INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

Analysis on the feasibility of electricity and pellet production in the District of Bragança using coniferous forest

Luís Manuel Fernandes Rocha

Final Report submitted to the

School of Technology and Management of Bragança

Polytechnic Institute of Bragança

for the degree of Master in

Renewable Energy and Energetic Efficiency

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Advisor:

Dr. João Miranda de Castro

Co-Advisor:

Dr. Luís Frölén Ribeiro

"This Final Report includes the criticisms and suggestion made by the jury."

November 2012

"El hombre es tanto lo que sabe, y si es sabio, es capaz de cualquier cosa. Un hombre que no conoce, es el mundo a oscuras."

Author: Baltasar Gracián y Morales

ACKNOWLEDGMENT

I would like to thank all those who had the opportunity to meet and work during this Master period. In particular, my thanks go to:

Dr. Luís Frölen Ribeiro and Dr. João Miranda de Castro for guidance, suggestions, contributions, encouragement and teaching given to this thesis, as well as the friendship;

Dr. João Azevedo for initial guidance and support, as well as given the opportunity to see in firsthand both industries analysed in this thesis;

My parents and family, who have always encouraged my education and supported my decisions;

My girlfriend, for companionship, patience, words of encouragement and confidence that never lacked;

Lieutenant-Colonel (OF-4) Lourenço, Lieutenant-Colonel (OF-4) Lajes, Captain (OF-2) Miranda, Captain (OF-2) Oliveira, Sergeant Major (OR-9) Antunes, Master Sergeant (OR-7) Oliveira, Master Sergeant (Or-7) Trindade, Master Sergeant (OR-7) Gaspar, First Sergeant (OR-6) Gomes, Quartermaster (OR-5) Teixeira, Quartermaster (OR-5) Ferrão, Quartermaster (OR-5) Cunha and all other military personal that supported my career and give the opportunity to conciliate both activities.

All other teachers, colleagues and friends who attended these three years, not only in the hours learning, but the tips and suggestions for activities and ways to go forward.

ABSTRACT

This thesis aimed to demonstrate the forestry potential of pellets and / or electricity production in the district of Bragança.

First, the use of Forest Biomass at international and national level was analyzed to better situate the forestry market and its growing potential up to today.

Then, the forest operating systems existing able to be used were analyzed, dividing them into five components: activities of production, forest biomass transportation, forest processing systems, and conversion technologies.

Next, a review of forest biomass in the district of Bragança, using the 2007 Land Cover Map for Continental Portugal, the 5th National Forest Inventory and Florestat 5.0 software, was carried. For annual values of forest biomass to be industrially processed, three scenarios were considered (conservative, regular and optimistic) estimating 144.645, 227.484 and 340.340 tones to be of industrial processes, using as example of study the pellet production plant and thermoelectric power station of Mortágua, Viseu.

The values of annual production of pellets range from 57.607 to 135.545 tonnes resulting in sales between 1,8 to 4,3 M€, and, for the thermoelectric power station the production was between 134,3 to 316 GWh achieving sales between 2,4 to 5,7 M€.

An estimate of electricity dependence reduction was performed to the district of Bragança using forest biomass, reaching 58% for a conservative scenario and 137% for an optimist scenario.

Finally, the political and environmental limitations are presented per scenario.

Key-words: Biomass, pellets, electricity, timber.

RESUMO

Esta tese teve como objetivo demonstrar o potencial florestal na produção de pellets e / ou eletricidade no distrito de Bragança.

Inicialmente descreveu-se o uso da Biomassa Florestal a nível internacional e nacional, para melhor situar o mercado florestal e o seu crescente potencial até aos dias de hoje.

Seguidamente foram analisados os sistemas operativos florestais, dividindo-os em cinco componentes: atividades de produção, transporte da biomassa florestal, sistemas de processamento florestal, transformação da biomassa florestal em produto final e tecnologias de conversão.

Com uso da Carta de Ocupação do Solo de 2007, do 5.º Inventário Florestal Nacional e *software* Florestat 5.0 foi determinada a área florestal de potencial interesse no distrito de Bragança. Consideraram-se três cenários de acréscimos médios anuais (conservador, regular e otimista) estimando valores de 144.645, 227.484 e 340.340 toneladas secas de biomassa florestal para serem industrialmente processadas, usando como exemplo de estudo a fábrica de produção de pellets e a central termoelétrica em Mortágua, Viseu.

Estimaram-se valores de produção anual de pellets entre 57.607 a 135.545 toneladas originando vendas de 1,8 a 4,3 milhões de Euros, e, a produção termoelétrica variou entre 134,3 a 316 GWh, atingindo vendas entre 2,4 a 5,7 milhões de Euros.

Ainda se estimou a redução da dependência elétrica no distrito de Bragança com uso da biomassa florestal, atingindo 58% para um cenário pessimista e 137% para um cenário otimista.

Finalizando, são apresentadas as limitações, conclusões e trabalho futuramente a desenvolver.

Palavras-chave: Biomassa, pellets, eletricidade, madeira.

PUBLICATIONS

Castro, J.; Azevedo, J.; Brzezińska, D.; Olechnowicz, M.; Rocha, L. *TechBioEnergy*. Lisbon, 2012.

INDEX

TABLE INDEX

FIGURE INDEX

GRAPHIC INDEX

ABBREVIATION LIST

AAI - Average Annual Increase

ADF - Alfândega da Fé

BGC - Bragança

ºC - Celsius degrees

CAOP - *Carta Administrativa Oficial de Portugal* or Official Administrative Portuguese Cartography

CEN - *Comité Européen de Normalisation* or European Committee for Standardization

CH_4 - Methane

CHP - Combined Heat and Power

cm - centimetre(s)

CO_2 - Carbon Dioxide

COS - *Carta de Ocupação de Solo* or Land Occupation Chart

CZA - Carrazeda de Ansiães

DGRF - *Direção-Geral dos Recursos Florestais*

DL - *Decreto-Lei*

EC - European Commission

EU - European Union

EU 27 - European Union constituted by 27 countries

FEC - Freixo de Espada à Cinta

FB - Forest Biomass

FEF - Fuel Emission Factor

FIT - Feed-In Tariffs

GDP - Gross Domestic Product

GHG - Green House Gases

GIS - Geographic Information System

GVA - Gross Value Added

ha - hectare

IFN - *Inventário Florestal Nacional* or National Forest Inventory

IPCC - Intergovernmental Panel on Climate Changes

J - Joule

Kg - kilogram(s)

kWh - kiloWatt hour(s)

LHV - Lower Heat Value or Lower Heating Value[1]

m - metre(s)

m. c. - moisture content

m^3 - cubic metre(s)

MCV - Macedo de Cavaleiros

MDO - Miranda do Douro

MIA - Mirandela

MIZ - Municipal Industry Zone

MJ - Mega Joule

mm - millimetre(s)

MOG - Mogadouro

MW - Mega Watt

MWhe - Electric Mega Watt

N_2O - Nitrous Oxide

O&M - Operational and Management

OECD - Organisation for Economic Co-operation and Development

PWN - Pine Wood Nematode

RAR - *Resolução da Assembleia da República*

RES - Renewable Energy Sources

RFB - Residual Forest Biomass

ROI - Return Of Investment

TMC - Torre de Moncorvo

toe - tonnes of oil equivalent

ton - tonne(s)

VLR - Vila Flor

VIM - Vimioso

VIN - Vinhais

W - Watt

yr - year

[1] Measured in units of energy per unit of substance, usually mass, such as kcal/kg, kJ/kg or Btu/m^3.

1. INTRODUCTION

1.1. FRAMEWORK

The present thesis is intended to evaluate the potential use of Forest Biomass (FB) considering two possible ways:

- Produce electricity;
- Produce pellets.

To implement this idea was necessary to create an algorithm to estimate the quantity and quality of FB in the district of Bragança, and, therefore, estimate the amount of electricity that can be generated through steam turbines or, the amount of pellets that can be produced.

Figure 1 represents the algorithm used as methodology.

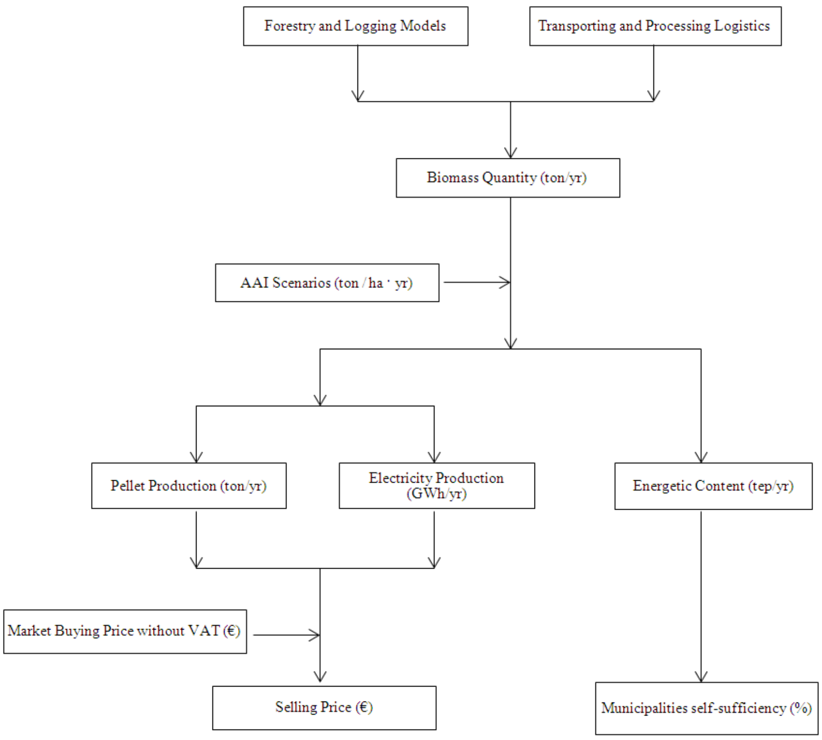

Figure 1 - Thesis algorithm.

