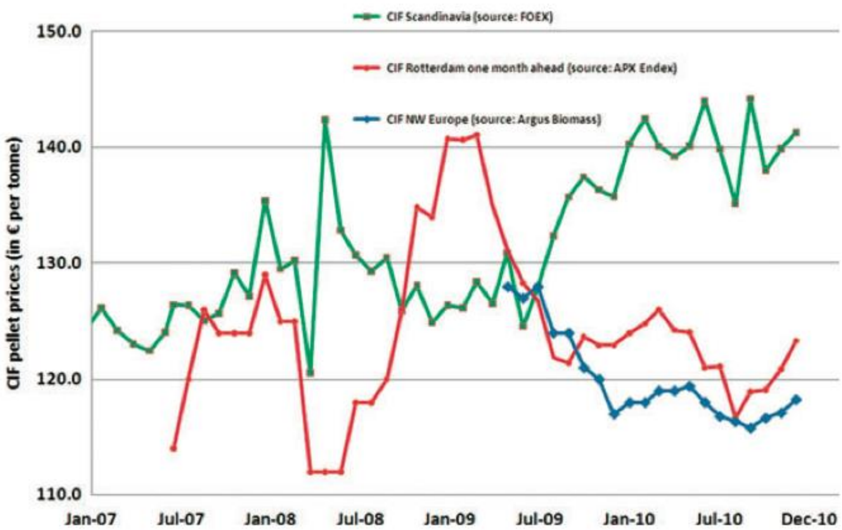
Figure 8- Global Wood Pellets Consumption & Production



Source: IEA Bioenergy Task 40, 2011

Most of wood pellets produced derive from sawdust produced as byproducts by others industries. Therefore, the price and availability of wood pellets in the market is subject to the wood industry's trends (Cocchi et al, 2011). Extremely high demand for wood pellets could generate a low tide in other wood industries, such as pulp and paper industry. Added to that, the fact that wood pellets are still not considered a commodity also helps to increase price instability in the pellet market. The idea is to create a commodity market, which will work as the market of oil, lumber and others. Once this happens prices will suffer less variability.

Figure 9- CIF Prices of Bulk Pellets for Large Scale Power Production in the Netherlands and UK



Source: Sikkema et al, 2010

Pellet prices in the Dutch market are considerably volatile (figure 9). In July 2007 prices were around €115/ton, while less than two years later the prices raise to €140/ton. A total of only five big energy companies and three international traders form the Dutch market (Sikkema et al, 2010).

Most of pellet trades are under short term contracts, which go from 1 to 2 years. Long-term contracts for pellets generally go from 5-10 years. As global pellet trade expands and with big utilities in Europe looking to increase its co-firing capabilities, many short to long-term contracts tend to be fixed to secure supplies. Pellet long-term contract prices are normally associated with the size and length of their contract and negotiated in dollars. Therefore, exchange rates directly influences pellets prices (Sikkema et al, 2010). Spot trades, which cover deals until 90 days, are also from time to time seen in this market and as in any other industry tends to be offer lower prices when the market of pellets is weak.

Negotiations for long term contract prices for 2013 have started from $190/ton, while last quarter of 2011 prices for FOB Vancouver were around $140/ton and $150/ton for FOB USA (Argus, 2011).

3.4 Wood Pellet Transportation

Wood pellets are more commonly transported as Bulk cargo. Dry bulk cargo is transported unpackaged and in large quantities. The main bullk ship sizes are: handysize, handymax, panamax and capesize. Very large bulk carriers are a subclass of the capesize group. In markets as in North American pellets exports is mainly done by Handymax ships due to draft limitation problems. Panamax ships would cut down costs of transportation of pellets originating from North America, therefore many studies have been done looking for use of Panamax ships in these ports in a near future (Argus, 2011).

Major Bulk Carriers	
Type	Size in Dwt
Handysize	10,000 to 35,000
Handymax	35,000 to 59,000
Panamax	60,000 to 80,000
Capesize	80,000 and over
Baby Cape*	Around 115,000
Very Large Bulk Carrier	200,000 and over

*Baby Cape vessel is one type of capsize vessel.

Table 2 – Source: Wikipedia, 2012

Pellets transportation as well as loading and storage need to be gentle in order to avoid to increase the amount of dust or fines when handling. Further, when transported as bulk, pellets receive the classification of hazardous goods. During long voyages pellets tend to expel high levels of Co, Co2 and methane, causing chemical oxidation, what can also cause explosions. Added to that, pellets for transportation need to be stored in dry conditions (Bradly, 2009).

The price of transporting wood pellets is in a big extension determined by the freight market, around 25% to 30% of total pellets cost come from maritime transport cost. Ocean freight, which is extremely volatile, can add from $35-45/ton to the final price of pellets (Biomass Magazine, 2010). Several factors can affect freight rates for pellets like: deployment of dedicated ships, existence of back haulage, existence of trade routes, distance (fuel) and ship size. Wood pellets are a new global traded good, therefore dedicated transportation directed exclusively to the transport of wood pellets are not very common. In terms of maritime transportation, some literature has previously mentioned the use of dedicated biomass ships. A larger flexibility of vessels available to be deployed in the pellets trade can help to decrease pressure on freight rates.

Moreover, the use of dedicated ships in general helps most of the times to increase freight rates as it is more likely that the vessels will need to come back empty in its back haulage. The existence or not of a trade route also affects freight. If the route requested is a less common route, shipping lines will charge extra for deviating to less popular routes. Distance or fuel consumption is a variable direct connected to freight prices, as increase in distance will result in higher costs and therefore higher freight prices. Finally, higher quantity of cargo load will allow economies of scale to do its work by decreasing the price per unit.

3.5 Biomass Competitiveness

The dilemma faced by the biomass industry is the same as in many industries, the famous “egg and chicken dilemma”. Biomass industry’s players see investments in the sector as “risky”, and end up by depending on European nations gas emission policies to make investment decisions. As the targets for decreasing greenhouse gas emissions within Europe become more ambitious, biomass market players tend to be guided by these government announcements.

Currently new technics for allowing wood pellets use into a power plant’s system are extremely expensive. Further, pellet final cost is much higher than fossil fuel total costs. This is the result of pellets high densification cost and of chlleneging transportation. Therefore, governmental incentives have showed so far to be the necessary way to increase pellets competitive price. Sweden has present in its tax system a charge of €10/GJth for CO_2 and sulfur emissions from the heat and power industry. Systems like that tend to stimulate the decrease of fossil fuel consumption.

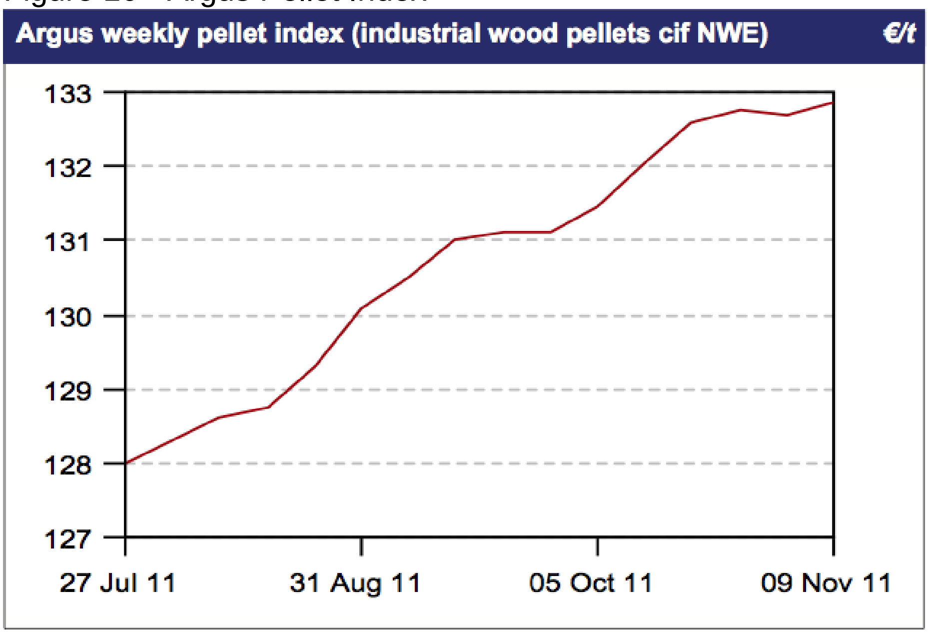
The price of CO_2 rights between 2007 and 2009 were on average €24/ton of pellets. Therefore, if the charge of CO_2 emissions becomes a common practice in the international market, pellets will finally become a highly competitive commodity towards mineral’s consumption (Sikkema et al, 2010).

3.6 Biomass Index

As the market in Europe and in The Netherlands develops, the formulation of a specific price index for wood pellets, which could help to increase market transparency for pellet prices became ever more necessary. APX Endex and Argus Biomass currently publish pellet market prices.

The APX Endex was created in the end of 2008 and since then prices are published on a monthly basis. The formulation of such index is done one month ahead of delivery and is compiled by different actors involved in the pellet trade: producers, traders and consumers (APX Endex interview). The calculation is done bytaking the sum of all prices divided by the number of actors involved in the sample (Sikkema et al, 2010). Argus offers price publication for many different commodities and on a weekly basis. The prices acquired by Argus for the wood pellets and wood chips come from market participants in order to create a benchmark price. Finally, factors as increased demand for pellets and possible transformation of pellets in a commodity together with price volatility were some of the drivers that pushed for a “biomass global trading platform” creation.

Figure 10 - Argus Pellet Index



Source: Argus Media, 2011.

3.7 Global Wood Pellets Trade Challenges

Despite the big prospects for the increase of pellet trade, some challenges contribute to discourage or slow down this trade. Lack of standardization and lack of prove of sustainability are big barriers to the trade of wood pellets as a commodity.

3.7.1 Standardization Issue

As any other industry wood pellets trade require a minimal commodity class to be traded. This makes it necessary to ensure consumers of the goods origin and quality. Some countries have created their own standard levels in order to stipulate properties of pellet consumed. In Europe, the CEN/TS 14961 classify wood pellets as per its size, ash content, moisture content, energy content and others features.

Nevertheless, Germany, Italy and Austria have also their own pellets quality standards, as well as some of the big utilities in Europe have also developed their own standards (Junginger et al, 2010).

The lack of a global standardization for pellets trade has not been showed to direct decrease pellets trade. Nevertheless, this could represent a big constraint to pellets supplier, once each country or player stipulates its owns standards. Therefore, the systematization of an organized and fair pellets trade should take place in a global level.

3.7.2 Sustainability Issue
One of the main reasons for wood pellet usage is the renewable motivation. The trade of non-sustainable pellets would be ironic. Therefore, sustainable origin has been for some time a critical topic of discussion of the international community. Several private sector standard labels have been created. Some of the big European power plants have also made standard labels, which requires prove of pellets sustainability. Some governments have also proposed the use of voluntary labels to guarantee a good origin of pellets.

The main concern of the market of voluntary prove of sustainability labels is that it can also generate good differentiation. The non-existence of a compulsory international or national label can generate the creation of a second market for companies willing to pay lower pellets prices.

3.8 Torrefaction
Torrefied pellets have several advantages when compared to conventional pellets: higher energy density, more homogeneous composition, absence of biological activity and better grind-ability. Torrefied pellets energy density is approximately 20-25 GJ/ton against 16.8GJ/ton for conventional wood pellets (<10% moisture content) and 9.5-14.3 GJ/ton for wood chips (50%-25% moisture content) (Cox, 2003). Therefore, the so-called “new coal” will allow wood to be transformed into a much superior material than conventional wood pellets, allowing huge savings of transportation and storage costs. Due to the higher energy density per m3 allowed by torrefaction, transport cost could be decreased until 40% (Sikkema et al, 2010). Further, as being a hydrophobic particle torrefied pellet would not required cover storages. Torrefaction is considered by many in the pellet business to be the revolution necessary to boost pellet trade.

Besides all the advantages, torrefaction technology has only been used in small scale. This happens because the densification process after torrefaction appears to be a very challenging process. Torrefaction eliminates all water and polluting parts, densification process is one of the main constraint for the introduction of torrefaction technology (Bioenergy Insight, 2012). Once these torrefaction production challenges are overcome, a torrefaction-based bioenergy is expected to introduce a high competitive commodity into the market.

3.9 Conclusions
The principal features regulating the wood pellets market were introduced in this chapter. Wood pellets are dry bulk cargo mostly transported unpacked and in large quantities. Handymax is the most common size of ships deployed by the world main exporters of pellets. The main players in this market on the export side are USA and Canada, both with a capacity potential that is not fully utilized. The main trading

patterns for pellets deployed in the energy sector are from USA and Canada to the Netherlands, Belgium and UK. Europe is the main consumer of wood pellets in the international market. In 2020, demand for pellets for energy purposes in Europe is expected to be from 105 to 300 million tons (Sikkema et al, 2010). National markets are foreseen not being able to keep up with Europe's increasing demand. Therefore, Brazil is one of the emerging players with the potential to supply a high share of pellets to Europe.

Wood pellet trade has vastly increased in the last years, putting enormous pressure into the international market system. The rise of an index classification, sustainability discussion and some individual standardization in the international arena are the results of a projecting market. All these features have been until a certain point introduced into the market and so far no international compulsory regulations have been established. A lot has been speculated in regards to torrefaction technology introduction and its advantages. Nevertheless, pellets still require subsidies from govern and implementation of CO2 prices to become competitive towards coal.

Chapter 4 – Brazilian Wood Pellets Market

4.1 Overview

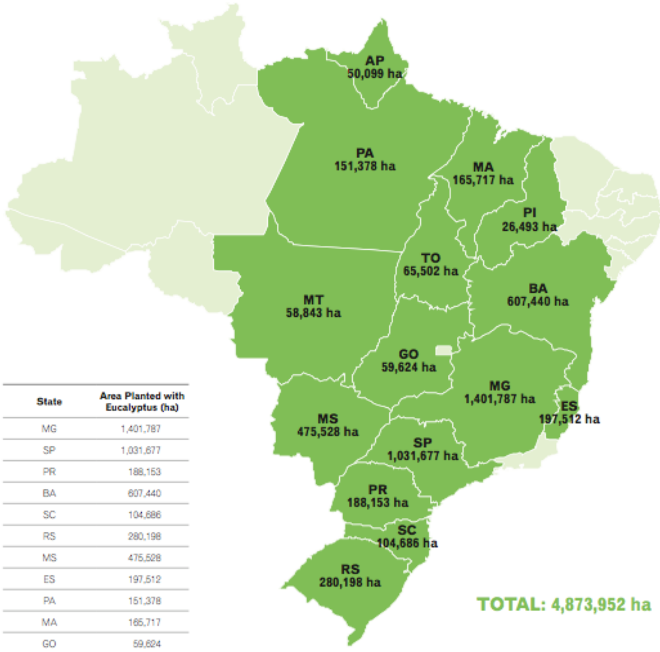
Brazil tradition on the production of biomass such as ethanol and woody biomass can transform the country on an important source of biomass in the world. Many Greenfield projects in Brazil have been initiated after European developments toward green energy utilization become more extensive. Brazil has in place all the appropriate conditions for the production of wood pellets, however challenges delaying the export of the Brazilian wood pellets are also present. The following years will serve as a readjust time for Brazil to become an important player participating in the European pellets market. Nevertheless, the speed in which the country can gather the necessaries change will determine if Brazil will be or not part of the game.

4.2 Pellet Production

Eucalyptus plantation in Brazil is located through the whole country, in exception of some localities in the extremely northeast and northwest of the country. Big part of country's native forest is located in the north, whereas most planted forests are located in the south of Brazil and it is directed to the national biomass market (Serrano, 2009).

Brazil vast space availability allows the vast cultivation of areas dedicated to the paper and pulp industry. Nevertheless, many new projects have been introduced in Brazil in order to be able to serve the emergent Biomass market. In 2011, Brazil had a total of 4,873,952 hectares of only eucalyptus forest planted (ABRAF, 2011). It is estimated that forest residual potential in Brazil for 2020 will be of approximately 272 million tons (Cocchi et al, 2011).