The several steps presented in Figure 1 are divided in three main chapters:

- Estimate the amount of yearly dry FB with potential interest (coniferous forest) in the District of Bragança, considering forestry and logging models, and, transporting and processing logistics;

- Estimate the yearly monetary value of pellets and electricity - at current market prices without VAT - producible in each factory, using as references the pellet factory and the thermoelectric power station, both established in Mortágua, Viseu;
- Estimate the yearly energetic self-sufficiency in the District of Bragança, considering Azevedo *et al*. (2012).

It was taking under primary consideration the possibility of 30 year between cuts in order to promote growth of trees, and maintain the logging processes as sustainable as possible. Also, this same period was used to estimate the Return of Investment (ROI) of each factory.

Therefore, the thesis has four main objectives:

- Quantify the production of FB with potential interest in the municipalities of the District of Bragança, considering forestry and logging models, and, transporting and processing logistics;
- Evaluate the industrial production of electricity through a thermoelectric power station, and, the pellets production through a pellet factory;
- Evaluate the energetic self-sufficiency in the District of Bragança, using FB with potential interest;
- Estimate the selling potential of the final product, either pellet or electricity to the grid, and estimate the ROI.

1.2. OUTLINE

This thesis is divided into seven chapters. Chapter 2 serves as the introductory chapter to the subject of the use of forest biomass, its development in Europe and Portugal, and incentives allocated to electricity production from forest biomass. In Chapter 3 are described the operating systems divided into production, logistics, operating systems, processing and technologies used to convert forest biomass into other form of energy. To explain the quality and quantity of forest biomass used in calculations, in Chapter 4 the District of Bragança is assessed in terms of soil occupation, forest characterization area and methodology employed to determine the potential interest forest area, as well as considerations used to achieve results. Chapter 5 presents the results of the annual production for a thermoelectric power station and a pellet factory, while Chapter 6 discusses the problems and limitations. The conclusions and recommendations for future work are described in Chapter 7.

2. USE OF FOREST BIOMASS FOR ENERGY PURPOSES

Quoting EC (2003), "biomass is the biodegradable fraction of products and waste from agriculture (including vegetal and animal substances), forest and industries, as well as urban and industrial activity", i.e. for this thesis, the result of different types of forestry activities - logging operations, forest maintenance, operations required for for-estation, recovery of burned areas or affected by pests or diseases.

This is applied as the concept of Forest Biomass (FB) referring to the wood biomass from available forest in the district of Bragança, namely coniferous forest, designated for the production of electricity or to be transformed into densified wood. To achieve this it is necessary to process FB - rolls, stumps, branches and leaves - although not all of these fractions are or ought to be used.

Notwithstanding, it is necessary to contextualize the historical data available from FB use across the world, and particularly in Portugal.

Until 1850, it was virtually the only source of energy used as presented in Figure 2.

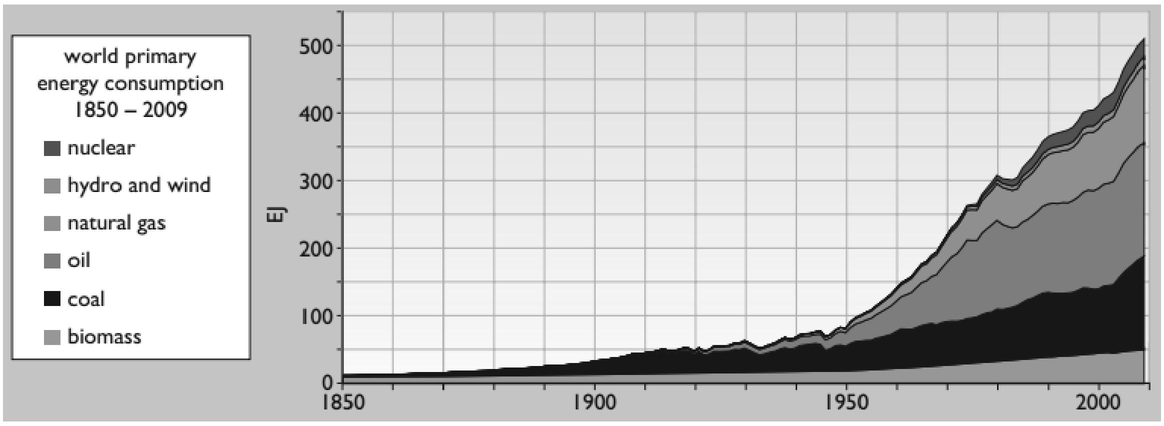

Figure 2 - World energy consumption by energy source. Source: (Peake, Everett and Boyle 2011)

The Industrial Revolution not only sparked the growth of production of energy through coal, but also exponentially increased population and economic activities, and, with that, growing energy needs. Despite already existed production of energy from oil in the first half of the 20th century, the Second World War was a major event which gave importance to oil that still has in the world economy. In recent decades, the trend towards diversity of energy sources assumed higher expression towards nuclear power and natural gas.

The decrease in biomass use - the majority from forest - since the Industrial Revolution, has obvious practical reasons, especially if the energy density of biomass is compared with other fuels, were the conversion to energy is most inefficient, as seen in Table 1.

Table 1 - Energy content (LHV) of solid and liquid fuels. Source:(IPCC 2000, Sims 2002, Tester, et al. 2005, Kopetz, et al. 2007)

Fuel	LHV (GJ/m^3)	LHV (GJ/ton)	LHV (toe/ton)
Diesel	35,4	42,9	1,00
Biodiesel	32,8	37,3	0,87
Gasoline	31,9	42,9	1,00
Bioethanol	21,2	26,7	0,62
Residual Forest Biomass (wood chips, 40% m. c.)	2,9	9,5	0,22
Pellets (8-9% m. c.)	10,2	16,9	0,39
Oil (crude)	36,4	42,9	1,00
Natural Gas	21,9	43,8	1,02

Note: LHV - Low Heat Value, toe - tonnes of oil equivalent, m. c. - moisture content.

The evolution to non-fossil fuels with higher power density and in liquid form was therefore a change in the nature of the search for efficiency savings. Moreover, the scattered distribution of forest biomass makes the use of this resource onerous in comparison with its alternatives, mainly because it is concentrated in deposits. These causes make biomass fuel relatively expensive to alternatives and transformed the importance from almost non-existing to about 3,5% of primary energy production in OECD (Organisation for Economic Co-operation and Development) countries in 2005 and 40% in non-OECD countries on a residential analysis (IEA 2007, IEA 2011).

This sudden interest in biomass - although some countries have already bet for more than two decades - is the result of a set of circumstances that privileged not only energy from biomass, but all renewable energies (Chambers and Bailey 1996, DGS & Ecofys 2005, Saidur, et al. 2011).

The most relevant cause to the current growth and potential of biomass is climate change. Although the consensus has been expressed since 2001, when the 3rd Assessment Report of the IPCC (Intergovernmental Panel on Climate Change) was published, the magnitude acquired another problem with the entry into force of Kyoto Protocol after Russia's ratification in 2005, and the visibility of the Al Gore documentary "An Inconvenient Truth".

Particularly relevant for the combustion of biomass is the indication that only CH4 and N2O emissions should be accounted for inventories and, therefore, biomass is considered a neutral source of energy in CO_2 emissions, which is already considered in European market for allowances (EU 2004).

2.1. SITUATION OF BIOENERGY IN EUROPE

Bioenergy can be classified into three main categories: solid, liquid and gases. The first is formed by wood, herbaceous and mixtures of biomass (Alakangas, Valtanen and Levlin, CEN technical specification for solid biofuels – fuel specification and classes 2006, ASI 2010), the liquid biofuels comprise mainly biodiesel and bioethanol (The World Bank; FAO; IFAD 2009); and, biogas comes from mostly anaerobic digestion of solid biomass (AEBIOM 2009).

To better explain the importance of Bioenergy, is necessary to describe the actions taken by political will to implement it.

In 1997, EU launched the "White Paper for a Community Strategy and an Action Plan" and, in 2007 was launched the communication "An Energy Policy for Europe" showing initiative to impose targets for the production of energy from RES (EC 1997, CEC 2007).

By that, the European energy policy has advanced on three fronts:

- Search of competitiveness leading to economic growth and job creation;
- Security of supply reducing energy dependence on countries;
- Sustainability committing itself to reducing GHG emissions.

All this established an overall contribution of 12% by RES in 2010 (ECS 2010).

In 2001 the European Commission (EC) established a global target for the production of electricity from RES of 22,1% in 2010, while the goal for individual Portugal was 39%. The 2010 data indicate that the contribution of renewable energy in electricity production in the European Union (EU 27) was 20,1% and Portugal stood at and 54,7% (Por Data 2010).

In 2010 the communication COM (2010) 639 (ECS 2010) provided a strong impetus for the establishment of three important and ambitious targets for 2020:

- A 20% reduction in GHG emissions from the levels of 1990;

- A contribution of 20% in renewable energy for primary energy production;
- A reduction of 20% of global primary energy.

EU aware that biomass can make a bigger contribution for the production of primary energy produced the “Action Plan for Biomass” which, in addition to stress the importance of biomass to target achievement, established a set of measures with the purpose of promoting and developing energy production from this resource. Among the most relevant was that Member States should develop their own plans, to review the Value Added Tax (VAT) on heating buildings biomass, implement and monitor the aid for energy crops, and encourage research into biofuels and biorefineries of 2nd generation (CEC 2005).

The Kyoto mechanisms - emissions trading, joint implementation and clean development mechanism - favour the development of biomass. The trading of allowances, already in operation at Europe, permit energy producers to reduce their emissions through the co-combustion of biomass, opening a way to develop projects considering a reference scenario without any project. The dedicated biomass power station can in this context be eligible to reduce GHG emissions and help to achieve the goals set (EC 2003).

Portugal demonstrated recently political will in using forest biomass on a near future, launching laws concerning the inherent use of biomass to produce electricity and protect forest (DL 5 2011, DL 179 2012, RAR 70 2012).

Along with these targets, it was estimated that the potential of the bioenergy can represent between 15-16% of energetic needs in 2030 on Europe and World (IEA 2003, Wiesenthal, et al. 2006, Kopetz, et al. 2007).