Figure 11- Area and distribution of Eucalyptus plantations in Brazil in 2012



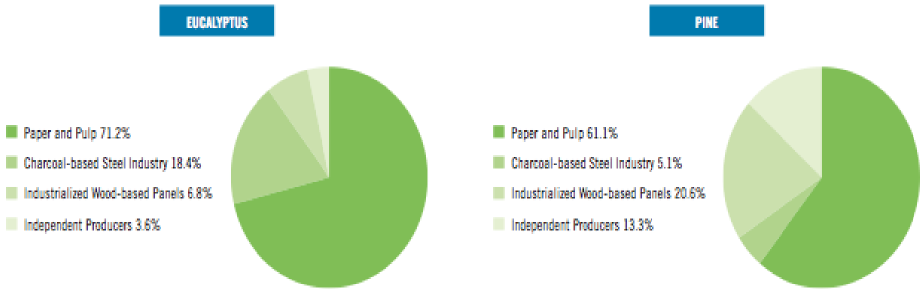
State	Area Planted with Eucalyptus (ha)
MG	1,401,787
SP	1,031,677
PR	188,153
BA	607,440
SC	104,686
RS	280,198
MS	475,528
ES	197,512
PA	151,378
MA	165,717
GO	59,624
AP	50,099
MT	58,843
TO	65,502
PI	26,493
Others	9,314
Total	**4,873,952**

Source: ABRAF member companies and collective members, 2012.

According to the Brazilian Association Industry Biomass (ABIB) there are currently in Brazil 10 wood pellets plants and together they are able to produce about 320ktons. Prospects showing that Brazil will become one of the main European suppliers of wood pellets are positive about the performance of Brazil in the pellets market the future**.**

Despite several projects recently developed targeting the production of wood pellets for export, pulp and paper industry is still the main destination of the Brazilian eucalyptus plantation. 70% of all industrial round wood consumption of eucalyptus trees and 36.1% of all Brazilian wood produced is directed to the pulp industry. The dimension of the Brazilian pulp and paper industry is still a positive factor to the biomass market, once by-products as sawdust generated by them are mainly absorbed by biomass industry. Nevertheless, it is expected that wood deployed by the pulp and paper industry in Brazil will be partially redirected to the biomass market, what would result in the reduction of the pulp and paper industry in Brazil.

Figure 12- Area planted with Eucalyptus and Pine by ABRAF member



Source: ABRAF member companies, 2012

Feedstock cost includes mainly all costs on harvesting, fertilizers, machinery and labor costs. Eucalyptus trees mature normally in a six years cycle with three time cuts, therefore 6th, 12th and 18th year cut. After the last harvest, field is prepared for a new rotation. Many pellets producer in Brazil have been adopting the use of clone eucalyptus to achieve higher trees productivity. Special clone of eucalyptus trees is able to increase forest density and shorten harvest period to 2-3 years. For instance, while eucalyptus regular clone average productivity is of 41m3/ha per year, special clone productivity can reach 50-70 m3/ha per year (ABRAF, 2012). The average yield of biomass from Eucalyptus trees is of 22 ton/ha per year (ABRAF, 2012).

Fertilizers costs for high productive plantations are constantly required. This can be explained by the fact that grassland needs substances as nitrogen to grow, which is introduced through fertilizers. Eucalyptus trees consume in average 8 kilos of fertilizers per ton (Biotimber project presentation, 2010). Nevertheless, high amounts of fertilizers are requires by these trees only in the first two years of the plantation cycle. Machinery and labor costs are harder to be estimated once these factors are connected to level of mechanization of the plant (Crago et al., 2010). Nevertheless, Suurs have acknowledged employee cost to be of 25euros/hour for a crew of two people (Suurs, 2002).

4.3 Challenges and Opportunities to Export

The main challenge for the Brazilian wood pellets export to Europe is the increasingly strong demand from the internal market. In the south of the country in special, residues of industrial wood have been for some time reutilized in the regional industries. Another possible barrier to exports is connected to wood pellets sustainability issue. As most of the forest source for wood biomass in the north of Brazil is part of the native forest. Two of the main bottlenecks hampering the export of the Brazilian wood pellets are structural issues: high logistics costs connected to the high dependency on the road transport and low port infrastructure. Most of the planted forest in the country is located further away from the port areas and truck transport for biomass transport has showed to be very low efficiency. Alternatives forms of national transportation until ports of exit are not structurally available, therefore multimodality in the transport of wood pellets is so far almost absent. Finally, ports as an important part of pellets supply chain are so far not ready to operate such a special commodity. Limitations in water draft, lack of special equipment and space availability for storage are some of the problems in the port area. Although the biggest constraint in the Brazilian ports is mostly the high congestion in port areas created by the excessive use of trucks.

Chapter 5 – Transport Network Design

5.1 Overview

In the view of the opportunities and challenges of wood pellet trade between Brazil and Europe, this chapter proposes the design of a transport network for pellets on this route. An analytical evaluation of the hypothetical transportation chains will form the main methodology of this thesis. The basic premise of this analysis is the high logistics costs for pellets on this route; outlining logistic costs as a crucial factor determining pellet final costs.. This transport network design for wood pellets will build up a framework for pellet transportation on this route.

Earlier studies have reviewed pellet intercontinental trade costs (Wasser et al., 1995; Agterberg et al., 1998; Suurs, 2002 and Hamelinck et al., 2003). Hamelinck and Suur have introduced a complete pellet network analysis through a detailed introduction of costs per transportation leg. In their 2003 work, they have suggested the use of a central gathering point (CGP), where small-scale forest site biomass is transported for pretreatment and finally shipped to Europe. However, the author does not know about the existence of studies focusing on different transport networks in order to optimize pellets trade costs from Brazil to Europe.

Transport Network Design was defined by Tom Mathew (2009, 1) in a broad sense as: “the configuration of transport network to achieve specified objectives”. The specific objective of this chapter is to create a framework where the transport of wood pellets from origin to destination can be optimized through minimization of transportation costs. The route chosen is the Brazil-Europe route because of increasing consumption of wood pellets in northwestern Europe and the potential of pellet production in Brazil. All the stages of this supply chain are to be individually analyzed in order to identify main bottleneck to pellet trade. The focus on the land and especially on maritime transportation will deal with the exploration of concepts as: Multimodal transportation, Consolidation of different exporters versus individual exporter, Hub-and-Spoke Network versus Multi-port approach, and in a smaller degree Dedicated versus non-dedicated ships and Dedicated terminal versus Third Party Terminal.

This chapter is divided mainly in three parts: Towards a Framework for Transport Network Design, Transport Network Design Options and Suzano Renewable Energy Business Case. The first part consist of an introduction of the basis of pellet trade from Brazil to Europe, the second part involves the options concerned to the transport network design and third a business case of a potential Brazilian pellet exporter.

In order to be able to design a valuable transport network for pellets on this route the next topic of this chapter presents the foundation necessary to structure the further discussion towards the Transport network formulation options. Brazilian Logistics, Brazilian Ports, Maritime Transport, European Ports and Distribution into Europe are the five sections presented in order to establish the basis for the wood pellets Transport Network Design.

5.2 Towards a Framework for Transport Network Design

Despite the environmental benefits biomass use has, other energy sources as coal have several advantageous in relation to transportation over biomass. In order to have an idea of pellet transportation constraints, a briefl comparison between coal and wood pellets is shortly introduced below.

As seen in chapter 3 pellets have low density and they are low aggregated value good. The average stowage factor of wood pellets is approximately 500 to 700kg/m3. This means that on average 0.7 ton of pellets can be load per m3 of ship. Whereas steam coal stowage factor is about 900kg/m3, and when compressed it can reach a factor of 1.2 to 1.4 tones per m3 (Mattheyer, 2012). Additionally, coal has a higher calorific value per kilogram than pellets.This means that in order to generate the same amount of electricity three times more pellets are needed.

Another aspect to be considered is the advantage storage of coal has over biomass. Pellets undergo a drying, grinding and compression process, which increases the density and decreases the moist content of pallets. Pellets cannot be stored outside in piles like coal, therefore pellets require special storage rooms (Suurs, 2002). The table below shows the main differences between wood pellets and coal.

Comparison Wood Pellets vs. Coal		
	Wood Pellets	**Coal (Anthracite)***
Density (kg/m3)	500-700	1.200-1.400
Net Calorific Value (KWh/Kg)	4.8	9.2
Energy Density (KWh/m3)	3,100	10,100
Hydrophobic	No	Yes
Storage	Special Storage	Storage outside
CO2 emissions	Neutral	Pollutant

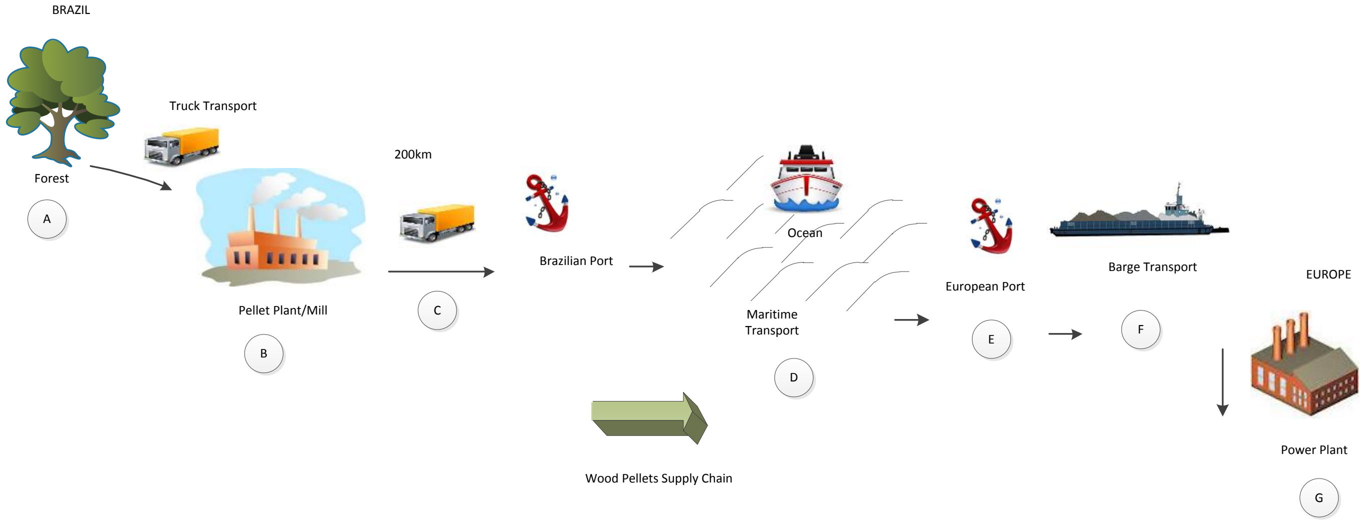
*Coal Anthracite is mainly used in power plants.

Table 3 - Source: Biomass Energy Center, 2012

As the above situation shows, wood pellets green advantages can still be offset by some of its particular characteristics. In this sense, wood pellet trade becomes much more dependent on CO2 price schemes or higher coal prices to become competitive. Logistics are an important determinant of biomass trade cost and therefore it is important to design an optimal Transport Network for pellets on this route. The particular characteristics of each component of this transportation network are analyzed in this chapter.

Each component of this supply chain is determined by its main cost drivers. This chapter will present in detail each chain component and their main cost drivers. The result is the total cost of this supply chain, which is the sum of all the components of the pellet chain from Forest site in Brazil to final distribution to Power plants in Europe (Figure 13).

Figure 13 - Brazil-Europe Transport Network for Pellets



Source: Author's

5.2.1Brazilian National Logistics

Brazilian national transport infrastructure is very behind if compared to other countries with the same dimensions as Brazil (World Bank, 2008). Recently Brazilian economy has been growing rapidly, further the country's' growth has increased the demand for Brazilian goods abroad. Nevertheless, demand for transport infrastructure in Brazil is growing faster than the speed of infrastructure changes. In 2011 a survey has shown that Brazilian road infrastructure still rank 118th and port infrastructure ranks 122th among the 142 countries surveyed.

Data collected from the World Bank about overall costs of Brazilian soy beans exports in 2006 has shown that while ocean freight from Brazil to Hamburg were $38.51/metric tons, transport costs from middle west of Brazil (MatoGrosso) to Brazilian Port facilities were of $84.65/metric tons (Zepetta, 2011). The high national transport costs have been holding back the comparative advantages Brazil has for instance in the soya production.

Most of the forest planted in Brazil is located far from port facilities, what makes logistics until port of exit a big challenge. Added to that, the fact that wood pellets are a low aggregate value commodity makes low transport costs decisive for margin generation when exporting (Nazario, 2000). As pointed out in the 2012 IEA Brazil Country Report, transporting wood pellets in Brazil can increase until 150% of pellets FOB price. This statistic can be explained by the weak Brazilian transport matrix.

Brazilian Transport Modal Split

Brazil has a very limited transport model split.. The country is very dependent on its road system, while others modes of transportation are underutilized. Brazil's road network is worlds third largest, while rail and waterway transport lag behind. As per Brazilian Ministry of Transport only 13% of all cargo is transported by inland and coastal waterways, 25% by rail and the majority of 62% transported by road compared to China and the USA where road transport is only 37% and 32% respectively (World Bank, 2008; Pedreira, 2006).

Added to that, many studies revealed the higher costs of Brazilian road transportation compared to other transportation modes (Nazario, 2000; Pedreira, 2006; World Bank, 2008). This imbalance is the result of years of government over reliance in road transportation. A study done by Dolzan and Walter showed that depending on plant's location, logistics costs in Brazil can range from 65% to 90% of wood chips production costs (Walter et al, 2009). These figures show how logistic costs in Brazil acts as a trade barrier hampering Brazilian favorable conditions to trade and therefore Brazilian exports.

Location and distances between forest to plant and plant to port are also important factors that can affect the Brazilian logistics costs. The choice of pellets' transportation is certainly dependent on the forests' location. For forests located in the Northern and Center-West of the country inland shipping would be a good solution for decreasing logistic costs. For forests in the Northeastern and Southeastern areas, the transport network should combine fluvial with rail transportation (Peksa-Blanchard et al, 2007). In 2009, Serrano presented a study showing that truck transportation for over 200km from forests in Parana to pellet plants located near the Paranagua Port are not cost efficient. This is due to the lost of economies of scale when mainly transporting the wood in a not highly dense form over such distances.

Production Costs in Brazil

Production cost of agricultural commodities in Brazil is highly competitive when compared to main players in the international market. Suurs presented in his paper pellets production costs in Europe to be more than six times the cost of production in Latin America (Suurs, 2002).

Again the market of soya beans in Brazil shows clearly country's comparative advantage in terms of natural resources production. In 2006, the production cost of soya in the Mato Grosso area in Brazil was approximately $157.86/ metric ton while in Iowa United States was $204,78 (Zepetta, 2011). Production cost for bulk commodities in Brazil can be from 10% to 30% cheaper than for Brazilian main competitors.

The main cost driver determining pellets production cost (with exception of raw materials) is the densification process of wood into pellets parts. Therefore, elements as labor cost, land cost, feedstock cost and others capital costs will not be discussed in detail in this study. It is known that plant capacity and hours of operation are important factors influencing pellet production cost (Sudhagar, 2005). This is to say that plants with higher production capacity result in lower pellets production cost. Other parameters as energy consumption and fuel cost also influence pellet plant production costs. Nevertheless, these factors will not be treated in this thesis, as the target here is only to have an indication of pellet production cost.

Densification Costs

Wood pellets densification normally involves drying, grinding and pelletizing process. These are energy intense and sequential processes to transform wood in a dry, compact and uniform body. Drying costs can represent until 40% of pelletizing plant capital cost (Urbanowski, 2005). Pelletizing allow wood parts to acquire some of the characteristics, which make them in many ways superior to wood chips or logs (Sudhagar, 2005). Whole densification process is very capital intense, further moisture content of raw material mainly determines plant densification cost. Therefore, higher moisture content pellets are cheaper to produce, however its quality in terms of energy content also decrease.