2.2. INCENTIVES FOR ELECTRICITY PRODUCTION FROM BIOMASS

Most of the incentives for biomass energy production are restricted to the electricity sector. They can be classified into four categories (CEC 2005):

Rates of acquisition (Feed-In Tariffs - FIT): are the introduction of a fixed price per unit of energy paid to the producer that uses a renewable source and valid for a period of several years. All electricity suppliers are supported, through their consumers, the additional costs of the scheme through a payment to the distribution company proportional to the sales volume. This system is more usual in the EU, namely in Portugal, Spain and France.

Green Certificates: in this incentive scheme the consumers, usually through their electricity suppliers, have to satisfy the requirement of having part of their consumption of electricity from of RES. The result is the creation of a competitive market in licenses acquisition, favouring producers who produce cheaper electricity.

Tenders: in public procurement, the state opens the possibility of companies to compete with power generation projects, establishing a contract with the winning company and ensuring a certain price. This mechanism is applied, in the Portuguese case, together with the Feed-In Tariffs.

Tax incentives: they reduce the tax burden of electricity produced from RES, increasing competitiveness with other producers.

FIT and Green Certificates are the usual incentives in EU because they can over-finance renewable energies system and when compared to the system of Green Certificates, which, if a well working market is created, can be more financial-effective. For example, the electricity market is very sensitive to seasonal weather, and, in a wet winter, hydropower can create market certificates in excess, which will reduce its price and affect the producers. Part of the solution may be to establish lower and higher limit prices in green certificates, safeguarding the interests of producers and consumers.

Nevertheless, FIT raises a problem that already exists in Portugal. The existing system is a mix between Green Certificates and FIT which encourages the use of biomass to produce electricity. The FIT for biomass, calculated using the guidelines laid by Decreto-Lei no. 33-A/2005, is between € 106 - 108 per MWhe for power stations exceeding 5 MW.

Due to the major differences between FIT in several Member States (Table 2), forest biomass in Portugal is currently exported in form of pellets to countries such as Italy (Alakangas, Heijjinen, et al. 2007), putting the exporting Member State facing a problem of shortage of biomass to supply its own power. At the environmental level, exportation makes this system have higher GHG emissions, if considered shipping or road travel.

Table 2 - Feed-In Tariffs for electric using forest biomass for some countries in the EU. Source:(Jager, et al. 2011, Obernberger and Thek 2004, DL 33-A 2005)

Country	Feed-in tariffs (€ / MWhe)
Portugal	106 - 108
Austria	130 - 150
Belgium	100 - 125
Spain	118 - 128
Italy	105 - 130

The harmonization of FIT in EU is a measure that has to be implemented, although nothing suggests that will solve the problem effectively. In fact, flushing rates for a high value means detrimental to the consumers' interests in countries with less purchase power; level rates for low value electricity producers and endanger compliance with European and national targets (Vagonyte 2007).

2.3. PORTUGUESE FOREST BIOMASS CURRENT SITUATION

The pulp and paper industry has been the pioneer to use forest biomass in Portugal. Early on they realized that forest and wood waste could be used to produce heat for their own industrial processes. The heat, which is not used for these processes, can be used for electricity generation, self-absorption or be injected into the utility grid, a process called cogeneration.

In 1995, Portugal had an installed capacity of 359 MWe for electrical energy production; fourteen years later, the power stood at 11% of gross electricity generation, meaning, 500 MWe, expecting 958 MWe by 2020. The installed power is relatively low when compared to other sources of contribution to the final electricity consumption, however, biomass accounted for 8,5% of total final energy consumption in 2012 (DGRF 2006, AIFF 2010, DGEG 2011).

The first dedicated biomass power station went into operation on 1997 in Vila Velha de Ródão. The plant, operated by Centroliva has a output power of 3 MW and consumes 120 tons per day of forest residues, including pine bark, sawdust and olive bagasse. The first power station specifically sized to consume Residual Forest Biomass (RFB) was built in Mortágua in 1999. This central has an installed capacity of 9 MWe and produces annually 63 GWh of electricity, using in 2011 a total 120.000 tonnes (EC s/d, ALTRI; EDP 2007, CBE 2007).

Currently in Portugal, the forest supports about 7.000 companies with more than 92.700 workers and the main core business is the exportation of renewable natural resources (AIFF 2010).

Although the forestry is not high rated at political level in Portugal, the Portuguese Gross Domestic Product (GDP) from forests is higher than the European average, ranking fifth in Europe, representing 3% of Gross Value Added (GVA) in the economy accounting for 3,1 billion €, 3,3% of total employment, 3,2% of GDP, 12% of industrial GDP and 11% of national exports representing 2,7 B€ (Kovalcík 2011).

Regarding the direct and indirect use, the Portuguese Forest has the highest values, extracting about € 344 / ha / year, while in Spain is € 90 and France € 292 (DGRF 2006).

2.3.1. Forest Market Internationalization

The internationalization of the Portuguese forest market is one aspect that contributes to the fall in wood prices, due to three essential factors: the integration of Portugal in the EU, the development of trade rules and the emergence of several international treaties and international agreements. The fall in prices reflects the consequences of price liberalization and competition in international markets (DGRF 2006).

Considering that the most traded biomass fuel is pellets (Alakangas, Heijjinen, et al. 2007), Portugal can have a major role in supplying self needs, boosting forest market prices and energetic European needs, as shown in Figure 3.

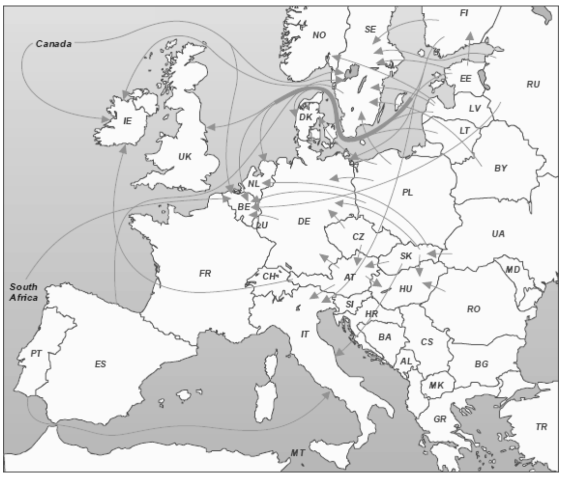

Figure 3 - Trading of pellets in Europe. Source:(Alakangas, Heijjinen, et al. 2007)

3. OPERATING SYSTEMS FOR FOREST BIOMASS

Biomass exploitation systems can be understood as the set of forestry operations undertaken with the final goal to supply a processing plant or an energetic producer power station. It is therefore a chain of supply divided into five main components:

- Production:
  - Forest Stand Management,
  - Industrial Activity,
  - Municipal Management.
- Logistics:
  - Primary Transport,
  - Processing,
  - Secondary Transport.
- Operating systems:
  - Forest stands processing,
  - Outside forest stands processing,
  - Terminal Processing.
- Industries:
  - Pelleting Factory,
  - Thermoelectric Power Station.
- Conversion technologies:
  - Thermochemical conversion,
  - Biochemical conversion.

These individual systems are extremely important to execute a future well developed forest stand management program in the District of Bragança. No costs have been estimated, but, the technologies presented and analysed are necessary to allow the creation of a good structure FB chain system.

3.1. PRODUCTION

The great contribution of forest biomass to factory plants comes from managed forestry stands, focused on timber production for a number of purposes: pellets, sawmill, posts or veneers. There are, however, other activities that produce FB and have to be considered.

3.1.1. Forest Stands Management

The management of forest stands is fundamental to properly explore forest stands in order to raise productivity, combined with the maintenance of soil characteristics, through cut management. Therefore, forest stands management can be realized in four different steps: thinning, pruning, cuts and health cuts.

Thinning

An operation that consists in removing immature trees aiming to reduce the competition between them, eliminating diseased trees, stimulating the growth and yield of remains, anticipating income by selling the material removed (Stokes, et al. 1989). The production of FB with this kind of operation varies quantitatively depending on the delay of years to remove timber.

Hakkila (2000, 2004) suggests that some FB has to be left on site, because the chips produced with thinning material are of poor quality and there is the need to maintain soil fertility levels.

Pruning

Operation that improves the timber quality by removing live or dead branches allowing a right set without nods. Chipping pruned material will originate low quality chips, therefore, not advisable to remove material. However, if it is performed simultaneously with delimbing, allows FB to be collected more efficiently (Stokes, et al. 1989, Sims 2002).

Cuts

Also known as clear cuts, consists of cutting all the trees of a forest stand for further processing and marketing. The trees are felled, pruned, peeled and turned into logs, being an operation particularly complex because it involves specific machinery in a first stage (e. g., feller delimber slasher buncher), and, if necessary, a second stage where major contaminants are removed (stones, sand, etc.).

Health Cuts

Used to prevent and control forest pests. A good example is the control of Pine Wood Nematode (PWN), requiring annual clear cuts of maritime pine stands. In a broader context, it is also necessary to consider the cleaning of areas covered by wild-fires.

3.1.2. Industrial Activities

Two types of industries create residues usable to be processed both in a pellet plant or a thermoelectric power station: Sawmills and Biomass Energy Industries and Pulp, Paper and Kraft paper Manufacture Industries.

Sawmills and Biomass Energy Industries

These industries use and transform wood, producing waste (sawdust, chips, etc.). In Portugal, the production from wood manufacturing in 2012 was 1.471.600 dry tons, with 65% m. c. (AIFF 2010).

Pulp, Paper and Kraft paper Manufacture Industries

Pulp and paper industries have a long tradition in the use of FB for energy purposes. A by-product of the process used in the pulp and paper, black liquor, is created from processes, such as combustion, gasification or pyrolysis, used to produce heat required for industrial processes (AIFF 2010).

3.1.3. Municipal Management

Municipal Management represents a small part of FB, mainly because the wood obtained does not come from forest stands. However, the residues have energetic potential. A proper management of urban parks and gardens can contribute with RFB through thinning. If allowed by municipal authorities, RFB can be used in biomass boilers to heat public buildings.

3.2. LOGISTICS

Within this chapter, the principal machinery used to transform FB (gather, cut, log and debark) to be used as fuel on the thermoelectric plant, or as material to produce pellets is focused.