For a better idea of the densification costs share in the total pellet production costs the table below shows the percentage of diverse elements forming the production total costs incurred by a Canadian pellet plant. Moreover, for a better notion of costs the plant here considered has productivity of 3 to 10 ton/hour and capital cost ranging from $CDN 3,00,000.00 to $CDN 8,780,000.00 (Urbanowski, 2005) (table 4).

Breakdown of Pellet Production Cost		
	Dry Material	**Wet Material**
Raw material	53%	64%(30%drying)
Staff	20%	13%
General investment	2%	3%
Grinding	2%	4%
Pelletizer	14%	9%
Cooling system	1%	0%
Storage	4%	3%
Periphery	4%	4%

Table 4- Source: Ernie Urbanowski, 2005

Although pelletizing technology represents a big investment and therefore a big part of production total costs, some savings in transportation cost can offset pelletizing cost (Hamelinck, 2003). Once in this format pellets are ready to be handled more easily, transported more efficiently and direct fed into boilers. These characteristics have allowed wood pellets to become one of the most used types of biomass in the European market.

In 1998, Agterberg pointed out pellet production cost of €48/ton. In 2002, Suurs indicated that only pelleting cost range between €10-20/ton plus drying costs ranged from €3.8 to 23.8/ton for a twelve month operation. A study conducted by Sudhagar in 2005 revealed that whole production cost of a pellet plant using coal as fuel and with an average productivity of 5ton/hour is approximately $48/ton. Serrano showed wood pellets production cost for a pelleting plant in the south of Brazil with capacity of 100.000 ton/year of R$171.49/ton (€68.34/ton). One feasible explanation for this difference in figures could be the efficiency in production per country or technology deployed.

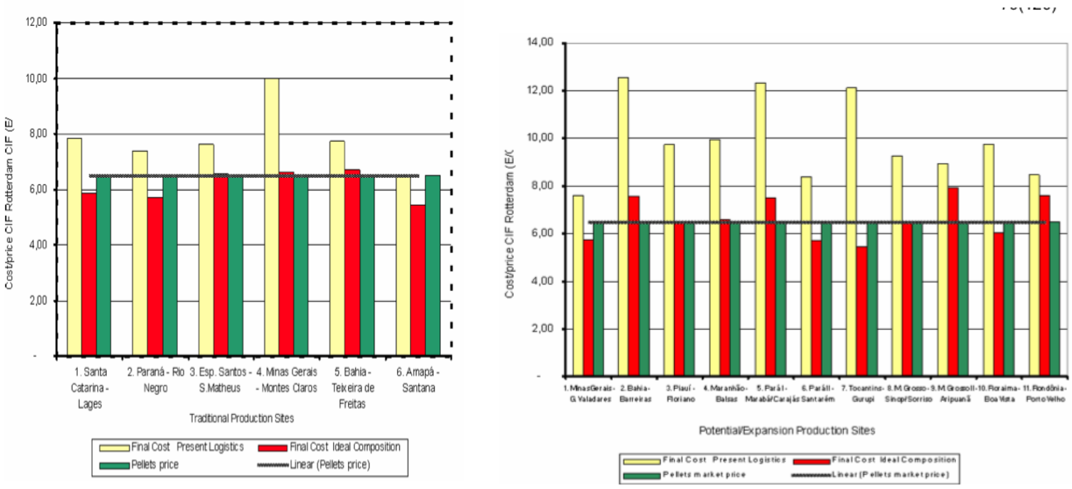
In order to describe pellets production cost more closely this thesis have selected a price range as derived from diverse literatures and interviews, $76/ton, as the most acceptable pellets production cost figure.

Logistics Costs in Brazil

Logistics cost is a key factor determining the competitiveness of a product traded. In Brazil, logistics costs represent a big part of the final price of Brazilian good traded abroad. The so-called “custo Brazil”, which refers to operational costs of doing business with brazil, is 20 percent of gross domestic product, while in OECD countries this cost is 10 percent of gross domestic product (Haddad, 2010). The main cost driver of Brazilian logistics considered in this thesis is the distance travelled by truck from pelletizing plant to port.

Most of the recent Brazilian pelletizing projects have been opting to position their pellet plants close to the forest (Peksa-Blanchard et al, 2007). This is to say that the extraction and densification of the wood in pellets is to be done in the same area. Because of wood logs and wood chips low density, lost of economies of scale in transportation would result in higher transportation cost. Nevertheless, the distance between pelletizing plant and port of exit is also tending to become shorter. As Serrano showed in 2009 in his study concerning pelletizing plants located in Parana region in Brazil, an overlap of more than 200km distance from forests to pelletizing plants result in loss.

Figure 14- Comparison on Pellets Final Costs Present Logistics and Ideal Logistics (Euro/GJ)

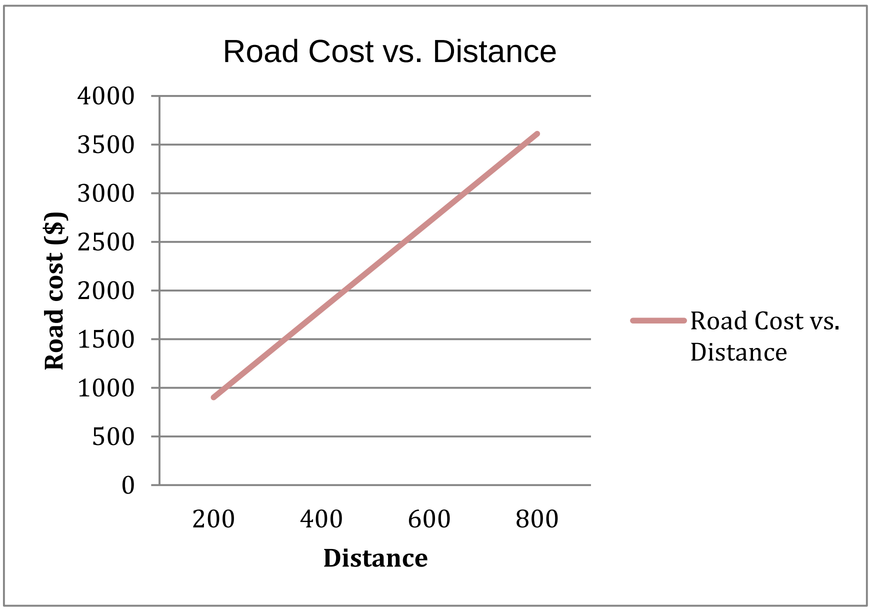


Source: IEA Bioenergy Task 40, 2007

The above graphics show that production sites located inland have their logistics costs much higher than what is considered to be reasonable logistics costs. Final costs for inland plant location are therefore above pellets market price, making international trade for pellets originated in these areas not attractive and consequently nonexistent. Therefore, this thesis assumes pellet plants’ location to be relatively close to the coastal area.

In 2009, a study made by Serrano showed short distance road transportation (considering 50m3 truck capacity) for pellets in the south are of Brazil to be of R$10/km or R$0,55/ton per km. In the Para region in particular values found by Serrano for a 150km distance was of R$0,195/ton per km considering 67m3 truck capacity. It is also important to note that road transportation cost in Brazil can vary as per region.

Figure 15- Road Cost vs. Distance



Figures considered for carrying 47.000 tons of pellets.
Source: Author's

Road transport cost and distance shows a corresponding increase. If a 47.000 tons of pellets is the amount loaded, as plant and port distances increases by four times road cost increases in the same proportion. Therefore, longer the distance travel by truck higher is the cost to be added by land transport in the total supply chain costs and less competitive is pellet final price.

The data presented by Serrano will be the rate considered in this thesis. An exchange rate of $1=R$2.03 is assumed, giving a road transport cost in Brazil of around **$0.096/ton per km**. Average transfer costs for two ways trip according to Suurs is of **$0.62/m3.** The formula to calculate road transport cost in Brazil used in this thesis is **RT=((0.37*tons) + (0.096*tons*km)).**

5.2.2 Ports

Ports as an integrative part of pellets supply chain needs to have physical structure in place in order to handle this specific cargo efficiently. This would mean requirements as special temperature adjusted and cover storage, handling equipment's, good hinterland connections and enough depth to receive big biomass' ships. As wood pellets are a low aggregated value, port charges can represent a high amount of sea transport cost. Suurs indicated that port charges represents approximately one third of sea transport costs (Surrs, 2002). Nevertheless, port charges in this thesis will be considered apart from ocean transportation cost.
The components of port costs in this thesis are storage costs and cargo transfer. Transfer cost implies here the loading of pellets on board of ship or unloading of pellets from ships. The main costs drivers determining ports transfer and storage costs are equipment deployed and storage time duration respectively. Transfer and storage costs for both port of exit and port of destination will be considered in this thesis and it will be denominated as port charges. Port charges can differ

enormously not only by nation but also from country to country. Therefore, an average charge for ports is extremely hard to be constructed. Other port services as pilotage, towage, boatmen or use of other equipment in the port area will not be included in the calculation costs of this thesis. Port dues will also not be included in the port charges costs as the author assumed that ocean freight rates already include port dues paid to port authorities.

When talking about maritime costs, economy of scale is an important concept to be taken into consideration. By increasing ship scale, the cost per ton of cargo load decrease. Nevertheless, as bigger ships for pellets transport are deployed, the number of trucks deployed increase, as well as storage capacity needed in ports. The time buffer between one batch delivered by truck and another already implies in a high port storage capacity in order to store complete order at port site. Further, companies inventory costs (and this its dependent on the Incoterm adopted) can be held high, as storage duration in ports depends on the distance and speed of truck deployed. Therefore, the deployment of bigger ships could also generate a deep logistic problem in the port area (Suurs, 2002).

5.2.2.1 Brazilian Port

Brazilian ports as part of the biomass' supply chain directed to export represent an important portion of total logistics costs. There are in Brazil approximately 37 public ports and 128 private terminals in the country (UK Trade and Investment, 2011). Belem, Itaqui, Santos, Paranagua and Rio Grande Port are expected to become some of the main exporter ports for the Brazilian biomass (figure 16).

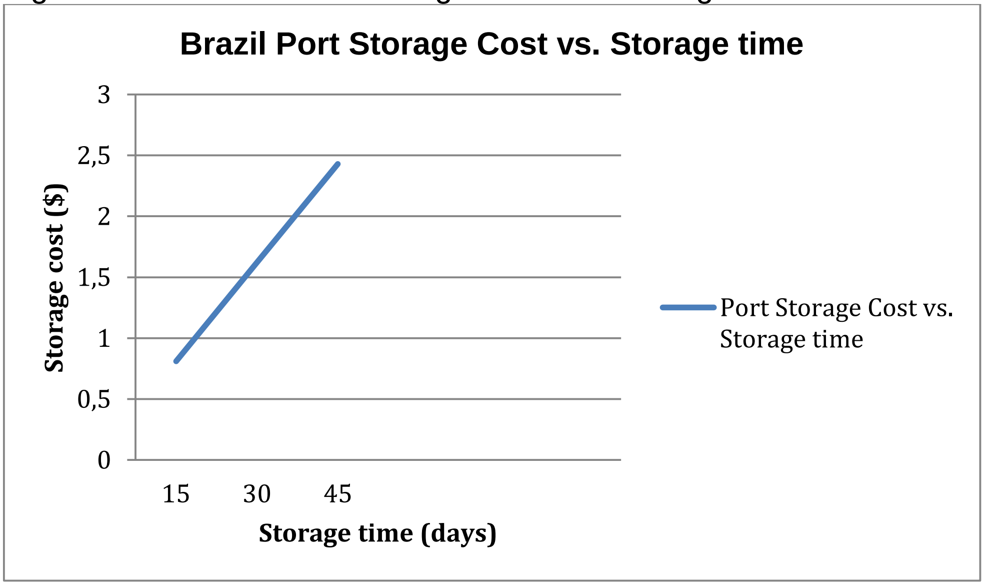
Figure 16- Brazilian Main Public Ports

Source: UK Trade & Investment, 2011

With the expansion of the Brazilian market towards biomass international supply, port infrastructure is one of the main concerns of biomass players. Some of the factors contributing for aggravating the situation of Brazilian ports are its public structure, bureaucracy and lack of significant investments. Therefore, when capacity is easily reached, Brazilian ports cost tends to increase as per function of loss per delay (Haddad, 2010). Only in 1993, Brazil's regulation towards concession of public ports to private sector introduced new directive allowing participation of private investors.

Port Storage & Transfer Costs
In this thesis the port charges considered to represent the Brazilian scenario are the figures presented by Rio Grande Port for bulk commodities. Rio Grande Port is one of the main ports for bulk commodities in Latin America and the main port for bulk cargo trade in the Mercosul. In some ports the access to this kind of information are very limited, therefore this port was selected because of two main reasons. Firstly, Rio Grande Port prospects towards biomass cargo handling and secondly, the availability of data from this port.

Figure 17- Brazilian Port Storage Costs vs. Storage Time



Source: Author's

Storage duration in the export side is mainly determined by truck travel duration and congestion in both landside and waterside. Storage costs and storage time in Brazil show a corresponding increase (figure 17). Storage costs in the Port of Rio Grande for bulk commodities is of R$2,03/ton ($0,81/ton) for each 15 days. Usually, after the first fifteen days this rate will increase as accorded by the parts. Nevertheless, because it's difficult to access a fix increase rate as storage duration increase, this rate will be considered as fixed.

The transfer cost for bulk is of R$6 per m3 or ton ($2.95/ton), the highest unit to be considered. Assuming exchange rate of €1=$1.24 and pellets' port stay in the export side of 45 days, Brazilian total port costs for 47.000 tons of pellets is of $5/ton. The formula to calculate port costs in Brazil used in this thesis is Pb= ((2.95*tons) + (0.054*day*tons)).

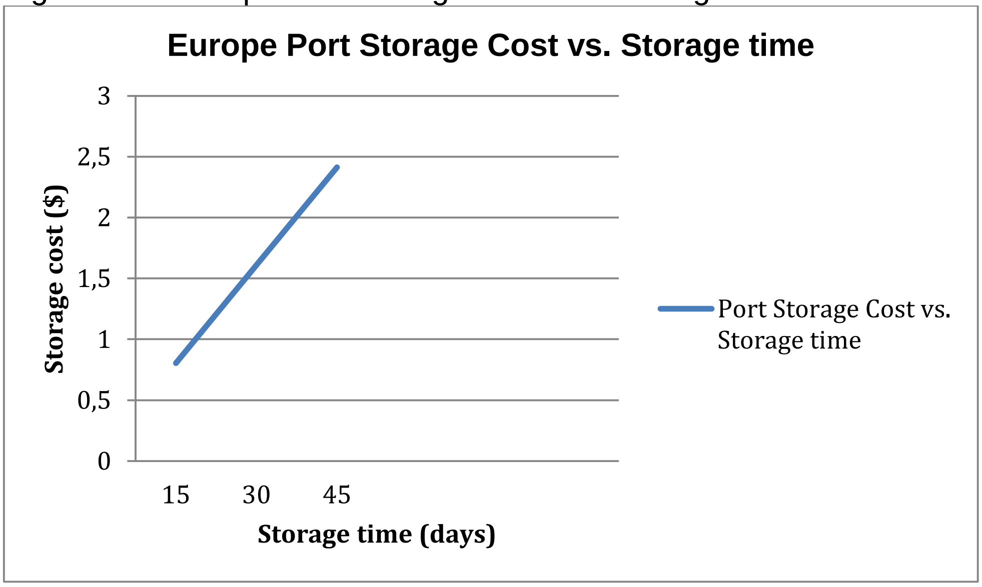
5.2.2.2 European Ports
As ports in Europe prepare to increasingly deal with the import of this commodity, only the ports with adequate infrastructure to accommodate pellets and space availability will participate as important players in this chain. Ports location in Europe

and its proximity to the main big utilities co-firing their production is believed to be the main factor determining key biomass hubs in Europe.

Port Storage & Transfer Costs
In the import side, transfer and storage costs are also the two costs considered. Storage duration in the import side is in general considered to be shorter than in the port of exit. Nevertheless, storage duration in the import side has been considered to be the same as in the export side in order to fairly compare port charges in Brazil and in Europe. Storage duration has been simplified for both ports as being of 45 days.

The main European port to be considered in this thesis is the Port of Amsterdam. Amsterdam is an important Energy Hub in Europe highly active in mineral energy commodities. Amsterdam is world's largest petrol port, second largest coal port in Europe and has initiated its ambition plan to become also a vital biomass hub in Europe. Therefore, the figures adopted for pellets port costs in the European side are from the Port of Amsterdam.

Figure 18 – Europe Port Storage Costs vs. Storage Time



Source- Author's

In the import side port storage duration is mainly determined by speed or quantity of pellets consumed by power plants and their own storage availability. Storage prices found was of €1.30/ton per month. The following assumptions were made: exchange rate of €1=$1.24. Finally, total port costs in Europe for 47.000 tons of pellets are of $5.5/ton**.** Storage costs for Rio Grande and Amsterdam Port has showed to be identical. Nevertheless, this figure varies from port to port and from country to country.

For the transfer costs in European ports previous studies have considered different figures. Olsson in 2001 have indicated this figures to be of €4.3/ton, another authors have considered figures ranging from €2.6 to 4.3/ton (Suurs, 2002). As per market information got from the Port of Amsterdam transfer cost for handling pellets board-to-board is of approximately €1.60/ton, while regular transfer from vessel to storage in the terminal is €2.50/ton. Therefore, the formula used to calculate port costs in Europe is Pe=((3.1*tons) + (0.0536*day*tons)).

5.2.3 Maritime Transport

The demand for freight is derived demand. Maritime freight is generated by the necessity of countries to trade their goods. In the case of biomass trade due to its low-density characteristic, higher quantity of ships would be needed than the quantity of ships deployed for fossil fuel transportation (Bonilla et al., 2009). For instance, the US would need approximately 1.6 billion tons of biomass per year to substitute their consumption of coal (Blakeslee, 2009). Therefore, the increase in pellet trade to a degree in which coal trade would be gradually substitute would generate even higher demand for ships. In this case the establishment of long-term contracts for shipping as experienced in the biomass market could secure more steady shipping rates. However, this would also mean long-term contracts between pellets suppliers and power generation plants.

Fuel cost and demand for ship are important factors determining freight rates in the biomass market. Ship size, dedicated ship or not, existence or not of back haulage, trade distance and common route are also drivers of maritime transport cost (Bradley et al, 2009). Despite the fact that distances for ocean transportation have less impact on total cost of transport than distances for road transport, economies of scale is an useful concept for this kind of transportation. Trade off between lower freight rates and bigger scale vessel is an important factor influencing maritime costs (Hamelinck et al., 2003).

Economies of scale in the bulk market has always been synonym of high volatilities, nevertheless currently market conditions have decrease the significance of ship scale advantages. Nowadays, a small difference of approximately $5 in price incurs as per bulk ship increase. As freight rates are difficult to be forecasted, the figures used in this thesis to represent it are the result of assumptions and estimations done by the author as per actual market. Therefore, these figures should not be considered as able to show the reality of future markets.

Cargill IMGA refers to hire, ballast bonus, bunker consumption and port costs as the higher fractions of operational costs for ships operating in the South America-Europe route. A typical voyage of 46 days can incur in $880.000 hire costs, $1.100.000 bunker costs and $100.000 port costs considering only one port of call. Therefore, chartering and fuel prices are important features determining maritime transportation cost.

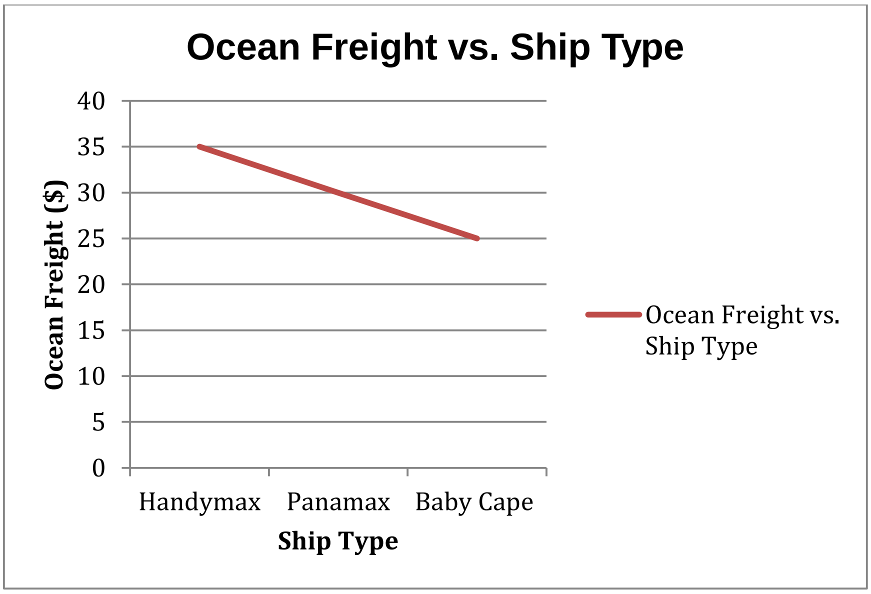
In the end of 2011, Argus published Handysize vessels rates for USG/ARA charter of $30/ton (Argus Biomass Market, 2011). In June 2012, charter rates published by Argus media for supramax vessels from USA to ARA region ranged was of $20/ton. Smaller vessels, as handysize received higher charter rates of around $35/ton. Suurs indicated pellets sea transport in a 1500 km distance is of approximately €12/ton considering a non-dedicated handysize ship and €13-16/ton for a dedicated ship. In a 10,000km distance, the figures raise to €21/ton and €27-39/ton respectively (Suurs, 2002).

In the United States ocean freight adds an average of $35 to $45 per ton in the final price of pellet (Biomass Magazine, 2011). In 2011, cost of shipping pellets from Southeast USA to the ARA region in Europe is of around $36/ton, while from

Southwestern Canada and Brazil is of $67/ton and $44/ton respectively (Forest2Market, 2011). Back haulage of bulk ships in general from Brazil is assumed to be empty for both dedicated or non dedicated biomass vessels. Further, ships are assumed to be non-dedicated biomass ships.

Freight rate in the Brazil-Europe route used in this thesis is ranging from **$25-35/ton.** Formula to calculate maritime transport cost is here simplified to **MT=freight rate*tons**. As difference in freight prices as per ship size decreases, rates assumed in this thesis for Handymax ship is $35, for Panamax ship $30 and for Baby Capes ship $25 (figure 19).

Figure 19- Ocean Freight vs. Ship Type



Source: Author's

5.2.4 Distribution into Northwestern Europe

Ports hinterland connections in the main European ports are able to offer all three forms of transportation connections: road, rail, barge and short sea shipping. Despite road transportation for trade in Europe being approaching its maximum capacity, truck still remains as the main mean of transportation in Europe. Europe has an extensive rail system with good connections inside and outside Europe, however not enough to sustain their national and international trade. Barges transportation in Europe has presented high level of integration between deep-sea transportation and inland distribution. Europe has also an extended short sea network. Barges and short sea shipping are so far the main mean of transportation used in the distribution of pellets from ports as Amsterdam to Northwestern Europe. Furthermore, The Netherlands is one of the top origins and destination for barges in Europe.

Road transportation as showed before in this thesis, depending on the distance to be transported, can add higher costs to total chain costs than other means of transportation. In Europe the figures showed by Suurs for pellet truck cost is €11.1/km for a 200km distance, including two way trip transfer cost and for pellet moisture content <10% and truck capacity of 80m3 (Suurs, 2002). Added to that, logistics infrastructure for pellets transported through hinterland by truck or rail is much more limited and require extra physical investments in machinery.

Barge distribution is so far considered the most optimal way to distributed pellets into Europe (Mattheyer, 2012). Main cost drivers for barges transportation price are fuel prices, weather conditions and draft limitation in certain areas. Very differently than the ocean freight rates scheme, back haulage system is not a very common practice in the barge business. Barge freight prices are extremely volatile.

Long-term contracts are also common in this kind of business. Nevertheless, these contracts usually stipulate adjustable rates as per fuel price variation, possible canal charges as per destination and compensations for low water period. Therefore, barge rates variations as per destination occurs not only depending on distances but also considering location accessibility. Spot rates offer usually prices in a daily basis and minimal tonnage to be load. Therefore clients opt for loading as much cargo as possible in order to take advantages of rates.

Barge size variations in Europe usually ranges from 250 tons to 10.000 tons. The barge size to be used in this thesis will be a 110 meter barge with a draft of 3,50 meters, which can load approximately 2.100 to 2.200 tons of wood pellets considering 0.6tons/m3 as pellets stowage factor. The loading speed assumed is 8/8 hours. Board-to-board barge loads have not been taken into consideration in this thesis. Finally, destinations considered in this thesis are in a range Amsterdam-Nijmegen or Amsterdam-Geertruidenberg. The rate here used is acquired from estimation given by some of the main barge companies in The Netherlands and take into consideration the points above describe. The barge rate assumed is $3.1/ton including barges loading rate. The formula used in this thesis is a simplified formula which reflects actual fuel price and 110-140km travel distances or 12-14 travel days, **B=3.1*tons.**

The main three factors determining Port participation in the pellets business is an attractive location (close to main utilities), port infrastructure adjust to handle such a particular commodity and finally its availability of barge connections to most popular pellets' destination. Port of Amsterdam is a good example of European port with available and extended barge and short sea connections. Port's location and barge connections can efficiently transport biomass to countries as Belgium, Germany and The Netherland itself (figure 20). Port of Amsterdam can become one of the main port of call for Brazilian pellets directed to most popular European destination.

Figure 20- Barge Transport Connections

Source: Port of Amsterdam, 2012

5.3 Total Cost of Supply Chain "Base Case"

All components of pellets supply chain were presented in detail in this chapter. The main goal of this chapter is to be able to define the share of each supply chain component in the pellets final cost and the main costs drivers determining each of the following chain components: Brazilian National Logistics, Ports, Maritime Transportation and Distribution into Europe.

The "Base Case" will form a typical example of a Supply Chain for pellets in the Brazil-Europe route. In order to be able to build such a benchmarking, a vast literature review, interviews with companies involved in the different parts of the chain and collection of market data available in the media were made. Moreover, the result of this data collection was combined with some assumptions and simplifications, which were necessary. The table below shows the main assumptions made:

"Base Case" Assumptions	
Handymax vessel	35.000 to 59.000dwt
Quantity loaded	47.000 tons of wood pellets
Dedicated vessel	No
Port Storage duration (Port of Rio Grande)	45 days
Port Storage duration (Port of Amsterdam)	45days
Route Brazil-Europe	It is and existent route for bulks
Distance origin-destination	Around 10.000km
Back haulage	No
Wood pellets moisture content	<10%
Wood pellets density	600 kg/m3
Exchange rates	€1=$1.24 €1=R$2.50

Table 5- Author's

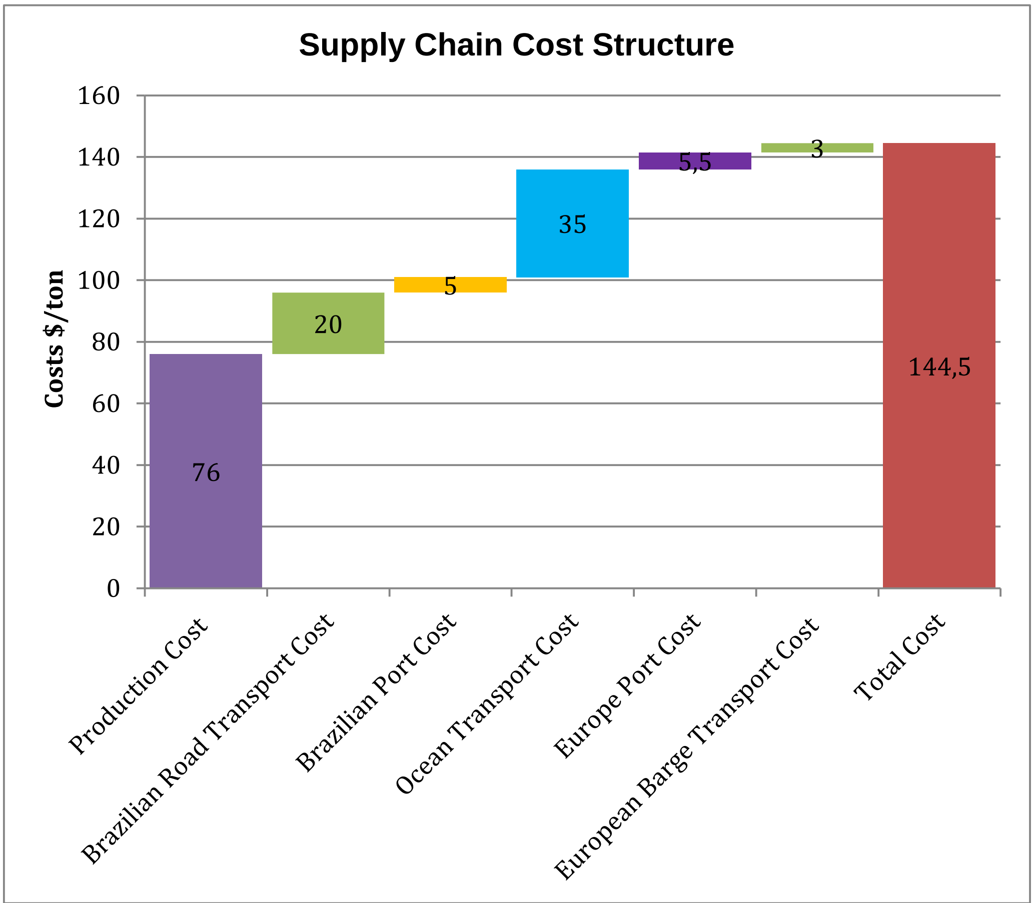
The production cost introduced in this thesis and to be used in the "Base Case" is an average found as per figure revealed by Suurs (2002) in his article about an assessment of costs and energy consumption for various biomass energy transport chains. An average of **$76/ton** is the average deduced from the range of $60-91/ton presented by Suurs. Despite the reference here made to pellets production costs, the focus of this thesis is on pellets logistics challenges.

The road transportation data used in the "Base Case" was the figure presented by Serrano (2009). Serrano considered an average of 150 km from plant to port and 67m3 truck capacity. He identified road cost in Brazil as being R$0,195/ton per km. Therefore, Brazilian road transportation cost in the "Base Case" including two ways transfer cost of $0.37/ton (Suurs, 2002) is **$20/ton.** Therefore, road transport formula in dollars is: **RT=((0.37*tons) + (0.096*ton*km))**

Port charges data for Brazil and for Europe were acquired from real port figures published by ports. In Brazil figures adopted were from Rio Grande Port and in Europe from Port of Amsterdam. As wood pellets international trade is relatively new and due to absence of pellet export from Brazil, figures as average storage duration in ports in Brazil and in Europe were a challenge for this research. Further, safe stock in ports has not been considered in this thesis calculation. The main factor determining storage costs is storage duration time. An average storage duration of 45 days for both port of exit and port of destination was assumed for a fairly comparison of chain costs. Costs were found as **$5**/ton in Brazil and **$5.50**/ton in Europe.

Maritime or ocean transportation cost figures for FOB ARA were selected from Forest to Market report of 2011. A **$35/ton** rate was the value used for handymax freight rates. Finally, total barge transport cost in Europe as per figures given in the "Base Case" was of **$3/ton** included transfer costs for loading barges.

Figure 21- Total Cost of Brazil-Europe Wood Pellets Supply Chain



Source: Complied by Author

In order to present a result close to reality the author has chosen to work with ranges for most of the components of this chain. The total cost of pellets supply chain originated in Brazil and transported to Europe is found to be of **$144.5/ton.** Nevertheless, it is important to have in mind that these figures can differ from case to case and especially with the use of bigger vessels in this route. Pellets final price sold in the market can vary a lot from country and as per market conditions.

5.4 "Base Case" Conclusions

A big portion of the total costs of pellets are the pellet densification cost. Investment in machinery and technology for transforming wood into pellets is very capital intensive as well as investment needed in power plants for co-firing. In the future implementation of torrefaction technology will allow some of these costs to decline.