Because the two factories are different in FB acceptance, the processing, material and machines used are also different. The pellet plant is not as specific on wood demand as a thermoelectric power station, receiving wood in any condition, logs, wood chips or wood with PWN. The principal difference lays that the thermoelectric power station boiler(s) only consume wood chips.

Some examples of specialized machines are: Harvesters (Figure 4), Grapple and Cable Skidders (Figure 5), Forwarders (Figure 6), trucks with cranes, tractors with trailers (preferably with crane) and Feller forwarders (Figure 7).

Figure 4 - Harvester. Source: www.deere.com

Figure 5 - Cable Skidder (left) and Grapple Skidder (right). Source: www.deere.com

These types of machines are used in primary transport of FB from forest stands to paved roads (Johansson, et al. 2006).

3.2.1. Primary Transport

Primary transport is the first stage in FB gathering and consists in the extraction of timber from the yard to paved roads, were the loading operations to trailers are held. This operation can be performed by agricultural or forestry tractors, but usually specific machines are used like Forwarders, Feller bunchers or Feller forwarders, which are more suitable to all kind of terrains and slopes.

Figure 6 - Forwarders carrying felled logs. Source: www.deere.com

If the road used to transport felled trees outside the yard does not maintain vehicles traction, it can be composed either by other felled trees. They can be retrieved before machines leave the forest stand.

3.2.2. Processing

The principal operations referring to the processing of felled logs are: packing, triage and chipping; performed with the objective of round wood marketing, or to be industrially processed.

Packing

Because FB remains have low density but high energetic content, this operation is highly recommended (Saidur, et al. 2011, Hogan, et al. 2012).

It is a process by which the FB remains are compressed and cut into cylindrical bales of 70 cm in diameter and length ranging from 2,5 to 3,2 m, having an average weight of approximately 500 kg, as presented in Figure 7 (Hakkila, Development technology for large-scale production of forest 2004, Johansson, et al. 2006, RE Consulting 2007).

Figure 7 - Feller Forwarder. Source: www.deere.com

Triage

Triage is used to remove contaminants from chipped FB, such as rocks and sand. This operation consists in introducing material in a ground vibrating sieve which separates the wood chips from contaminants. The material that passes the first sieve drops into a second and tighter sieve where is made another triage separating them between acceptable chips and fines.

The first sieve serves to collect the large irregular contaminant particles, being therefore necessary to have a second grinding of acceptable quality, obtaining a homogeneous amount of wood chips. As such, it is necessary a second sieve process.

Figure 8 represents a triage stage in a pellet factory.

Figure 8 - Sieving wood chips produced from wood logs. The stack of chips (right) should pass new chipping to obtain better quality.

Chipping

Chipping is the process where FB is converted into smaller particles commonly known as chips, distinguished by size (Hakkila, Kalaja and Nousiainen, Use and prices of forest chips in Finland in 1999 2000):

- Wood chips have 5-50 mm and are created with knives chippers;
- Chunk wood chips have 50 -150 mm and result from hammer chippers.

The chippers, machines that create wood chips, vary in mobility, and if necessary are towed by tractors or Forwarders. The mobile chippers have the advantage of chipping FB with higher density, but, the disadvantage of reduced productivity due to only work in flat terrains (Hakkila, Development technology for large-scale production of forest 2004).

Chippers can be divided into knives chippers and hammers chippers, as given next.

Knives Chippers

Knives chippers create particle wood chips (Figure 9) and there are two types: disk or drum (Figure 10).

Figure 9 - Wood chips resulting from knives chipper. Source: www.barkerdelivered.com

The disc type, compared to the drum type, produces chips with lower quality when the original material has small and flexible branches (Spinelli and Hartsough 2001).

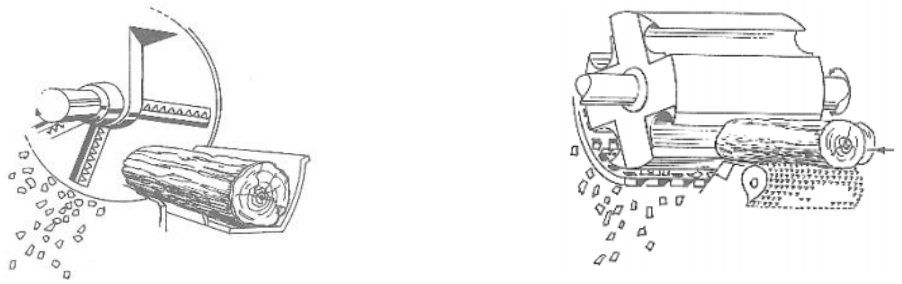

Figure 10 - Disk (left) and drum (right) knives chipper. Source: (Pottie and Guimier 1985)

The knives chippers have the advantage of project chips into a trailer or container. They are more suitable for processing low quality or whole trees because it is a material substantially free of contaminants, which cause great wear on the knives (Pottie and Guimier 1985, MacDonald 2007).

Hammers Chipper

The FB chipping is through the impact of hammers in a rotating drum, and the chips produced are more heterogeneous than the produced by knives chippers (Figure 11).

Figure 11 - Chips resulting from hammers chipper. Source: www.barkerdelivered.com

Depending on the strength of hammers, they can handle material with more or less contaminants (Figure 12).

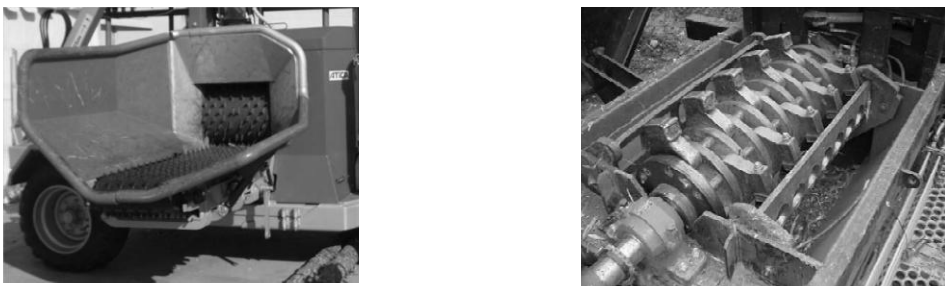

Figure 12 - Fixed hammers chipper (left) and free hammers chipper (right). Source: www.gemacosales.com; (RE Consulting 2007)

In addition to these two types of chippers, there are screw chippers (tapered screw) and spirally curl disk type chippers, producing chips with a particle size between 50-250 mm (RE Consulting 2007).

3.2.3. Secondary Transport

The secondary transport refers to the transport of FB from the loading place to a terminal or consumer unit (pellet factory or thermoelectric power station), and, can be done by road tractor, trailer, airway or water (these last two not common in Portugal).

Generally in secondary transport, FB is left to dry naturally, if weather conditions allow it, being chipped and then is transported to the consumer unit. Another possibility is to leave FB previously grinded in the ground, although there may exist fermentation problems due to excessive heat in stack(s) originating spontaneous fires.

Because the processing unit offers a price relate to the degree of contamination and moisture, it is important to deliver wood chips or wood logs as free of contaminants as possible and with the lowest m.c. possible. If not, the process can cost more, and cause operational problems in boilers, therefore, there is the advantage of drying FB in the loading place to get a better price at the time of sale.

In terms of transportation, the tractor is only used for short journeys up to 10 km, due to its low speed and small load; beyond this distance, the mean transport used is the truck. In Portugal, the *Decreto-Lei* no. 203/2007 allowed to transport up to 60 tons of wood logs by truck contributing to reduce transportation costs. However, not all roads are suitable for this kind of operation.

Figure 13 - Unloading wood chips using a hydraulic trailer. Source:(RE Consulting 2007)

In some cases, the transport is done with a trailer-container (Figure 13) which collects the containers left on the side of the road filled with chips, allowing greater autonomy, avoiding waiting times, although it requires some investment and available space.

In the context of the international market, it is possible to carry FB through sea. In fact, Portugal has been exporting FB from the ports of Aveiro and Sines, by vessels with capacities of 5.000-6.000 tons of FB to Italy and northern countries in Europe (Alakangas, Heijjinen, et al. 2007) as seen in Figure 3.

3.3. OPERATING SYSTEMS

In this chapter, the different approaches of where FB can be chipped are abroad. The operating systems, or operations held to chip FB, are divided according to the variety of FB type and place. According to Hakkila (2004) the system classification of forest exploitation is different - tree chipping in forest stands is different from FB chipping in the consuming unit - being necessary to classify them.

As such, the classification is divided in three options: processing in the forest stands, outside forest stands or in the terminal.

3.3.1. Forest Stands Processing

FB processing within forest stands is not always in flat terrains, requiring mobile lightweight hammers chipper(s), producing low quality chips, which is less productive, once is towed by a tractor or forwarder, or, demands specific machinery as presented in Figure 14.

Figure 14 - Branches of Populus trees being crushed.

One possibility is to open secondary logging roads making able a chipper to move, collect and chip whole trees harvested with a Feller Buncher. When the container is full, the chipper discharges into the loading place. The advantage of this system is to make two simultaneous operations (primary transport and chipping) whit the viable use in smaller stands.

3.3.2. Outside Forest Stands Processing

A variant of the forest stand processing is the system in which a mobile chipper to chip stacks placed along the road filling containers, as seen in Figure 15.

Figure 15 - FB being chipped near a forest stand and loaded directly into trailer.

Is common to see this operation practiced when stacks of logged FB with 4-5 m in height are placed along paved roads outside forest stands. After this, the wood logs can be chipped either to trailers or containers (more usual in Nordic countries). When these are full, they are transported to the consumer unit, allowing independence and time reduction.

3.3.3. Terminal Processing

At the opposite end of cutting and chipping in forest stands, there is this system where FB is transported to a terminal, a storage location or the energy production plant.

Has the significant drawback of being delivered material with low density and high m. c., although is frequent in some mature markets, where the FB chipping machines are scarce. Nevertheless, one advantage is that chipping in the consumer unit, by the available space and conditions, is more efficient than the other systems. To increase the density of FB in the loading place, FB packing can be done.