Brazilian national logistics is one of the most expensive components through the whole chain. Logistics infrastructure in Brazil so far only makes feasible the use of roads for the delivery of pellets until port of exit. National railway system and inland waterways system leg much behind and need to be further developed in order to push national logistics costs in Brazil down. The main cost driver for road transport is distance. Further, the costs assumed in this thesis took into consideration optimal forest and plant location. Forest locations were considered to be in the same site as pellet plants. Distance from plants to the port of exit was considered to be of 200km, what is pondered as an ideal location for pellet plants. Therefore, it is important to mention that once these locations are not at an optimal place, road transportation cost in Brazil will contribute in a higher degree for pellets final price. Another factor is the space limitation of trucks for transporting big amounts of pellets, what would result in very high numbers of trucks deployed. For instance, 1.169 trucks of 67m3 are necessary to delivery 47.000 tons of wood pellets. Finally, because the final figure found for road transportation indicate the price per ton and per kilometers, the reader could wrongly assess the contribution of this part of the chain to final pellet price.

Port Charges as part of the pellet chain is a difficult part to be assessed fairly. Port storage costs in particular are a big bottleneck for pellets supply chain. As cargo ship size increases, storage costs increase also as function of longer storage duration time. Storage time in ports is also connected to truck travel time from plant to port once total quantity to be shipped need to be present all together in the port area. Longer truck travel time will generate longer storage time and therefore higher storage costs. Therefore, the bigger is the ship deployed, the bigger will be the challenge to integrate land and maritime transportation and most possibly the higher will be the storage costs. Therefore, it is very hard to assume a reasonable port storage time, as this figure depends on quantity of total cargo to be load, storage facilities in the port area and truck travelling time. The main cost driver for storage is storage time and space availability, machinery for handling pellets is the main driver for transfer costs in the port area. For the sake of simplification port charges for goods designated for cabotage will be the same as charges for goods designed for export. Storage duration in the port of exit for cabotage and export goods will also considered to be the same.

Maritime transportation main cost drivers are distance, existence of back haulage, deployment of dedicated ship, existence of trade route and ship size. Long distances, no existence of back haulage and no existence of the trade route to be traveled are potential factors contributing to increase ocean freight costs. Dedicated ship could mean most probably the no existence of back haulage cargo, what for ocean freight is a variable increasing freight rates. Nevertheless, it is considered that bulk ships in general departing from Brazil to Europe normally return empty back to Brazil, the use of a dedicated ship for pellets in this route would not affect freight rates.

Ship size as a function of economies of scale is an important maritime transport cost driver. As the ship size deployed increase, the cost per unit of cargo loaded decreases. Nevertheless, it is extremely important to take into considerations all components of supply chain and its main cost drivers in an integrate way, these components should therefore not be considered individually. It becomes clear in the result of this thesis that increase in ship size is not always pushing down overall pellets supply chain cost. Increase in truck costs, storage costs and lack of available space in ports contribute to decrease the advantages resulted from bigger ships use. Nevertheless, when rail and inland navigation for pellets transportation becomes feasible in Brazil, as well as better port infrastructure becomes available, the use of bigger ships could become more cost efficient.

Besides *Cabotage* being a less polluted modal and less inclined to robbery than road, this modal can transport higher amounts of cargo than truck and its consume of fuel is until 15 times less than road transportation (Cristiane et al, 2009). The difference in cost between road and cabotage in Brazil is of approximately 25% cheaper for cabotage for distances as from extreme south of Brazil to northeast of the country (Cristiane et al, 2009).

The cabotage freight cost used in this thesis is the data collected from the publication of World Bank in 2010 about how to decrease freight logistics in Brazil. The price given considers 1000 tons of cargo transported for every one kilometer traveled, US$12 (T/Km x 1000).

Barge transportation main costs drivers are fuel and final destination location. The adoption of long-term barge contracts with barge operator companies could help to maintain more stables barge transportation prices.

To sum up, in the logistics side road transport costs are a big constraint to pellets competitive price. Road transport cost in Brazil is a serious bottleneck affecting comparative advantages of the Brazilian pellets. Ocean transportation until Europe also represents a big share of pellets final cost and need to be optimized in order to make the pellet trade between Brazil and Europe more competitive. Therefore, in the next section some features of Transport Network Design and possible options to improve this Transport Network will be introduced.

5.5 Transport Network Design Options

5.5.1 Bulk Carriers

Like grains, iron ore and coal, wood pellets can be classified as bulk commodity. This denomination refers to goods which characteristics are favorable to be transported in Bulk Carriers. The following factors are able to explain the principles, which determine Bulk Carrier as the most appropriate vessel for the transportation of Bulk commodities (Stopford, 2009):

a) Bulk commodities are characterized by its small size, which make high volumes to fill a ship suitable for economies of scale returns.
b) Its compact composition allows the use of automated equipment (e.g. grabs and conveyers) in order to enable the efficient handle of big volumes of these small commodity.
c) Pellets are low value commodity, which makes bigger quantities to be transported over long distance more profitable. Further, they are less sensitive to inventory costs.
d) Regular commodity flows allows the periodic use of bulk carriers and allow investment in handling system.

Wood pellets fit almost all above-mentioned factors as suitable for transport in Bulk. However, pellets global trade is still relatively small, therefore its flows are still very unsteady and so far difficult to be precisely predicted. Nevertheless, in middle to long term biomass market tends to expand and become standardized. Pellets trade shows a strong tendency to change into a regular flow trade. Nowadays, there are three main ways for pellets transportation/packing: the eighteen-kilogram bags, the one-tone bags or “Super Sacks”, containers and loose bulk form.

Pellets in small quantity are usually bagged for transportation. Pellets sold in retail in the residential market are normally packed in plastic bags. The smallest bag is of 18 kilogram, while standard woven plastic bag fits one tonne metric quantities. The standard 18 kilogram bag is transported on wooden pallets which can hold between 50 to 70 bags stacked three pellets high (Artic Energy Alliance, 2009). Because palletized 18kg bags cost more time and requires extra handling for packing in the mills, this form of transportation becomes more expensive. However, as they are packed in compacted piles, the time for handle it into a mean of transportation saves time as forklift can be deployed for loading/unloading.

The one ton bag also called “super sacks” requires a higher volume of pellets and it is in its majority directed to the residential or small industrial heating systems. Forklifts are also used for the easy handle of these big sacks and sometimes an “add-on hook device” is required to be attached to forklift. These sacks are sometimes reused by plants, which offer refund for returned bags. Despite the fact that Super Sacks can be cheaper than the deployment of 18kg sacks, plants charge the same price per ton of pellets (Artic Energy Alliance, 2009). Finally, the transportation of pellets in containers is currently not very common.

Loose bulk is the most common transport form for large pellets plants used to trade big amounts of pellets. Loose bulk transport requires no packing but appropriated equipment for transferred of cargo with similar characteristic to grains. Auger, gravity feed or pneumatic system is normally equipment required to handle pellets as bulk loose (Artic Energy Alliance, 2009). This special way of handling pellets ensure minimal handling, therefore plants usually offer cheaper price per tonne for this kind of handle. Bulk loose transport is in a small scale also used for residential delivery. In this thesis, pellets transported as bulk loose cargo are the one assumed.

5.5.2 Independent Export vs. Consolidations

The choice of Independent Exporter versus Consolidation of different exporters will determine the first step towards the construction of transport network to bring Brazilian wood pellets to Europe.

In the last years, the demand for wood pellets in Europe have increased and some of the big European utilities start to consolidate their pellets imports from outside Europe in order to be able to fill bigger ships and decrease long distance logistics costs. Considered the situation introduced above, market data available and the formulas introduced in the first part of this chapter, three sub scenarios will be introduced below: (A, B) as integrating the *independent exporter* option (1) and (C) describing a basic *consolidation* scenario.

Several trade offs are done between these scenarios as tentative to decrease price per ton of some of the supply chain components. Scenario 1A is a simply export scenario; 1B is a long land transport scenario, which is introduced due to port draft limitation and 1C is a basic consolidation scenario, which introduces cabotage transport and extra port charges in order to be able to export pellets produced further away from each other.

One Exporter vs. Consolidation				
	Scenario 1A	**Scenario 1B**	**Scenario 1C**	
Sea Ship Size	Handymax	Baby Cape	Baby Cape	
Cargo load (tons)	47000	90000	First trip	47000
			Second trip	43000
			Cargo consolidated	90000
Truck Distance (km)	200	600	Each trip	200
Number of trucks	1169	2239	First trip	1169
			Second trip	1070
Maritime distance				780

Table 6- Source: Author

Figure 22- Scenario 1A: One Exporter Network- 200km Road

Source: Author

In the scenario (1A), production is transferred from the farm directly to Belem Port. The distance between the farm in Belem to Belem Port is assumed to be of 200km. A handymax vessel is the ship deployed in the route carrying 47.000 wood pellets (Figure 22).

The next step is to input the data of this scenario in the formulas presented in the first part of this chapter, detailed calculations is in annex 1:
(1) Road Transportation (RT)
RT=((0.37*tons) + (0.096*ton*km))

Considering that each truck can carry 67m3 of pellets and pellets stowage factor as being 0.6 tons/m3, around 1.169 trucks will be needed to transport 47.000 tons of pellets. Road transport cost including two ways transfers cost, one loading at farm site and one unloading at port site, is **$ 20/ton.**

(2) Brazilian Port (Pb)
Pb= ((2.95*tons) + (0.054*day*tons))

Total Brazilian Port Charges for transfer and storage is **$5/ton.**

(3) Maritime Transportation (MT)
MT= freight rates*tons

Total maritime transportation cost for one voyage is **$35/ton.**

(4) Amsterdam Port (Pe)
Pe=((3.1*tons) + (0.0536*day*tons))

Total Europe Port Charges for transfer and storage is **$5.5/ton.**

(5) Barge Distribution into Europe (B)
B=3.1*tons
21 barges will be needed to distribute 47.000 tons of pellets into Europe. Barge transportation cost is **$3/ton.**

Finally, total supply chain cost for transport network 1A is **$69/ton.** For this network, a considered small-scale quantity is transported direct from farm to port and from there follow to Amsterdam Port. The advantage of this network is the small distance travelled by truck, smaller quantity of trucks deployed to transport the 47.000 tons pellets and no extra port charges or shipping costs. This network is considered as a very simple transport network with almost no trade offs.

Figure 23- Scenario 1B: One Exporter Network- 600km Road

One Exporter Situation – 600 km Road & Itaqui Port

Source: Author

In the scenario (1B), pellets production is transferred from the farm in Para to a further away port, the Itaqui Port in Maranhao State. The distance between the farm in Para to Itaqui Port is assumed to be of 600km. This time a Baby Cape vessel is the ship deployed in the route carrying 90.000 wood pellets (figure 23).

By imputing the figures in the formula:
(1) Road Transportation (RT)
RT=((0.37*tons) + (0.096*ton*km))

Considering that each truck can carry 67m3 of pellets and stowage factor of pellets as being 0.6 tons/m3, around 2.239 trucks will be needed to transport 90.000 tons of pellets to the port area. Total road transportation cost including two ways transfer cost is **$58/ton.**

(2) Brazilian Port Charges (Pb)
Pb= ((2.95*tons) + (0.054*day*tons))

Total Brazilian Port Charges for transfer and storage is **$5/ton.** There are no extra port costs in this network as only one port of call in Brazil is planned.

(3) Maritime Transport (MT)
MT= freight*tons

As ship deployed increase, maritime transportation price per unit is expected to decrease as per economies of scale. Here the author assumed that freight rates would decrease from $35/ton for Handymax to **$25/ton** for Baby Cape.

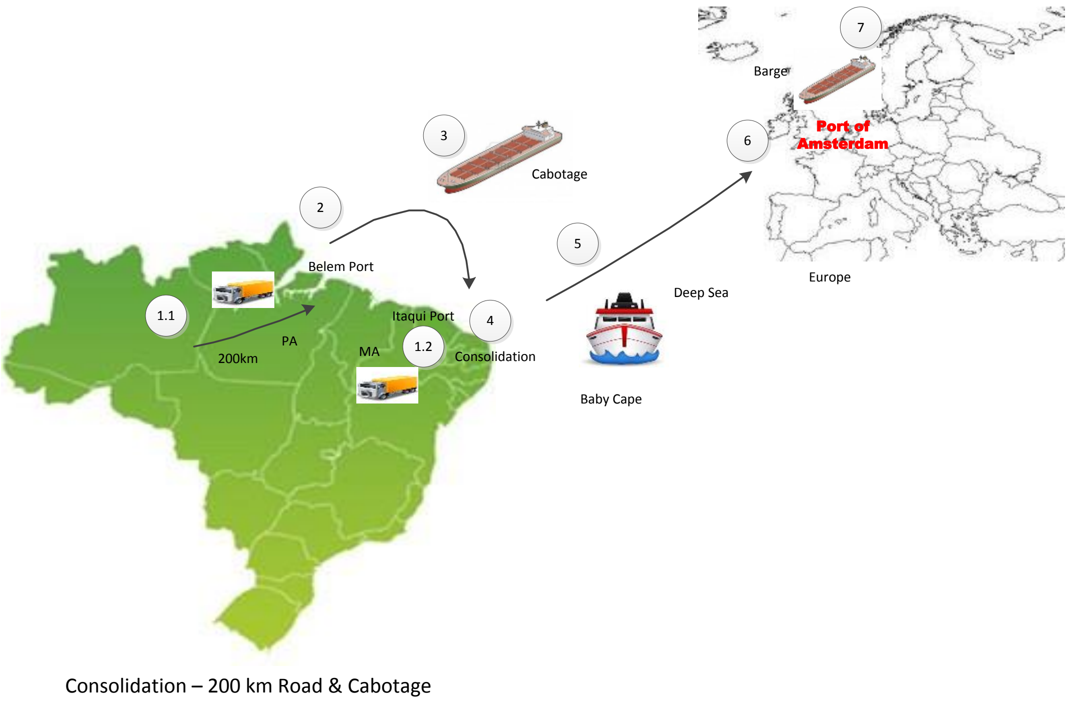
(4) Amsterdam Port
Pe=((3.1*tons) + (0.0536*day*tons))

Total Amsterdam Port Charges for transfer and storage for 45 days is as expected the same as 1A, **$5.5/ton**. The cost per unit for Amsterdam is expected to be the same as the same formula and prices is charged for different networks.

(5) Barge Distribution into Europe (B)
B=3.1*tons
Barge transportation cost is **$3/ton.** The barge cost per unit also remains the same as all networks are considered to end in the same port and therefore receive the same prices.

Finally, total supply chain cost for transport network 1B is of **$97/ton.** For this network, land transport is three times the distance used in network 1A. The trade off between longer truck transport and deeper draft port contributes for pushing up the final supply chain cost for this network.

Figure 24- Scenario 1C: Consolidation



Source: Author

In this scenario the truck transportation will travel a distance of 200km from the farm in Para to Belem Port. A handymax vessel will be deployed to transport by cabotage

47.000 pellets from the Port of Belem to a second and deeper draft port, Itaqui Port. In Itaqui this first pellet cargo will be consolidate with 43.000 tons of pellets and follow to Europe in a Baby Cape vessel (115.000 dwt). This last scenario is build in order to assess the costs of consolidation and possible advantages or disadvantages of this network over the independent export network (figure 24).

By imputing the figures in the formula:
(1) Road Transportation (RT)
RT=((0.37*tons) + (0.096*ton*km))

(1.1) From Para to Belem Port (First trip)
1.169 trucks will be needed to delivery 47.000 tons of pellets to Belem Port. Road transportation cost is **$20/ton**.

(1.2) From Maranhao to Itaqui Port (Second Trip)
1.070 trucks will be needed to delivery 43.000 tons of pellets to Itaqui Port. Road transportation cost is also of **$20/ton.** Hence, total road transportation cost in this network is 1.9 times higher than 1A and three times cheaper than 1B.

Brazilian Port Charges (Pb)
Pb= ((2.95*tons) + (0.054*day*tons))

(2) Belem Port (First trip) and (4) Itaqui Port (Second Trip)
Port Charges in Belem and Itaqui Port for storage duration of 45 is of **$10/ton.**

(3) Cabotage Cots (C)
C= ((12* tons)/1000*km)
Cabotage cost from Belem to Itaqui Port considering the distance between these two ports to be of 780km is of **$9/ton.**

(5) Maritime Transportation Cost (MT)
MT= freight rate*tons
Maritime transportation cost is of **$25/ton.**

(6) Amsterdam Port (Pe)
Pe=((3.1*tons) + (0.0536*day*tons))

Total Amsterdam Port Charges remains as **$5.5/ton**.

(7) Barge Distribution into Europe (B)
B=3.1*tons
Barge transportation cost is **$3/ton.**

Finally, total supply chain cost for transport network 1C is of **$68/ton.** In this network extra costs for cabotage and port charges in Brazil are added. The trade off in this network happens between these extra costs and the possibility to consolidate pellets from two different origins.

In the next topic “Hub-and-Spoke and Multiport Network are introduced as other more complex forms of pellets consolidation.

5.5.3 Multiport vs. Hub-and-Spoke Network

Multiport and Hub-and-Spoke are two distinct network systems both developed in order to optimize the transportation of goods. Multiport network combines cargos from different origins resulting in diverse calls in different ports. Hub-and-spoke networks have emerged as a tentative way to reduce costs by consolidating cargo at hub points. This thesis will not focus on the selection of transshipments and hub locations, but on the identification of transport cost from these two networks. The regions introduced in the previous topic remains as regions considered. Further, Baby Cape Ship (115.000 dwt) is the ship deployed in the Hub-and-Spoke network, while Panamax ship (60.000 to 80.000 dwt) is deployed in the Multiport network.

Multiport network scenario allows shippers or buyers to combine quantities produced far away from each other into one shipment to Europe. One limitation of this network is the draft limitation in some of the Brazilian ports. In Brazil many ports have draft limitations of around 13 meters or less, therefore maximum ship size considered in the Mulitport network is Panamax ship. Others adversities of this network are the extra port charges, longer travel time and deviation costs. Deviation cost is the cost ship-owner charge when ship needs to deviate its route in order to collect an extra cargo.

Hub-and-Spoke network allows bigger ships to be deployed and therefore higher amounts of pellets transported to its final destination. Economy of scale is one of the main advantages of this network, however the trade off between bigger ships and other extra costs incurred in this network need to be taken into consideration. Extra costs as cabotage costs and extra port charges are contributing to increase this network cost.

Figure 25- Scenario 2D: Hub-And-Spoke Network

Source: Author

In this scenario truck travel distance from all three farms (Para, Maranhao and Bahia) to Port areas (Belem, Itaqui and Salvador respectively) is assumed to be of 200km each. A handymax vessel will be deployed for cabotage to carry 30.000 tons of pellets from Belem to Itaqui and another handymax from Salvador to Itaqui. After consolidating these first two cargos with cargo in Itaqui Port, 90.000 tons of pellets will follow to Europe in a Baby Cape vessel (115.000dwt). The extra costs introduced by this scenario are the additional port costs and expenses with cabotage (figure 25).

The consolidation area for pellets originated in Belem and Salvador is Itaqui Port. The following inputs are necessary:

(1) Road Transportation (RT)
RT=((0.37*tons) + (0.096*ton*km))

(1.1) From Para to Belem Port (First trip)
(1.2) From Maranhao to Itaqui Port (Second Trip)
(1.3) From Bahia to Salvador Port (Third Trip)
In each trajectory 746 trucks will be needed in order to delivery 30.000 tons of pellets to each of the above three ports. Total road transportation cost is **$20/ton.** Total road transport cost in this network is 1.3 times higher than land cost in network 2E.

(2) Brazilian Port (Pb)
Pb= ((2.95*tons) + (0.054*day*tons))

(2.1) Belem Port (First trip)
(2.2) Itaqui Port (Second trip)
(2.3) Salvador Port (Third trip)
Total Brazilian Port Charges for transfer and storage is $**11/ton.**

(3) Cabotage Cost (C)
C= ((12*tons)/1000*km)

(3.1) From Belem Port to Itaqui Port
(3.2) From Salvador Port to Itaqui Port

Cabotage cost from Belem to Itaqui Port considering the distance between these two ports to be of 780km is **$9/ton** and from Salvador to Itaqui Port considering the distance between these two ports to be of 1.500km is of **$18/ton.** Cabotage costs in 2D is 1.9 times bigger than 1C.

(4) Maritime Transport (MT)
MT= freight*tons

Maritime transportation cost for a Baby Cape is **$25/ton**.

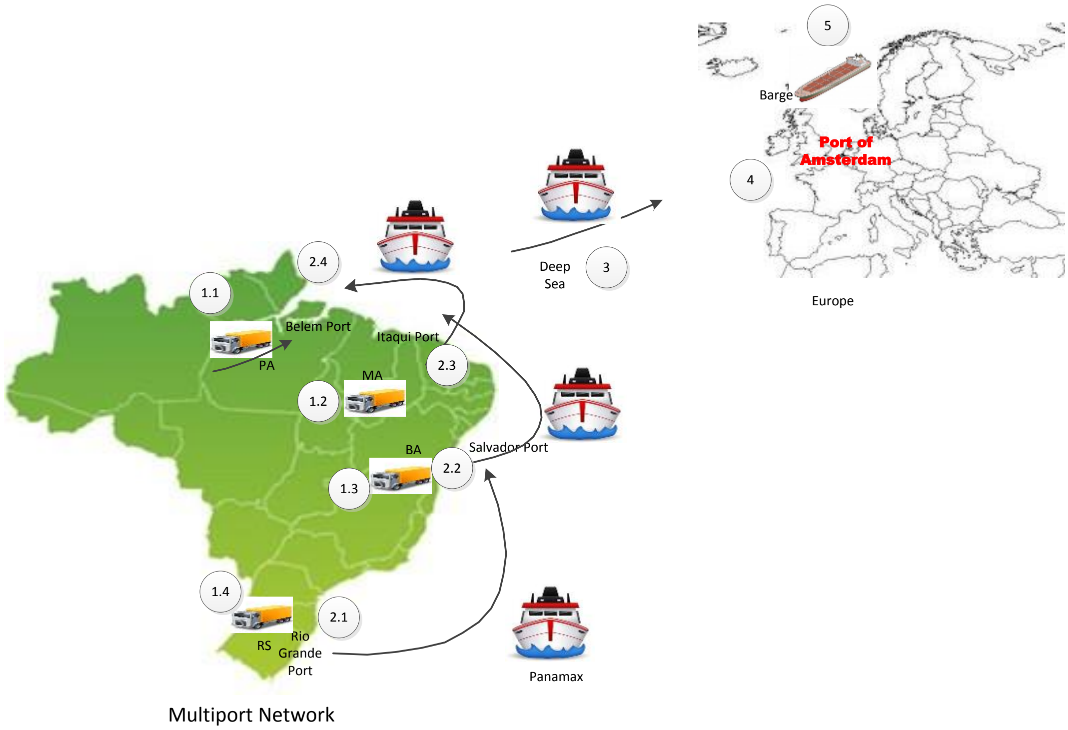
(5) Amsterdam Port (Pe)
Pe=((3.1*tons) + (0.0536*day*tons))

Total Amsterdam Port Charges for transfer and storage is **$5.5/ton.**

(6) Barge Distribution into Europe (B)
B=3.1*tons
Barge transportation cost is **$3/ton.**

Finally, total supply chain cost for transport network 2D is **$73/ton.** In this network three land side route is done to delivery three different pellets sources to three different ports. Therefore, this network incurs in extra land transport costs and extra port costs. Apart from that, cabotage transport is used to consolidate pellets from three different farms cargo into the hub port. The main trade off in this network happens between land, port, cabotage extra costs and bigger ships deployed in this network.

Figure 26- Scenario 2E: Multiport Network



Source: Author

In the Multiport scenario, road transport will be more extensively used then in the scenarios introduced before. Pellets originated in four different farms located in Para, Maranhao, Bahia and Rio Grande do Sul will have its production directed to the closest port, this distance is also assumed to be 200km. The maritime route in Brazil originates in the extremely south of the country, Rio Grande Port, going up in the direction of Belem Port. The vessel to be used is a Panamax vessel carrying a total of 70.000 tons of pellets. Four stops will be done in the Brazilian coast (Rio Grande Port, Salvador Port, Itaqui Port and Belem Port) before the vessel proceeds to its final destination, Northwest Europe, 17.500 tons of pellets will be loaded in each stop. The extra costs introduced by this scenario are port costs, longer travel time (increase in fuel consumption) and deviation costs, which occur as vessel reroute to pick up an extra cargo (figure 26).

By inputting the figures in the formula:

(1) Road Transportation (RT)
RT=((0.37*tons) + (0.096*ton*km))

(1.1)From RS to Rio Grande Port
(1.2) From BA to Salvador Port
(1.3) From MA to Itaqui Port
(1.4) From PA to Belem Port
Road transportation from four different farms to ports area is of **$20/ton**. Total road transport cost in 2D is 1.3 times higher than 2E.

(2) Brazilian Port Charges (Pb)
Pb= ((2.95*tons) + (0.054*day*tons))

(2.1)Rio Grande Port
(2.2)Salvador Port
(2.3) Itaqui Port
(2.4) Belem Port
Total Brazilian Port Charges for transfer and storage is **$5/ton.**

(3) Maritime Transportation (MT)
MT= freight*tons
Maritime transportation cost for a Panamax ship is **$30/ton.**

Extra costs are incurred in this network for deviations in the route to Europe. Deviation cost is of **$30.000/day**. In this route author have considered 5 days of deviation, therefore $9/ton.

(4) Amsterdam Port (Pe)
Pe=((3.1*tons) + (0.0536*day*tons))

Total Amsterdam Port Charges for transfer and storage is **$5.5/ton**.

(5) Barge Distribution into Europe (B)
B=3.1*tons

Barge transportation cost is **$3/ton.**

Finally, total supply chain cost for transport network 2E is **$66/ton**. In this network, the road transport cost is $20/ton, however there are 4 road trajectories against 3 road trajectories from network 2D. No extra cabotage costs is added. Brazilian port costs is lower than in Hub-and-Spoke network, once the cargo is direct transfer from storage to ship and not from cabotage to ocean ship as in network 2D. However, a deviation cost of $30.000 per day is added to this network for the route deviation. This network face trade off between land transport, extra port charges (however still lower than hub-and-spoke port charges), deviation costs and the direct consolidation of different sources of pellets in the shipment to follow to Europe.

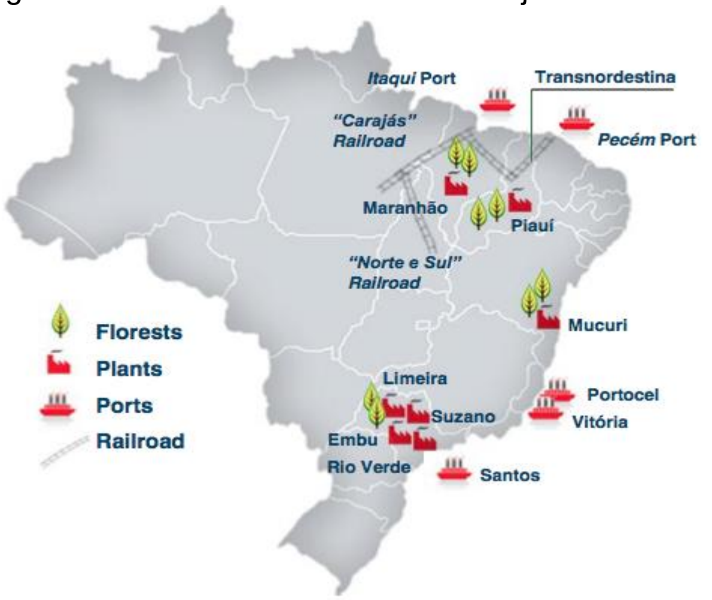
5.6 Suzano Renewable Energy Project

5.6.1 Overview

As introduced in the chapter 4, the eucalyptus and pines plantation in Brazil is located in its majority in the northeast of Brazil and south of the country. Brazil's vast space availability allows the vast cultivation of areas dedicated to the paper and pulp industry. Nevertheless, many new projects have been introduced in Brazil in order to be able to serve the emergent Biomass market.

One of the most promising projects towards the wood pellets market exploration in Brazil is the ambitious plan launched by the Suzano group. The company, which is the second largest eucalyptus pulp producer in the world, is in the paper and pulp industry for over 85 years. The wood pellets project of Suzano launched in 2010 will be able to supply markets with certified plantations and products, which will become essential in order to trade pellets globally in the future. The first phase of the project will have 3 pellet plants in Brazil. Production of 3 million tons of pellets per year will be exclusively allocated for the European market. The project is a large scale and fully integrated project, which will contain land and port infrastructure (figure 27). Its first phase is expected to become operational before 2014.

Figure 27- Suzano's Wood Pellets Project in Brazil



Source: Suzano, 2011.

5.6.2 Suzano Business Case

In this part the Suzano Renewable Energy project is transformed in a small business case in order to be able to foresee the costs companies, as Suzano will face when exporting its pellets to Europe.

In its first phase project, Suzano intends to use their forests located in the north of the country for the production of pellets to be exported to Europe. Suzano's strategy is to locate their pellet plant close to the forest unit and around 60km distance from port facility (figure 27). Company's plan is to use rail transport to delivery pellets from farm to the port. Further, storage duration in the export side will be considered the same as in the import side, 45 days. A simplified transport network for the Suzano Business Case is implemented below for general analysis. Handymax ship will be deployed in the route loading 47.000 tons of pellets:

By imputing the figures in the formula:

(1) Train Transportation (TT)

Train transport price for pellets is subtracted from Suur paper, which makes reference to data published by Borjesson in 1996. Train capacity considered is of 1000 tons and distances of 500km (Suurs, 2002).

TT=$11/ton (€9.0/ton)

(2) Brazilian Port Charges (Pb)

Transfer and storage cost for is $5/ton.

Pb=$5/ton

(3) Maritime Transportation (MT)
Handymax freight rates are estimated as $35/ton.

MT=$35/ton

Furthermore, the number of ships needed to be deployed through the year in this route in order to deliver 3 millions tons produced by Suzano is showed below:

Handymax Ship	
Number of Vessels/year	**64**
Number of Vessels/month	**5**

(2.2) Amsterdam Port (Pe)
Transfer and storage for is $5.5/ton.

Pe=$5.5/ton

(4) Barge Distribution into Europe (B)
Barge cost including transfer costs is $3/ton.

B=$3/ton

From the above calculation, each voyage made will incur in logistics total cost per ton of $60/ton. These costs will repeat five times a month and 64 times every year.

5.7 Conclusions
Transport Network tradeoffs have shown to be decisive in terms of determining Networks cost efficiency. Because each network is dealing with some specific features as different quantity of pellets transported, the comparison has been done in cost per ton and not absolute values. Network 1A is efficient in minimizing its land transport distance travelled, on the other hand by prioritizing short truck distance this network is limited to use smaller vessels. Its logistics total cost is $69/ton. Network 1B is characterized by longer land transportation and bigger vessels. This network is efficient in terms of maritime cost per ton ($25/ton), which was $10/ton cheaper than network 1A. Its total cost is $97/ton. Network 1C opts for consolidating different sources of pellets and end up by increasing its Brazilian port charges. The increase of cabotage charges does not affect this network as much as the increase of one extra port of call. Its total cost is $68/ton. Network 2D faces the following trade off; 2D chooses to collect three different sources of pellets and consolidates it in a hub port. By opting for a hub connection scheme, this network has extra cabotage costs and higher port charges in Brazil. The Brazilian port charge of Hub-and-Spoke network is the highest of all networks. Its total cost is $73/ton. Finally, network 2E chooses for diversifying its pellet sources and as a consequence it results in extra deviation costs.