The transport of not chipped FB allows the terminal to act as a logistics platform turning the whole processes more productive, reducing m. c., and be used when there is more market need. Figure 16 represents a FB chipping in a terminal storage.

Figure 16 - Terminal storage FB chipping.

3.4. INDUSTRIES

The FB, after a first process of chipping, is delivered at the consuming unit to be transformed. The industrial units - considered in this thesis - are pellet factories and thermoelectric power stations, which act as consuming units and storage facilities.

To better explain the major components in these two industries, they are further analysed in detail.

3.4.1. Pelleting Factory

In Portugal there are 16 pelleting factories working[2]. Nevertheless, independent from where are located or FB used, a generic pelleting factory is composed by different parts and components, as demonstrated in Figure 17.

[2] Data from of the former Portuguese Ministry of Economy and Innovation in 2007.

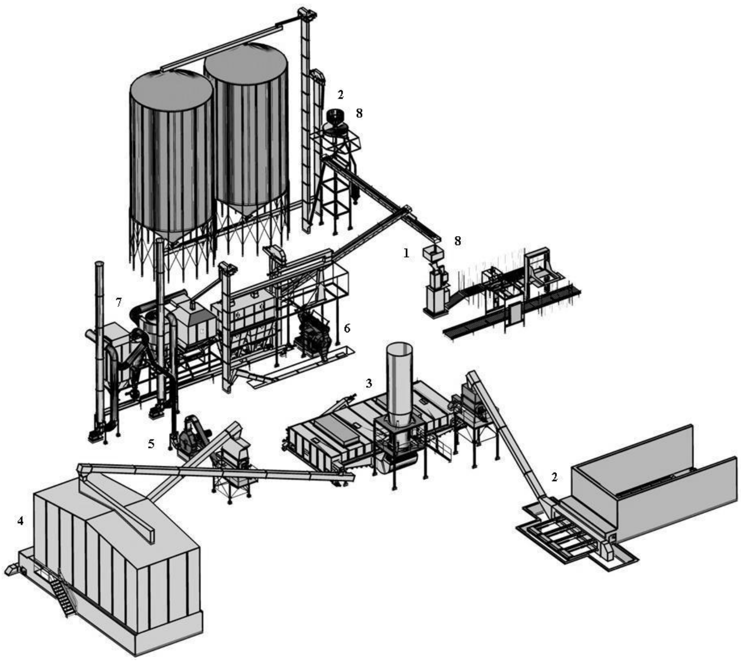

Figure 17 - Example of Pellet plant diagram. Source: www.prodesa.net

The pelleting plant is composed by the following parts:

- **(1) Raw Material:** FB is received, in any form, and stored in order to be processed.
- **(2) Product Input**: The FB material received requires a removal of contaminants (sand, rocks, foreign elements, etc.), using several sieves. The different types of FB are mixed and, using hammers chippers turning the output homogeneous.
- **(3) Thermal Drying**: Because most of the wood chips processed previously have high m. c. (above 50%), it is necessary to be dried, so that in the final stage, the amount of m. c. is about 10%. To achieve this reduction of m. c., two technologies are available:
    - **High Temperature Drum Dryer**: Usually a cylindrical heated drum with 25 m and 5 m in diameter using as fuel FB that is not suitable to pellet processing;
    - **Low Temperature Belt Dryer**: Not usual in Portugal, but allows a reduction in energy consumption, because saw dust m. c. is monitored.
- **(4) Dry Product Storage**: The low m. c. saw dust is stored to be mixed with existing saw dust in order so that the final product is uniform before entering the pelleting process.

- **(5) Dry Product Chipping**: The stored saw dust receives a new chipping in order to reduce particle before entering the pelleting matrixes.
- **(6) Pelletizing**: The product is compressed using a vertical die, reducing volume, being the particles bonded at 80ºC through steam or corn flour, creating the pellets.
- **(7) Pellet Cooling / Screening**: A chiller is used to reduce temperature in pellets in order to facilitate storage. A rotary or vibratory screen is used to remove the fines or dust, returning them to the pelletizing process.
- **(8) Storage**: This can be done in three different systems:
    - **Packing / Bagging**: The final product in conducted to bags of 15 kg and are stored to later use.
    - **Silos with direct trailer loading**: A truck stops below a conduct which fills the trailer, being transported to the consumers.
    - **Bulk with direct trailer loading**: The pellets, after passing the step of packing are loaded directly to a trailer.

As any factory, a pellet factory comprises FB demand and market necessities.

3.4.2. Thermoelectric Power Station

Other industry that uses FB to produce other form of energy, in this case electricity, are thermoelectric plants. Portugal has 4 plants running, producing a total of 62,1 MWhe[3].

To explain how FB can be transformed into electricity, Figure 18 shows a diagram of a generic thermoelectric plant.

[3] www.altri.pt

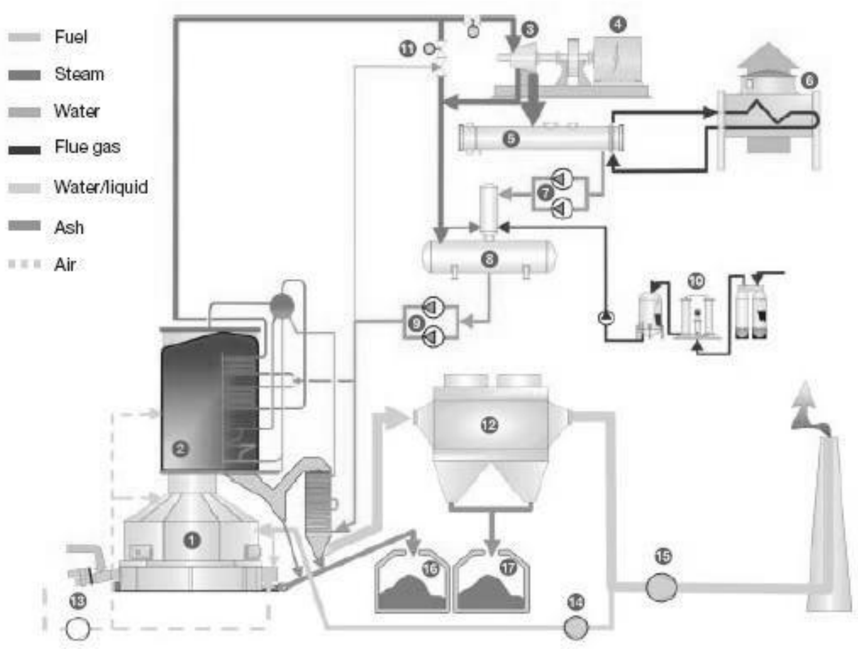

Figure 18 - Example of a thermoelectric power station. Source: www.wartsila.com

As before, to explain the functioning of a thermoelectric plant (or power station), the following points are separated in 17 parts, as described next:

- **(1) Fuel Feeding**: FB is received only as wood chips. To obtain this, is necessary to use hammers chippers (mobile or fixed). The FB is burned using combustion temperature control, removing the ashes resulting from burning.
- **(2) Steam Boiler**: a drum boiler with natural circulation using water above 100ºC and approximately 70 bar achieves a steam flow of 21 ton/h and 150ºC.
- **(3) Turbine**: the turbine(s) uses the steam proceeding from the boiler, rotating to about 1500 rpm.
- **(4) Generator**: the output power (depending on the managed output energetic needs and economic availability) is cooled by water circulation, through cooling towers (more usual), radiators or condensers.
- **(5) Condenser**: uses ambient temperature.
- **(6) Air cooled radiator**: using gravity, the water is dropped in a cooling tower, being reintegrated in the system.
- **(7) Condenser Pump**: regulate water flow in the cooling system.
- **(8) Feed Water Tank**: storage tank, in order to reduce natural water consumption, maintaining the temperature of water as natural as possible.

- **(9) Feed Water Pumps**: water is pumped from the tank to the system.
- **(10) Water Treatment**: either to retrieve water to the system, or to reintegrate this in rivers, it is necessary to normalize it, cleaning contaminants sustainable to affect both systems.
- **(11) Reduction Station**: regulation of water flow.
- **(12)Electrostatic Precipitator**: particles suitable to damage the system are gathered and separated.
- **(13) Combustion Air Fan**: The gases derived from the combustion of chipped FB, is released, after treatment.
- **(14) Flue Gas Re-circulation Fan**.
- **(15) Flue Gas Fan**.
- **(16) Wet Bottom Ash Container**: ashes are retrieved from the combustion process to be sold as fertilizer.
- **(17) Dry Fly Ash Container**: ashes retrieved from the electrostatic precipitator, being also sold and used as fertilizer.

As stated in the pelleting factory, the thermoelectric plant can be different depending on manufacturing company, necessities and sustainable gathering of FB in the region where are erected.

3.5. CONVERSION TECHNOLOGIES

To achieve final product, several technologies exist and are possible to use, converting biomass into heat energy and / or electricity. Since the restricted context of this thesis is to FB, the biological conversion processes such as digestion anaerobic, are omitted.

Depending on the FB m. c., Loeser *et al.* (2007) explains that there are two possible ways: dry biomass (under 50% of moisture) is processed thermochemically, whereas wet biomass (over 50% of moisture) is normally treated biochemically.

3.5.1. Thermochemical Conversion

To treat dry biomass, the foremost among the conversion technologies in thermochemical conversion are combustion, gasification, pyrolysis and liquefaction. Sims (2002), Faij (2006) and Saidur *et al.* (2007) discuss this issue further.

3.5.2. Biochemical Conversion

As above, wet biomass can be processed in two ways: fermentation and anaerobic digestion. Loeser *et al.* (2007) and Saidur *et al.* (2011) explain further acknowledgement on this matter.

4. EVALUATION OF FOREST BIOMASS FOR LOCAL SCALE ENERGETIC PURPOSES

In this chapter, the methodology to estimate potential interest Forest Biomass (FB) of the District of Bragança usable for energetic purposes is described.

The first stage was the characterization of the District of Bragança and its land occupation using the 2007 Land Cover Map for Continental Portugal, the 5th National Forest Inventory and the software Florestat 5.0.