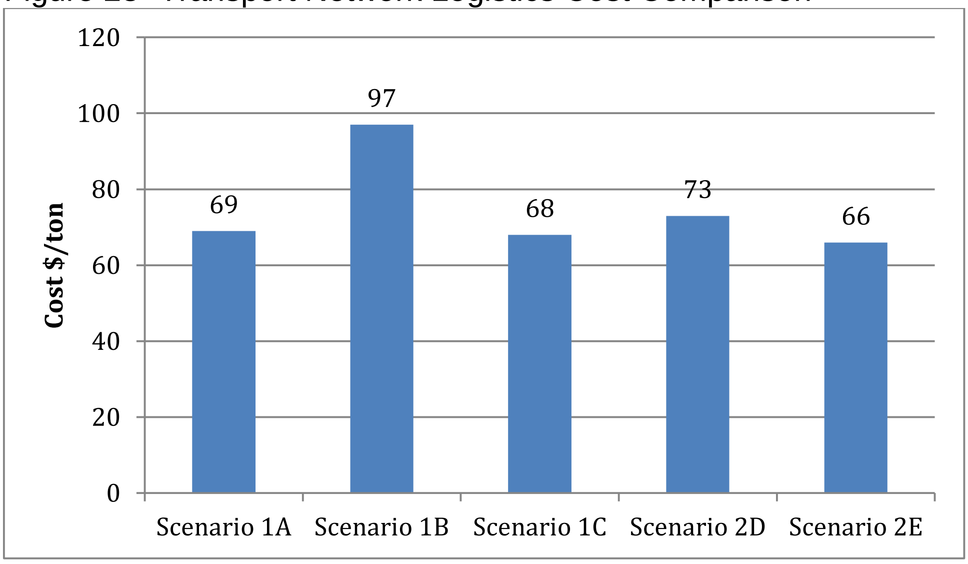
Total Supply Chain Overview

Scenarios Costs ($/ton)	Trade offs	Road Cost	Cabotage Cost	Brazilian Port Cost	Maritime Cost	European Port Cost	Barge Cost	Deviation Cost	Total Cost	Total/ton
Scenario 1A	**Closest Port-Smaller Vessel**	$919,790.00		$252,860.00	$1,645,000.00	$259,064.00	$145,700.00		**$3,222,414.00**	**$68.56**
Scenario 1B	**Longer land distance-Bigger Vessel**	$5,217,300.00		$484,200.00	$2,250,000.00	$496,080.00	$279,000.00		**$8,726,580.00**	**$96.96**
Scenario 1C	**Consolidation-Higher Port Charges**	$1,761,300.00	$439,920.00	$875,710.00	$2,250,000.00	$496,080.00	$279,000.00		**$6,102,010.00**	**$67.80**
Scenario 2D	**Hub Connection-Cabotage/Port Charges**	$1,761,300.00	$820,800.00	$984,000.00	$2,250,000.00	$496,080.00	$279,000.00		**$6,591,180.00**	**$73.24**
Scenario 2E	**Diverse calls-Deviation Costs**	$1,369,900.00		$376,600.00	$2,100,000.00	$385,840.00	$217,000.00	$150,000.00	**$4,599,340.00**	**$65.70**

Table 7- Source: Author's Calculation

From the scenarios presented in table 7 Multiport network (2E) is the most cost efficient network. Followed by network 1C, 1A, 2D and 1B in this order (figure 28). The results withdrawn from the formulation of different transport networks are outcomes of trade offs done each network. Some supply chain components have revealed to have a higher weight when determining network costs than others. For instance, by deciding to deploy bigger ships, network 1B ends up by increasing its truck transport cost to the highest of all networks. This tradeoff has shown to be the less efficient compared to all different scenarios.

Figure 28- Transport Network Logistics Cost Comparison



Source: Author

Therefore, a tentative formulation of a Hierarchical Framework has been introduced in order to have a better idea of the weights of different supply chain components in final network costs (Table 8). The Hierarchical Framework introduced by this thesis has shown to be valid for the realities presented here. Moreover, it has been formulated based on table 7.

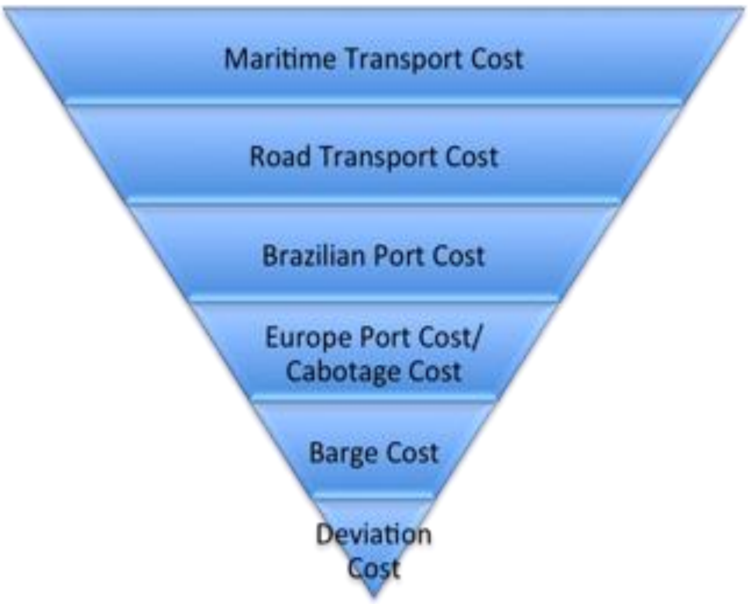
Pellets Transport Network Hierarchical Framework in Percentages

	Road Cost	Cabotage Cost	Brazilian Port Cost	Maritime Cost	European Port Cost	Barge Cost	Deviation Cost
Scenario 1A	29%	0%	8%	51%	8%	5%	0%
Scenario 1B	60%	0%	6%	26%	6%	3%	0%
Scenario 1C	29%	7%	14%	37%	8%	5%	0%
Scenario 2D	27%	12%	15%	34%	8%	4%	0%
Scenario 2E	30%	0%	8%	46%	8%	5%	3%

Table 8- Source: Author's Calculation

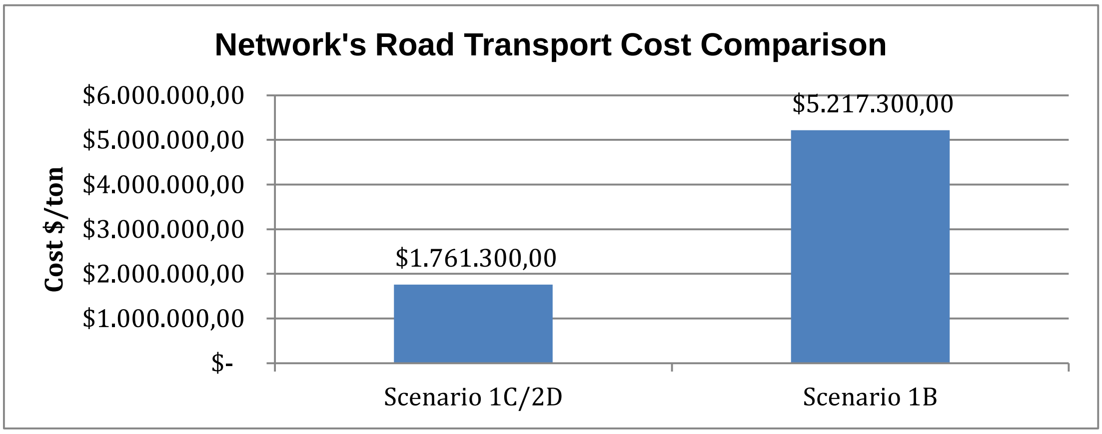
Road transport costs and Maritime Transport costs have shown to be the main cost drivers of the networks and therefore are located at the top of the hierarchy triangle (figure 29). For most of the networks maritime transport cost represents the biggest share of total supply chain cost (51%, 26%, 37%, 34% and 46%). This indicates that maritime transport cost is the main cause for wood pellets high logistic cost and therefore final price. Brazilian road transport cost is the second main cause for the pellets high logistics cost (29%, 60%, 29%, 27% and 30%). However, these figures used are for optimal plant location in Brazil, meaning distance between plant and ports of 200km. Greater distances than the ones considered in this thesis will generate a more expensive transport network. Therefore, as distances between plant and port in Brazil increases, road transport cost tends to move up in the triangle, as seen in Network 1B (600km) (table 8).

Figure 29- Hierarchical Framework for Pellets Transport Network



Source: Author

Figure 30- Road Transport Comparison



Source: Author's Calculation

When comparing road costs between networks with the same quantity of pellets (1B, 1C, 2D), trucks in 1B (600km) travel a three times longer route than trucks in 1C or 2D (200km). The result is truck costs in 1C or 2D are almost one third of truck costs in 1B () 30). This analysis shows how the weight of road transport cost increases as higher land distances are considered.

Road transport costs in the Multiport network is the second cheapest (in absolute values) from all the different networks. The lowest land transport cost are in network 1A, where only 200km is traveled by reduced 47.000 tons of pellets by truck to a one exclusive port of exit. Road costs in 1B travel a much longer road, 600km, while in 1C and 2D the same total amount of pellets are transported to port and each route remains the same 200km. This shows how important pellet logistic costs in Brazil in determining transport network efficiency.

Brazilian port costs are ranked in the third place in the hierarchical triangle (figure 29). Despite the small differences in fares charged for storage and transfer costs between Brazil and Europe, Brazilian port cost in the triangle tend to be ranked above the European port cost due to the extra port calls of some of these networks (1C, 2D and 2E). For the sake of simplification port charges for good designated to cabotage were considered the same as charges for goods designed to export. Storage duration in the port of exit for cabotage and export goods was also considered the same.

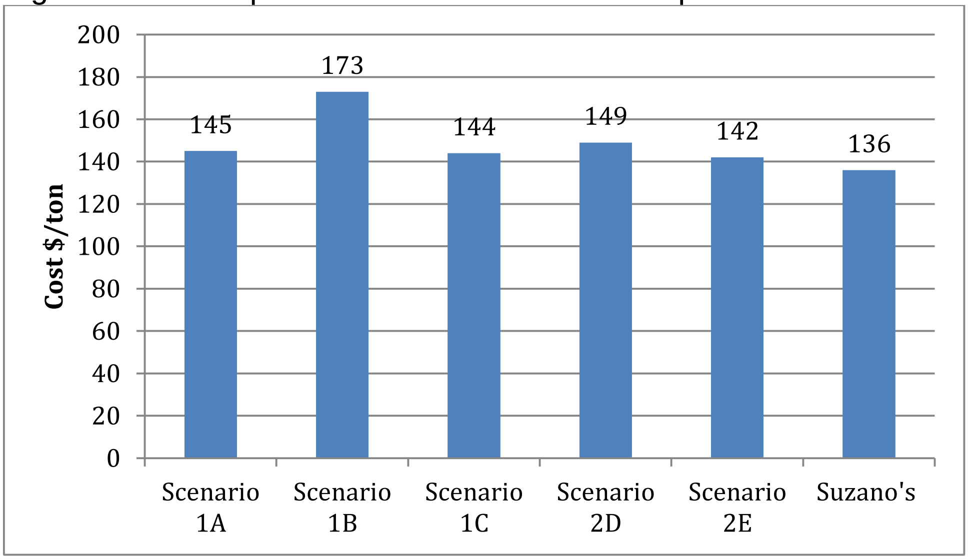
Cabotage costs and European port costs were both ranked in the forth place in the hierarchical triangle. With exception of network 2D, cabotage cost percentages (0%, 0%, 7%, 12%, 0%) from total costs were lower than European costs percentages (8%, 6%, 8%, 8%, 8%) (table 8). Nevertheless, when cabotage costs were present in a network, these costs are close to European port costs. Therefore, Cabotage costs and European port costs were both ranked in the same position in the hierarchical triangle. European transport costs are equal for 1B, 1C and 2D as these networks are unloading the same amount of pellets in the Port of Amsterdam.

Finally, barge cost and deviation cost are located in the bottom of the backward triangle (figure 29), meaning that they are the chain components that contribute less substantially to increase pellets final cost than all other costs.

The costs result presented by the Suzano's business case, $60/ton, is lower than any other transport network presented in this thesis. This occurs mainly because of the deployment of train transport in spite of road transport. Road transport cost in Brazil is the main drawback for pellets final price. Therefore, by introducing a cheaper modal to this supply chain Suzano will be able to decrease overall supply chain costs.

The formulation of these networks and business case show through an analytical methodology the main logistics bottlenecks for Brazilian pellet trade. In order to be able to access the final prices of Brazilian pellets to be exported to Europe, the below graph presents the comparison of the total cost of each network considering their logistics cost plus an average production price ($76/ton) (figure 31):

Figure 31 - Transport Networks Total Cost Comparison



Source: Author's Calculation

The average cost for ready to burn and transport wood pellets from Brazil to Europe, found in this thesis are ranging from $136-173/ton. Price of pellets varies a lot from country to country, and they are also subject to season and market conditions. Pellet costs published by Suur (2002) shows total cost for delivered and ready to burn pellets from coastal areas in Latin America to Europe to be ranging from $92-188/ton. Further, since 2007 a study done by the Germany's Biomass Research Center has revealed pellet prices in Europe to be ranging from $144-186/ton (Schaubach et al, 2012).

Therefore, the range found in the transport network introduced by the author can be considered a realistic range if compared to cost figures presented by Suurs and price overviews presented by Germany's Biomass Research Center. This shows that when good tradeoffs are done, transport network costs are brought down. As final conclusion, road transport distance should be kept down or when possible altered to another modal in Brazil. Brazilian pelletizing plants location can contribute significantly to networks effectiveness when they are located close to coastal areas. As ocean transport represents a big share of pellets final price, economies of scale should be when possible taken advantage of. Finally, port costs can be brought down if supply chain management is integrated and storage duration time is kept short.

Chapter 6– Brazilian Biomass Export Scenario Conclusions

6.1 Key findings and Implications

As energy policies in Europe develop towards stimulating biomass practices, international players gradually adjust to follow the new tendency of the market. Co-firing is becoming the new trend in the energy sector, and gradually biomass gets closer to becoming the next new commodity.

The route selected in this thesis has the potential to become in the near future the main trunk road for wood pellet trade. Northwestern Europe wood pellet consumption is rapidly increasing and Brazil has all factors necessary to become one of the top wood pellet producers in the world. The combination of factors as good climate, space availability and lower production costs makes of Brazil a potential exporter of primary goods as wood pellets. In order to guarantee the bilateral pellet trade between potential partners as Brazil and Europe, biomass supply chain costs in this route needs to decrease.

Wood pellets are a primary good with very particular characteristics. Pellets are very low-density goods. Its stowage factor is 0.6 to 0.7 tons/m3, while coal's factor is at least 1.2 tons/m3. Its big volume generates a major logistic challenge for its transportation over long distances. Apart from that, pellets require special covered storage and some handling techniques almost exclusively designed for this particular good. All of these factors contribute to pellets final costs making them less competitive compared to mineral commodities.

Consequently, despite Brazil and Europe's tendency to become strong partners into the pellet market, this bilateral trade is presented with some constraints able to jeopardize considerable trade gains for these two countries. Therefore, the analysis of different networks was made in order to formulate a system to counterweight pellets unfavorable characteristics and minimize some of these disadvantages.

Transport Network Design was defined by Tom Mathew (2009, 1) in a broad sense as " the configuration of transport network to achieve specified objectives". The formulation of a transport network in this route has as target to transform this trade into a more cost efficient trade through the study of different transport networks options to deliver the Brazilian pellets to Europe. In this thesis, wood pellets supply chain is composed by: Brazilian land transportation, Brazilian port, Ocean transportation, European port and Europe barge distribution. The main cost drivers for landside and waterside transports are distances (fuel), while storage duration and availability of machinery are the main cost drivers for port costs.

A denominated "Base Case" has been constructed in order to identify an average cost for each supply chain component. A handymax ship carrying 47.000 tons of pellets is selected for this case. Production costs are identified to be $76/ton, Road transport in Brazil is $20/ton, Brazilian Port costs are $5/ton, Ocean maritime costs is $35/ton, European Port costs are $5.5/ton and Barge for pellets distribution into Europe are $3/ton.

Considering the situation presented in the "Base Case", production costs were found to contribute to 53% of total supply chain costs and the breakdown of 47% originated from total logistics costs. Walter and Dolzan revealed that logistics costs for wood chips can represent from 65% to 90% of the production costs, with logistics costs representing 65% of production cost for coastal sites and 90% for inland sites. In this thesis production costs and logistics costs are both responsible for almost half of total costs for ready to burn and delivered pellets. This shows that despite production costs for pellets being extremely high, logistics costs represent almost the same share of total costs. With a clear picture of logistic cost structure, different transport network or scenarios were created with the purpose to find the most efficient transport network from Brazil to Europe. The networks proposed are: One exporter network (1A, 1B), Consolidation network (1C), Hub-and-spoke network (2D) and Multiport network (2E).

The results withdrawn from the formulation of different transport networks in the Brazil-Europe route are outcomes of trade offs done between the networks. Scenario 1A main trade off is done between closest port and smaller vessel. Pellets in this network are directed to the closest port, however it is on the other hand limited by ship size constraints in the nearest port. Scenario 1B faces a similar concept trade off as 1A, however this network opts to travel longer land distances in order to be able to deploy bigger scale vessels. Scenario 1C opts to consolidate different pellet origins and has extra port charges. Scenario 2D trade off happens in a similar way as 1C however in a more complex way. Consolidation of pellets originated in different places and extra port/cabotage costs are the main trade offs. Scenario 2E main trade off is done by diverse port calls with pellets consolidation direct into ships and extra port/deviation costs. Final pellet logistic costs (excluded production cost) were of $69/ton for Network 1A, $97/ton fro Network 1B, $68/ton for Scenario 1C, $73for Network 2D and $66/ton for Network 2E/ton.

From the analysis of the different network trade offs a hierarchical framework is build up showing which components contribute more to pellet logistic costs. Road transport costs and Maritime Transport costs were found to be the main legs determining network cost efficiency or inefficiency. Maritime transport cost is the component with the highest weight in this supply chain. Road transport cost (assuming 200km distance between plant and port) was the second factor contributing to pellets high logistics cost and the main reason for transforming network 1B in the less cost efficient network. Brazilian Port cost, Europe Port Cost/Cabotage Cost, Barge Cost and Deviation Cost were in this order ranked as contributing to pellets' logistic challenge.

Multiport Network was found to be the most cost efficient network ($66/ton) when exporting Brazilian pellets to Europe. The reduced land transport cost, economies of scale by deploying a panamax vessel, lower transference costs in Brazilian ports by consolidating the cargo already on board and the absence of cabotage costs have allowed this network to outstand the others networks. A business case of Suzano was also added to the comparison of networks costs. The business case presented even lower logistics costs, $60/ton. The main reason for that was the use of train transport on the landside in spite of road transport, proving the high weight of road transport cost in Brazil as determinant of pellets price effectiveness.

The average cost for ready to burn and delivered wood pellets in the Brazil-Europe route were found to be ranging from $142-173/ton. The market price of pellets can vary a lot from country to country and depending on several other market factors.

Since 2007, pellet prices in Europe have been ranging between $144-186/ton (Schaubach et al, 2012).

It can be concluded that when efficient transport networks are utilized for transporting pellets to Europe, final Brazilian pellet prices can be relatively cost efficient. Therefore, as Brazil becomes an active player in pellet production dedicated for export, the use of transport networks as Multiport Networks will allow Brazilian pellets to compete with countries as USA and Canada. To sum up, when costs for supply chain components located in the top of the hierarchical triangle are kept down, Brazilian pellet export to Europe can become successful. Nevertheless, the same barriers, which apply for active players in the market as USA and Canada, will be valid for Brazil. Wood pellet trade still completely depends on governmental subsidies and CO_2 charges schemes.

6.2 Limitations

Global biomass trade is very peculiar and still vague due to its recent significant expansion. Therefore, most of the patterns of this trade still do not follow a global standart. Because of biomass trade immaturity, in depth studies into this market can be a big challenge. Many gaps and constraints were encountered when conducting this study. In order to be able to provide a realistic study about this market, many assumptions and estimations were made necessary. The three main limitations to this thesis were: relatively new and inconsistent global wood pellet trade market, inexistence of wood pellet export from Brazil and finally reluctances of different players in the market in sharing its valuable data.

6.3 Future Research

Because of biomass trade fast growth many researches have been conducted in different fields of biomass. An interesting and necessary subject for future researches could be the formulation of supply chain costs after the introduction of torrefaction technologies in the market. A second subject for future researches could be the cost benefit analysis of investments in port infrastructure in order to be able to accommodate the forecasted high demand of wood pellets in the near future. The same analysis could be done for investments in other parts of the chain, such as landside transport. Another potential area for research is the analysis of how the use of dedicated ships and or dedicated terminals for pellets trade could affect pellets supply chain.

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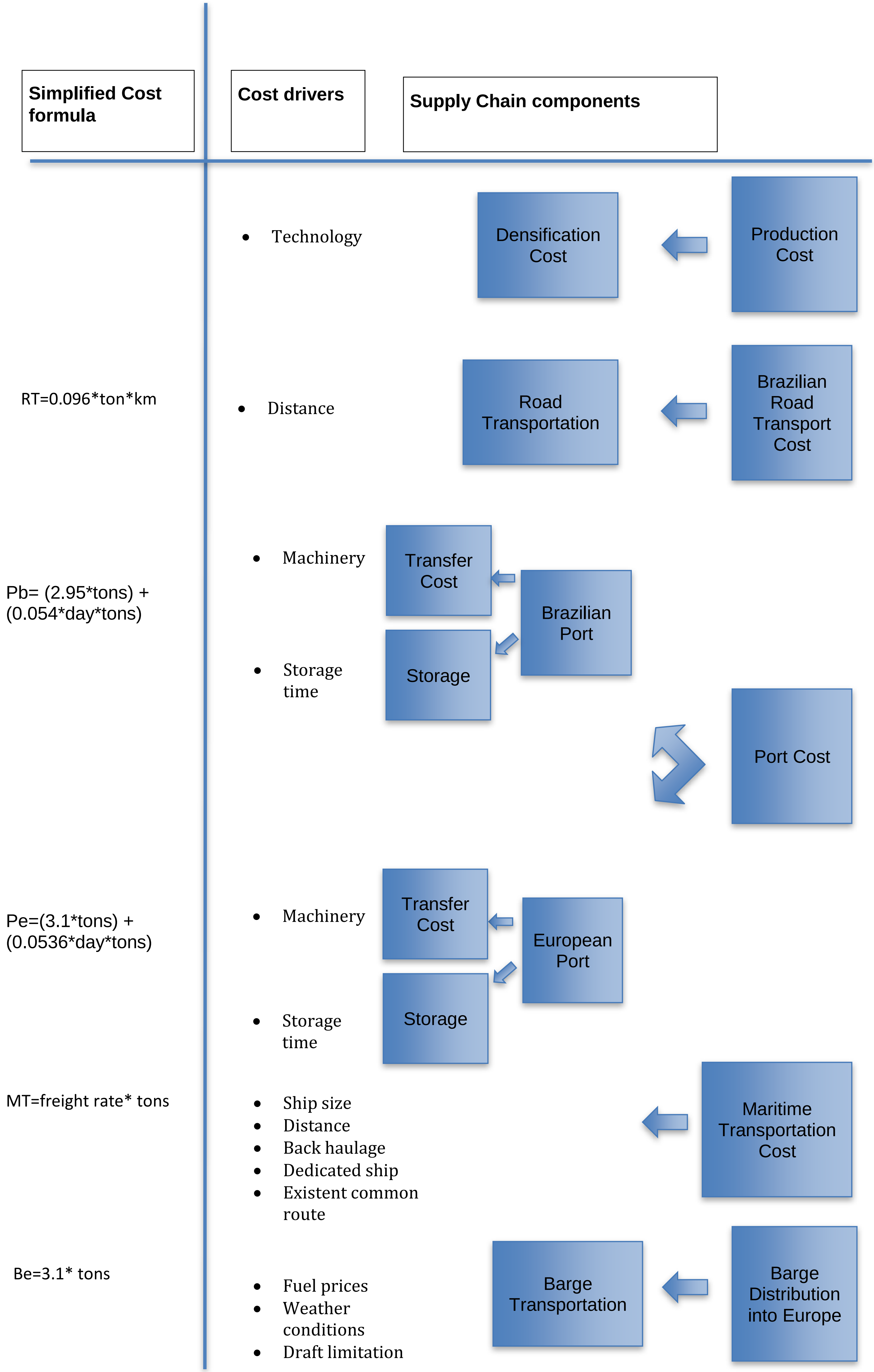
Appendices

Appendix 1



Simplified Cost formula
Cost drivers
Supply Chain components
Technology
Densification Cost
Production Cost
RT=0.096*ton*km
Distance
Road Transportation
Brazilian Road Transport Cost
Pb= (2.95*tons) + (0.054*day*tons)
Machinery
Transfer Cost
Storage time
Storage
Brazilian Port
Port Cost
Pe=(3.1*tons) + (0.0536*day*tons)
Machinery
Transfer Cost
Storage time
Storage
European Port
MT=freight rate* tons
Ship size
Distance
Back haulage
Dedicated ship
Existent common route
Maritime Transportation Cost
Be=3.1* tons
Fuel prices
Weather conditions
Draft limitation
Barge Transportation
Barge Distribution into Europe

Appendix 2

One Exporter vs. Consolidation				
	Scenario 1A	Scenario 1B		Scenario 1C
Sea Ship Size	Handymax	Baby Cape		Baby Cape
Cargo load (tons)	47000	90000	First trip	47000
			Second trip	43000
			Cargo consolidated	90000
Truck Distance (km)	200	600	Each trip	200
Number of trucks	1169	2239	First trip	1169
			Second trip	1070
Maritime distance				780
Road Price ($)				
RT=((0.37*tons) + (0.096*tons*km))				
Two way transfer costs ($)	$ 17,390.00	$ 33,300.00	First trip	$ 17,390.00
			Second trip	$ 15,910.00
Rt Cost	$ 902,400.00	$ 5,184,000.00	First trip	$ 902,400.00
			Second trip	$ 825,600.00
			First trip	$ 919,790.00
			Second trip	$ 841,510.00
Total RT ($)	$ 919,790.00	$ 5,217,300.00	Total	$ 1,761,300.00
			First trip	$ 19.57
			Second trip	$ 19.57
Total Rt Cost/ton	$ 19.57	$ 57.97		
Maritime Price ($/ton)	$ 35.00	$ 25.00		$ 25.00
MT= freight*tons				
Total MT ($)	$ 1,645,000.00	$ 2,250,000.00		$ 2,250,000.00
Cabotage Price ($)				
C=(12*tons)/1000*km)				$ 439,920.00
Total Cabotage Cost/ton				$ 9.36
Brazilian Port Price ($)				
Storage (days)				0
s=0.054*day*tons			First port	114210
			After Consolidation	218700
45	$ 114,210.00	$ 218,700.00		
	$ 2.43		After Consolidation	$ 332,910.00
Transfer Cost ($)				$ 3.70
t=2.95*tons				
Transfer cost/ton ($)	$ 2.95	$ 2.95	First Port	$ 277,300.00
Total Transfer	$ 138,650.00	$ 265,500.00	After Consolidation	$ 265,500.00
				$ 542,800.00
Brazil Port Cost 45 days	$ 252,860.00	$ 484,200.00		$ 875,710.00
Brazil Port Cost/ton 45 days	$ 5.38	$ 5.38		$ 9.73
Europe Pe=st				
Storage (month)				
st=0.0536*day*tons				
45	$ 113,364.00	$ 217,080.00	Ater Consolidation	$ 217,080.00
Transfer Cost ($)				
t=3.1*tons	$ 145,700.00	$ 279,000.00		$ 279,000.00
Europe Port Cost 45 days	$ 259,064.00	$ 496,080.00		$ 496,080.00
Europe Port Cost/ton 45 days	$ 5.51	$ 5.51		
Barge Price (€)				
B=3.1*tons	$ 145,700.00	$ 279,000.00		$ 279,000.00
Total Supply Chain Costs	$ 3,222,414.00	$ 8,726,580.00		$ 6,102,010.00
Total Supply Chain Costs/ton	$ 68.56	$ 96.96		$ 67.80

Appendix 3

Hub-and-Spoke			
	Scenario 2D		
	Belem Port	Itaqui Port	Bahia Port
Sea Ship Size	Handymax	Baby Cape	Handymax
Cargo load (tons)	30000	30000	30000
Total to Export			90000
Truck Distance (km)	200	200	200
Number of trucks	746	746	746
Distance Cabotage	780		1500
Road Price (€)			
RT=((0.37*tons)+(0.096*ton*km))			
Two way transfer costs	$ 11,100.00	€11,100	$ 11,100.00
Rt Cost	$ 576,000.00	$ 576,000.00	$ 576,000.00
Total RT	**$ 587,100.00**	**$ 587,100.00**	**$ 587,100.00**
			$ 1,761,300.00
Cabotage Price			Total
C=(12*tons)/1000*km)	**$ 280,800.00**	**$ 540,000.00**	**$ 820,800.00**
Total Cabotage Cost	$ 9.36	$ 18.00	**$ 9.12**
Port Price (€)			
s=0.054*days*tons			
Storage (days)			
45	$ 72,900.00	$ 218,700.00	$ 72,900.00
Transfer Cost			
t=2.95*tons	$ 177,000.00	$ 265,500.00	$ 177,000.00
Total Brazil Port 45 days	**$ 984,000.00**		
Total Brazil Port 45 days	**$ 10.93**		
Maritime Price (€/ton)	$ 25.00		
MT= freight*tons	**$ 2,250,000.00**		
Europe Pe=st			
Storage (month)			
st=0.0536*day*tons			
first 15 days free of charge	free of charge		
45	$ 217,080.00		
Transfer Cost (€)			
t=3.1*tons	$ 279,000.00		
Europe Port Cost 45 days	**$ 496,080.00**		
Europe Port Cost/ton 45 days	**$ 5.51**		
Barge Price (€)			
B=3.1*tons	**$ 279,000.00**		
Barge cost/ton	$ 3.10		
Total Supply Chain Costs 30 days	**$ 6,591,180.00**		
Total Supply Chain Costs/ton 30 days	**$ 73.24**		

Appendix 4

Multiport Network					
	Scenario 2E				
Sea Ship Size - Panamax	Rio Grande Port	Salvador Port	Itaqui Port	Belem Port	Total
Cargo load (tons)	17500	17500	17500	17500	70000
Truck Distance (km)	200	200	200	200	
Number of trucks	435	435	435	435	
Distance Cabotage (km)	3180	1500	780		
Road Price (€)					
RT=((0.37*tons) + (0.096*ton*km))					
Two way transfer costs ($)	$ 6,475.00	$ 6,475.00	$ 6,475.00	$ 6,475.00	
Rt Cost ($)	$ 336,000.00	$ 336,000.00	$ 336,000.00	$ 336,000.00	Total/ton
Total RT ($)	**$ 342,475.00**	**$ 342,475.00**	**$ 342,475.00**	**$ 342,475.00**	**$ 1,369,900.00**
Total Rt Cost/ton	$ 19.57	$ 19.57	$ 19.57	$ 19.57	$ 78.28
Brazilian Port Price (€)					
Storage days					
s=0.054*days*tons					
45	$ 42,525.00	$ 42,525.00	$ 42,525.00	$ 42,525.00	
Trabsfer Cost ($)					
t=2.95*tons	$ 51,625.00	$ 51,625.00	$ 51,625.00	$ 51,625.00	
Brazil Port Cost 45 days	**$ 376,600.00**				
Brazil Port Cost/ton 45 days	**$ 5.38**				
Deviation Cost (per day)					
d=30.000*day					
30000	**$ 150,000.00**				
5	**$ 8.57**				
Maritime Price (€/ton)	$ 30.00				
MT= freight*tons	**$ 2,100,000.00**				
Europe Pe=st					
Storage (days)					
st=0.0536*day*tons					
45	$ 168,840.00				
Transfer Cost (€)					
t=3.1*tons	$ 217,000.00				
Europe Port Cost 45 days	**$ 385,840.00**				
Europe Port Cost/ton 45 days	**$ 5.51**				
Barge Price (€)					
B=3.1*tons	**$ 217,000.00**				
Barge/ton	€3.10				
Total Supply Chain Costs	**$ 4,599,340.00**				
Total Supply Chain Costs/ton	**$ 65.70**				