The second stage was to estimate the area of potential interest forest from the district forest area, being considering coniferous forest stands as the potential interest forest.

Finally, restrictions and models for transporting, processing and logging to be used in the District of Bragança were established.

4.1. THE DISTRICT OF BRAGANÇA

The District of Bragança is in the north corner of Portugal, composed by 12 municipalities (Alfândega da Fé, Bragança, Carrazeda de Ansiães, Freixo de Espada à Cinta, Macedo de Cavaleiros, Miranda do Douro, Mirandela, Mogadouro, Torre de Moncorvo, Vila Flor, Vimioso and Vinhais).

Is bordered to the north and east by Spain, the Districts of Viseu and Guarda in the south and west by the district of Vila Real.

It is constituted by 299 parishes with an area of 6.608 km^2, and, according to the latest census, there are 139.344 inhabitants, giving to the District of Bragança a low density population of approximately 21 inhabitants per km^2.

4.2. STUDY AREA CHARACTERIZATION

The data regarding the Forest Biomass framework of the district of Bragança, come from the 2007 Land Cover Map for Continental Portugal (COS 2007) (IGP 2007), and from the values present in the 5th National Forest Inventory (AFN 2008), which was aggregated in the software FloreStat 5.0.

The final product resulted from the analysis of the above landscape database of the district of Bragança.

4.2.1. Land Occupation in the District of Bragança

The forest area in the District of Bragança corresponds to 191.426 ha (29,02%), while the agricultural area is 230.259 ha (34,91%). The shrubland[4] areas account to 225.039 ha (34,10%) and the in land water areas represent 3.201 ha (0,49%). The area with other use (i.e., living area) represents 9.795 ha (1,48%) as shown in Table 3.

Table 3 - Land occupation in the district of Bragança. Source: (IGP 2007)

Municipality	Forest (ha)	Shrublands (ha)	In land water (ha)	Agriculture (ha)	Other use (ha)
ADF	7.802	12.561	125	11.234	477
BGC	41.581	37.923	150	35.761	1.942
CZA	11.001	8.485	274	7.774	390
FEC	8.894	8.529	374	6.190	431
MCV	18.239	23.603	401	26.631	1.041
MDO	8.986	13.090	351	25.460	834
MIA	16.043	20.301	275	27.935	1.342
MOG	17.594	22.618	525	34.262	1.046
TMC	15.058	24.224	401	12.855	620
VLR	5.977	9.679	100	10.231	595
VIM	13.451	18.430	175	15.597	510
VIN	26.836	25.595	50	16.429	566
Total	**191.426**	**225.039**	**3.201**	**230.259**	**9.795**

Note: ADF - Alfândega da Fé, BGC - Bragança, CZA - Carrazeda de Ansiães, FEC - Freixo de Espada à Cinta, MCV - Macedo de Cavaleiros, MDO - Miranda do Douro, MIA - Mirandela, MOG - Mogadouro, TMC - Torre de Moncorvo, VLR - Vila Flor, VIM - Vimioso, VIN - Vinhais.

Analyzing the municipal land use, Bragança (BGC) is the one with the greatest absolute value of forest occupation with 41.581 ha, followed by Vinhais (VIN) with 26.836 ha, and the municipality with less forest area is Vila Flor (VLR) with 5.977 ha. The larger area occupied by shrubland areas is BGC with 37.923 ha. The occupation in agriculture, in general, is higher than the 10.000 ha with the exception of Carrazeda de Ansiães (CZA).

[4]According to the Merriam-Webster's Collegiate Dictionary, 11th Edition (2003), shrubland areas are plant communities characterized by vegetation dominated by shrubs, often also including grasses, herbs, and geophytes (perennial plant with an underground food storage organ, such as a bulb, tuber, corm, or rhizome).

4.2.2. Potential Interest Forest Characterization

There is a high diversity of forest types in the district, but not all of the species in the district can or will be used in the study due to most of them not having potential interest for energetic use or are protected by law.

According to the Official Administrative Portuguese Cartography (*Carta Administrativa Oficial de Portugal* - CAOP) of 2010 and the 2007 Land Occupation Chart (*Carta de Ocupação do Solo* - COS) the species accounted were categorized as coniferous forest[5] (IGP 2007). This information was summarized in Table 4.

Table 4 - Comparison between the land and potential forest areas in each municipality. Source: (AFN 2008)

Municipality	Land Area (ha)	Forest Area (ha)	Potential Interest Forest Area[1] (ha)
ADF	32.196	7.802	3.707
BGC	117.543	41.581	15.169
CZA	28.091	11.001	9.780
FEC	24.449	8.894	2.678
MCV	69.923	18.239	5.370
MDO	53.826	8.986	3.419
MIA	64.003	16.043	6.737
MOG	75.798	17.594	12.963
TMC	53.322	15.058	7.049
VLR	26.552	5.977	4.826
VIM	48.147	13.451	5.464
VIN	69.468	26.836	7.923
Total	663.318	191.426	85.085

Note: [1] - Coniferous forest area.

Nearly 43% of forest land area is composed by these categories, offering an opportunity to create an exploration chain.

[5] Presented in the COS 2007 as points 3.1.2 and 3.1.3.

4.3. CONSIDERATIONS

4.3.1. Transporting and Processing Logistics

The production of potential interest forest in the district of Bragança is unlikely to be targeted for quality wood sawing because the current context does not allow it. Coniferous timber has little monetary value and there is no industrial structure that can absorb this product. Smaller timber that could be used for industrial processes (agglomerates, cellulose) loses economic interest because there are not any local industrial units in the District of Bragança, translated in the scarcity of will from companies or municipal policies (DGRF 2006, Amaral, et al. 2009, AIFF 2010).

Thus, the utilization for FB as material to be industrially processed appears to be the most viable solution, but only if regional conditions are created for that to happen, which is expected to reduce costs of transportation and transformation, and rise profit both to industry and producer (ALTRI; EDP 2007, Alakangas, Heijjinen, et al. 2007, CBE 2007). Near future forestry and logging models should be directed to high density forest plantations subjected to shorter rotations.

It was considered the possibility that when biomass is already dry enough and there is already a considerable stock, the best option is to load them into semi-trailer trucks, adapted from equipment to bulk cereals transportation that would transport the load to main central. After FB had been discharged in each of 12 MIZ (Municipal Industry Zone), it was necessary to leave it there, drying, and after FB presents low m.c.(under 50%), it is transferred to the most central point in the district of Bragança, where the FB industries will be held.

Johansson *et al.* (2006), Kopetz *et al.* (2007) and Kovalcík (2011) refer that logging and transportation normally represents 2/3 of total monetary value from cutting to final product selling, and it was assumed the same proportion of the distribution. This information although not important due to not have been made an economic evaluation in terms of global costs, is needed to be taken as reference when facing the choice of equipment and methods for logging because they depend on various factors, such as local availability of specialized equipment and conditions of the ground.

An easy way to reduce costs is to hire companies and machinery existing in the District.

With this concern, it was necessary to determine the central point in the district of Bragança to allocate both industries. The distances are summarized in Table 5.

Table 5 - Distance between Municipalities.

Municipality	Distance (km)		
	Minimum	**Maximum**	**Average**
ADF	28,6	87,6	58,1
BGC	33,3	128,0	80,7
CZA	18,5	135,0	76,8
FEC	39,6	142,0	90,8
MCV	26,9	89,0	58,0
MDO	27,7	133,0	80,4
MIA	25,8	112,0	68,9
MOG	36,6	105,0	70,8
TMC	24,4	103,0	63,7
VLR	18,4	116,0	67,2
VIM	28,0	117,0	72,5
VIN	33,3	142,0	87,7
Minimum	**18,4 (VLR)**	**87,6 (ADF)**	**58,0 (MCV)**
Maximum	**39,6 (FEC)**	**142,0 (VIN)**	**90,8 (FEC)**

Is possible to see that Macedo de Cavaleiro (MCV) is the municipality having the shortest distance to all the other municipalities (58 km), followed by Alfândega da Fé (ADF) (58,1 km). Due to MCV is closest to good road network (IP 4 / A4) it was the chosen to be the central point of FB gathering from all MIZ in the District, as seen in Figure 19.

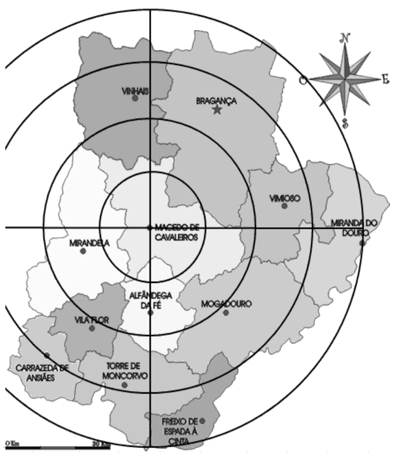

Figure 19 - Central storage of Forest Biomass held in Macedo de Cavaleiros.

After, through analysis of the road network using Google Maps® it was determined the distance between the centre of each parish (production) and the point of each MIZ (collector); and, from each MIZ and MCV, establishing the distance needed to travel FB to the industrial facilities. This is presented in Table 6.

Table 6 - Distances between each municipality and its Municipal Industrial Zone (MIZ) and distances between each MIZ and Macedo de Cavaleiros.

Municipality	Average Distance to MCV (km)	Average Distance to MIZ (km)
ADF	33	12,4
BGC	41	20,5
CZA	55	8,7
FEC	89	13,2
MCV	-	18,8
MDO	84	15
MIA	22	16,7
MOG	50	14,7
TMC	57	17
VLR	45	9,2
VIM	55	14,5
VIN	48	19,3
Average	**53**	**15**

Table 6 indicates the average distances from each municipality to MCV, important to determine the amount of km necessary to be executed to transport FB from each MIZ to MCV, necessary to estimate the trailers needed to supply the FB industries.

4.3.2. Forestry and Logging Models

In the District of Bragança, existing high density forest plantations are scarce, so, future forestry and logging models should be directed to intensify forest plantations subjected to shorter rotations.

Logging companies also do not exist in order to provide a strong logging system that can provide FB to the pellet and thermoelectric industries. As such, if possible, is preferable to hire specialized companies from biomass logging to transportation: Skidders (Figure 5), Forwarders (Figure 6), trucks and tractors with cranes, tractors with trailers and Feller Forwarders (Figure 7).

The primary and secondary transport of FB (logs and bales), from forest stands to the Municipal Industrial Zone (MIZ), shall be with truck or tractor, with load capacity equal to or greater[6] than 30 ton. The use of FB at regional level could promote the creation of a forestry industry and transport, stimulating the local economy and providing opportunities for forest owners. As an example, the price of the biomass in the final reception of the thermoelectric power station of Mortágua, Viseu, can reach € 30/ton.

It was considered also that the FB consumed only comes from regional forests managed sustainably. As such, all CO_2 released in the combustion will be compensated by the absorption of an equivalent amount of CO_2, because, as stated before, the burning of FB is considered CO_2 neutral (Wihersaari 2003, EU 2004, Yoshioka, et al. 2005).

Finally, in order to assess the energetic amount of FB, it was used the *Despacho* no. 17313/2008 of June 26 which establishes the Lower Heat Values (LHV) and Fuel Emission Factor (FEF) in some fuels, important to estimate a comparison between industries.

[6] By applicable law (DL 203/2007), for activities relating to the transport of timber, it is possible that vehicles with five or more axles carrying only timber reaches the maximum gross weight for the all motor vehicle-trailer 60 tonnes.

5. RESULTS

The results were differentiated in four chapters:

- **Productivity scenarios**: Considering three different scenarios of Annual Average Increase, obtaining three different FB productivities in the District of Bragança, important to estimate the amount in tonnes of FB that can be delivered to an industry.
- **Industrial production**: The values obtained before are here used to assess the amount of yearly tonnes of pellets and electricity, both for:
    - **Pellet production**;
    - **Thermoelectric production**.
- **Economic evaluation**: An estimative of the yearly monetary content from pellets or / and electricity produced was assessed.
- **Energetic self-sufficiency**: A analysis was made to the District of Bragança to estimate a reduction of energetic self-sufficiency, using the production of electricity by the thermoelectric power station.

All values presented are supported by Annex C which is represents the Return Of Investment estimated to both industries.

5.1. PRODUCTIVITY SCENARIOS

To achieve a range of values accepted as near real, three scenarios were considered, involving different Annual Average Increases(s) (AAI) defined by tonnes per area, determining the growth of FB, as presented in Figure 7.

Table 7 - Scenarios used to estimate FB productivity in the District of Bragança.

Scenarios	Potential Interest Dry FB[1] (ton/ha·yr)	Potential Interest Dry FB (ha)	Potential Interest Dry FB (ton/yr)
Conservative (Azevedo, et al., 2012)	1,700		144.645
Regular (AFN, 2008)	2,674	85.085	227.484
Optimistic (Amaral, et al., 2009)	4,000		340.340

Note: [1] - Annual FB productivity for coniferous forest stands in the District of Bragança.

The conservative scenario, with AAI of 1,7 ton/ha·yr is referent to a low productivity of FB, which can occur in bad or dry weather season years, non fertile lands, large amount of wildfires, among other situations, resulting in non favourable growth of trees.

The regular scenario refers to AAI of 2,674 ton/ha·yr achieved using the values of FloreStat 5.0 for the District of Bragança to the forest species of coniferous (subchapters 3.1.2 and 3.1.3 in COS 2007).

The optimistic scenario with AAI of 4,0 ton/ha·yr is held on a opposite context of the conservative scenario, i. e., a good year in growth for forest stands, low number of wildfires, stimulating programs of forest stands managements appropriate for the forest species in the District of Bragança, among others.

These three scenarios allow different perspectives of achievable theoretical content held in FB, constituted on a 30 year cut rotation, promoting growth in forest stands, which is the period considered as life-time for both industries, maintaining the production as sustainable as possible.

A final stage was the assessment of the amount of trucks necessary to transport fresh biomass from forest stands to each municipal MIZ (FB transported with 65% m.c.) and dry FB (5-10% m.c.) from each MIZ to MCV. These are shown in Table 8.

Table 8 - Annual FB available in different scenarios.

	Dry FB Scenarios[1]			Wet FB Scenarios[2]		
Municipality	**Conservative (ton/yr)**	**Regular (ton/yr)**	**Optimistic (ton/yr)**	**Conservative (ton/yr)**	**Regular (ton/yr)**	**Optimistic (ton/yr)**
ADF	6.104	9.601	14.362	10.071	15.841	23.697
BGC	25.736	40.482	60.556	42.465	66.795	99.917
CZA	16.532	26.004	38.899	27.278	42.907	64.184
FEC	4.551	7.158	10.708	7.509	11.811	17.667
MCV	9.069	14.265	21.338	14.963	23.537	35.208
MDO	5.784	9.098	13.610	9.544	15.012	22.456
MIA	11.252	17.699	26.476	18.566	29.204	43.686
MOG	22.015	34.629	51.801	36.325	57.138	85.471
TMC	11.985	18.851	28.199	19.775	31.105	46.529
VLR	8.205	12.906	19.305	13.538	21.294	31.854
VIM	9.265	14.574	21.801	15.288	24.047	35.972
VIN	13.338	20.980	31.383	22.007	34.616	51.782
Total	**144.645**	**227.484**	**340.340**	**237.330**	**373.306**	**558.424**

Note: [1] - 5 - 10% m.c., [2] - 65% m. c.

From Table 8 it is possible to see that it is necessary to make more journeys to transport FB from forest stands to each MIZ than from each MIZ to MCV. This is linked directly to the m. c. present in FB as the moment of transportation from the yards to a storage facility. There is the necessity of drying FB (preferably stored and naturally dried) in order to increase the reduction of journeys and overall costs.

However, the volume occupied by FB (either dried or not) does not achieve the maximum load capable by the trailer, and, as such, the number of trailers is superior, meaning further increase in fuel expended to transport FB.

As such, is preferable to transport FB from the forest stands to each MIZ using forestry machinery, and from the MIZ to MCV is preferable to use cereal trailers.

Nevertheless, the values presented in Table 8 reflect the large potential of FB in the District of Bragança. In a wet base scenario (transport FB from the forest stands to a MIZ.), with, at least, 3.956 trucks with 60 tonnes (conservative scenario), meaning that is possible to transport 11 trailers full loaded each day, and on an optimist scenario, it is possible to raise the amount of loaded trailers to 25.

From the secondary MIZ to the MIZ of MCV it is possible to achieve from 6 (conservative scenario) to 15 loaded trucks a day (optimistic scenario), in the same pardons as verified in a generic processing FB industry.

No emissions from activities in the forest have been considered. Also, the emissions from transport of pellets for the various destinations of consumption have not been considered. Nevertheless, the logistics of transporting FB imply a total distance by road of more than 750.000 km/yr, carried out by a fleet of trucks in about 12.000 short distance trips (~30km) for the transport of fresh biomass and 4.000 trips of longer distance (90-100 km) for the transport of dry biomass (chips), with a fuel consumption of almost 150.000 l/yr and 400 ton/yr of CO_2 emissions.

5.2. INDUSTRIAL PRODUCTION

This chapter is divided in the chapters of:

- Pellet production, and,
- Thermoelectric production.

Here the quantity of tonnes and electricity production are obtained considering similar production yields as the one verified in the pellet factory and thermoelectric power station in Mortágua, Viseu.

5.2.1. Pellet Production

Using the example of the factory Pellets Power® held Mortágua, Viseu; the values to maintain as references are:

- Annual consumption of 100.000 tonnes of FB,
- Annual production of 45.000 tonnes of pellets,
- Overall efficiency of 45%, considering a basis of 89% of working time (7.800 hours in one year).

As result of this efficiency, Table 9 presents the amount of pellets estimated to be produced.

Table 9 - Annual pellet production available in different scenarios.

	Scenarios (ton/yr)		
Municipality	**Conservative**	**Regular**	**Optimistic**
ADF	2.445	3.845	5.752
BGC	10.307	16.213	24.253
CZA	6.621	10.415	15.579
FEC	1.823	2.867	4.288
MCV	3.632	5.713	8.546
MDO	2.317	3.644	5.451
MIA	4.507	7.089	10.604
MOG	8.817	13.869	20.746
TMC	4.800	7.550	11.294
VLR	3.286	5.169	7.732
VIM	3.711	5.837	8.731
VIN	5.342	8.402	12.569
Total	**57.607**	**90.612**	**135.545**

From Table 9 it is possible to see that in a conservative context, the pellet production achieves more than 57.000 tonnes (+21%), and in an optimistic scenario, the amount of pellets capable of being produced is more than 135.000 tonnes (+200%).

Even in a conservative scenario, the presented values are superior to the pellet production in Mortágua.

5.2.2. Thermoelectricity Production

Typical biomass plants are relatively small in capacity (50 MW or less) with an overall efficiency in the range of 30-34%, depending on m.c. (IEA 2007, Petrecca and Preto 2010).

The production of electricity from FB combustion is recent in Portugal, starting in 1999 with Mortágua, Viseu. Now, there are established 4 FB power stations - Mortágua, Constância, Vila Velha de Rodão and Figueira da Foz - contributing to a total amount of electricity produced of 443 GWh. In 2007, there were projects to set 8 FB Thermoelectric power stations, however, only 4 are running (ALTRI; EDP 2007).

As such, the considerations applied to the pellet production are the same in the thermoelectric production, i.e., using an existing example. The industrial example is the thermoelectric power station of Mortágua.

The results of power output are presented in Table 10.

Table 10 - Electricity produced using different scenarios.

Scenario	Potential Interest Dry FB (ton/yr)	Annual production at full capacity (GWh)	Installed capacity (MVA)	Installed capacity (MW)
Conservative	144.645	134,3	21,3	19,2
Regular	227.484	211,2	33,5	30,2
Optimistic	340.340	316,0	50,2	45,1

Note: Mortágua thermoelectric power station values: FB: 67.000 ton/yr; annual production at full capacity: 63 GWh; installed capacity: 10 MVA.

The values present in Table 10 indicate that the electricity produced can be superior even in a conservative scenario, taking under consideration a gross yield of 26,5%, very low, but it is presented through this technology, mainly due to the small size of the plants, which usually do not exceed 25 MW of generating capacity.

Nevertheless, these values only reflect the thermoelectric potential that can be obtained using district FB, not taking under consideration material limitations to this industry (power generation, steam flow, boiler size, among other).

5.3. ECONOMIC EVALUATION

The use of FB implies acquisition and selling prices from each factory. Therefore, using the factories of Mortágua as example, the estimate economical potential of the FB in the district of Bragança is presented in Table 11. The values presented are according to power or weight units.

Table 11 - Acquisition and selling prices per factory.

Thermoelectric power station		Pellet plant	
Acquisition price (€/ton)	**Selling price (€/MWh)**	**Acquisition price (€/ton)**	**Selling price (€/ton)**
21,56	13,86	11,55	16,94

Note: The present values are without VAT equal to 23%.

To better assess how much can be obtained per power or weight unit, it is necessary to transform FB in tones of oil equivalent (toe), equalizing the price of FB either in a final form of electricity or pellets.

Despacho no. 17313/2008 was created in order to gather a comparison between LHV and FEF in fuels. Table 12 is a resume of LHV and FEF levels from *Despacho* no. 17313/2008 for solid primary biomass and pellets. The determination of toe/ton for electricity depends on the electric yield of the thermoelectric power station, but is advised to assume 1 kWh = 215x10^{-6} toe.

Table 12 - Comparison of energetic content and CO2 emissions between fuels. Source: (Despacho 17313 2008)

Fuel	LHV (MJ/kg)	LHV (toe/t)	FEF ($kgCO_2e/GJ$)	FEF ($kgCO_2e/toe$)
Wood / Wood residues	13,8 - 15,6	0,330 - 0,373	0,000	0,000
Pellets / Briquettes	16,80	0,401	0,000	0,000
Form of energy		**LHV (toe/kWh)**		**FEF ($kgCO_2e/kWh$)**
Electricity		215x10-6		0,470

Note: LHV - Lower Heat Value, FEF - Fuel Emission Factor.

As such, using Table 12 as reference, it is possible to obtain the amount of toe in FB available in the District of Bragança, present in Table 13.

Table 13 - Energetic content in FB.

Scenarios	Potential Interest wet FB[1] (toe/yr)		Potential Interest dry FB[2] (toe/yr)
	0,33 toe/ton	0,373 toe/ton	0,401 toe/ton
Conservative	47.733	53.953	58.002
Regular	75.081	84.853	91.223
Optimistic	112.312	126.946	136.476

Note: [1] - Wood / Wood residues, [2] - Pellets / Briquettes.

From Table 13 it is possible to see the amount of toe annually available in the District of Bragança, using coniferous forest, ranges from 47.733 to 126.946 toe in a wet base (65% m.c.), and, from 58.002 to 136.476 toe in a dry base (5-10% m.c.).

Finally, to determine the amount of monetary content, it is necessary to use the selling prices used by each factory to sell FB in form of pellets or electricity. This is important to determine the amount of monetary value obtained per factory.

These values presented in Table 8 and Table 11 are considered to obtain Table 14.

Table 14 - Monetary value of FB sold as pellets or electricity.

Scenarios	Pellets (€/yr)	Electricity (€/yr)
Conservative	2.450.286	1.861.201
Regular	3.853.663	2.927.186
Optimistic	5.765.359	4.379.282

Note: The present values are without VAT equal to 23%.

From Table 14 it is possible to see the monetary amount of FB saleable in the District of Bragança for each industry, being the pellet factory more favourable in terms of € per year with close to 2,5 M€ up to 5,7 M€, in comparison to a thermoelectric power station, which reach between 1,8 M€ to 4,3 M€ (a difference in profitability of almost 25%). The presented values are all without VAT.

These values originate the necessity of estimate the Return of Investment and lifetime profit, if such facilities were implemented. Calculations are present in Annex C.

5.4. ENERGETIC SELF-SUFFICIENCY

The District of Bragança still has a large amount of energy consumption using firewood (representing 27% of the final energetic consumption), in rural areas for heating and/or cooking. In cities, the use of pellets becomes more intense, thus, it is necessary to create a regional structure in order to implement a pellet (or briquette) industry or a thermoelectric industry that can absorb the production (Azevedo, et al. 2012, Castro, et al. 2012).

Therefore, it is necessary to establish a relation on FB energetic content and the energetic consumption in the District of Bragança. This is explained in Table 15.

Table 15 - Energetic self-sufficiency in the District of Bragança.

Municipality	District Energy Demand (TJ)	District FB Energy Content (TJ)[1]		
		Conservative	Regular	Optimistic
ADF	142,4	113,4 (79%)	178,4 (125%)	266,9 (187%)
BGC	2.233,4	464,1 (20%)	730,1 (32%)	1.092,1 (48%)
CZA	396,0	299,3 (75%)	470,7 (118%)	704,2 (177%)
FEC	107,0	81,9 (76%)	128,9 (42%)	192,8 (180%)
MCV	612,2	164,3 (26%)	258,5 (42%)	386,6 (63%)
MDO	507,4	104,6 (20%)	164,6 (32%)	246,2 (48%)
MIA	1.346,9	206,1 (15%)	324,2 (24%)	485,0 (36%)
MOG	623,9	396,6 (63%)	623,9 (100%)	933,3 (149%)
TMC	619,4	215,7 (34%)	339,3 (54%)	507,5 (81%)
VLR	261,3	147,6 (56%)	232,2 (88%)	347,4 (133%)
VIM	123,0	167,2 (135%)	263,0 (213%)	393,4 (319%)
VIN	253,4	242,4 (95%)	381,3 (150%)	570,4 (225%)
Total	**7.226**	**2.603**	**4.095**	**6.125**
Average (%)		**58%**	**92%**	**137%**

Note: [1] **- 1ton = $18*10^{-3}$TJ, Source:** (Ferreira 2008)**.**

It is possible to conclude that the District of Bragança can see its energetic necessities reduced from 58% (conservative scenario) to 137% (optimistic value), being Vimioso (VIM) the municipality most favourable to see its energetic dependence reduced and Bragança the least favourable.

If forest management is implemented as a good infrastructure of dedicated industries using local FB resources, the overall percentage can be raised, and exportation is possible in an optimistic scenario. This is linked directly to the amount of FB area available and energetic consumption, thus, if a municipality has high energetic consumption and a small area to supply this need, the value of energetic self-sufficiency is very small.

A viable way to rise the percentage of self-sufficiency is through the introduction of industrial facilities such as pellet or thermoelectric factories.

6. LIMITATIONS

There were presented across the making of this thesis several limitations, mainly due to the non existence of this type of industry in the northeast of Portugal, and the existing studies did not focused the economical aspects in such depth.

The existent Forest Biomass electricity and pellets industries analysed are located in centre regions, where Eucalyptus is the main tree used. There, this type of tree has short periods of cut (15 to 20 years) due to have fast growing when compared to coniferous (25 to 30 years). Also, forest stands management are implemented before these industries appear. A good implementation of forest management in the District of Bragança could resolve this problem in terms of productivity.

Other limiting factor is that Portuguese forest is consumed every year by wildfires, reducing forest area. The values used are 7 years old, being not as accurate as possible. There is the necessity of further studies.

Although were not considered aspects relevant to express the problem of FB gathering (availability of biomass, road slope to and from the yard, size of road which may forbid the passage of trucks, etc.) these kind of information is vital, but only if a project is considered to be implemented in the region. Therefore, it was not considered in this thesis.

Another aspect of the district of Bragança is that 25% of its surface area is protected by law (Montesinho Natural Park, Douro International Natural Park and Azibo Resevoir Protected Landscape) attending to about 165.000 ha of the 660.800 ha of the land surface of the District of Bragança. These protected areas were created to protect wild life and habitats, and, therefore, the cut of forest stands is conditioned, but, not impossible. This aspect was not considered, due to the objective of this thesis is to estimate the potential interest FB to be obtained in the District of Bragança. Nevertheless, it is as vital as the previous aspects, mainly because it is necessary to obtain permits from nature conservation agencies, as from other organisms in the District, if such a project will be started.

7. CONCLUSIONS / FUTURE WORK

The District of Bragança has a vast potential in forest biomass that has not been explored in terms of pellet and thermoelectric market and energy dependence reduction.

Analysing the areas of coniferous forest it was obtained annual productivity levels between 144.645 to 340.340 tones with 30 yearly cut rotations.

Considering yields from similar factories (pellet and thermoelectric) in Mortágua, Portugal, the amount of pellets produced was between 57.607 and 135.545 tons per year and from 134,3 to 316,0 GWh in the thermoelectric industry.

Using selling prices (all without VAT, which is currently 23%) practiced in each factory, the amount of pellets that can be sold was between 2,5 M€ up to 5,7 M€, and the thermoelectric power station reached between 1,8 M€ to 4,3 M€, near 25% less.

Finally on district energetic dependence, the Forest Biomass considered accounted to a reduction of this dependence from an average of 58% to 137%. On an optimistic level, this can permit to export / sell electricity, if conditions are gathered.

The objectives initially indicated were obtained. All values presented through the thesis are interesting because they show the possibility to promote further and more profound studies concerning forest stands management projects, creating or attracting companies dedicated to use forest biomass, fomenting political will and establish industries that use local resources and local hand job. Also, it can mobilize farmers, once not organized, creating a chain system and be a row model to other districts and countries less developed.

As future work, one possibility interesting to be approached is the use of pellets from the pellet factory to be used as combustion fuel in the thermoelectric power station. It was not considered because in Portugal there is not such interaction between factories and power stations, mostly because they are from different companies. This is an aspect to be considered in further studies because it can promote more efficiency in forest stands management.

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ANNEXES

ANEX A - PELLETING PROCESS

The transformation of FB in to pellets (or briquettes), is generally translated into Figure 20.

The pelleting process starts is divided into two major stages - Pretreatment and Post Treatment - in which the first is where FB is transformed into chips with homogeneous aspect and consistence, passing to the other stage, Post Treatment, where wood chips are compressed (or densified) turning into pellets, being either stored or transported to the customers.

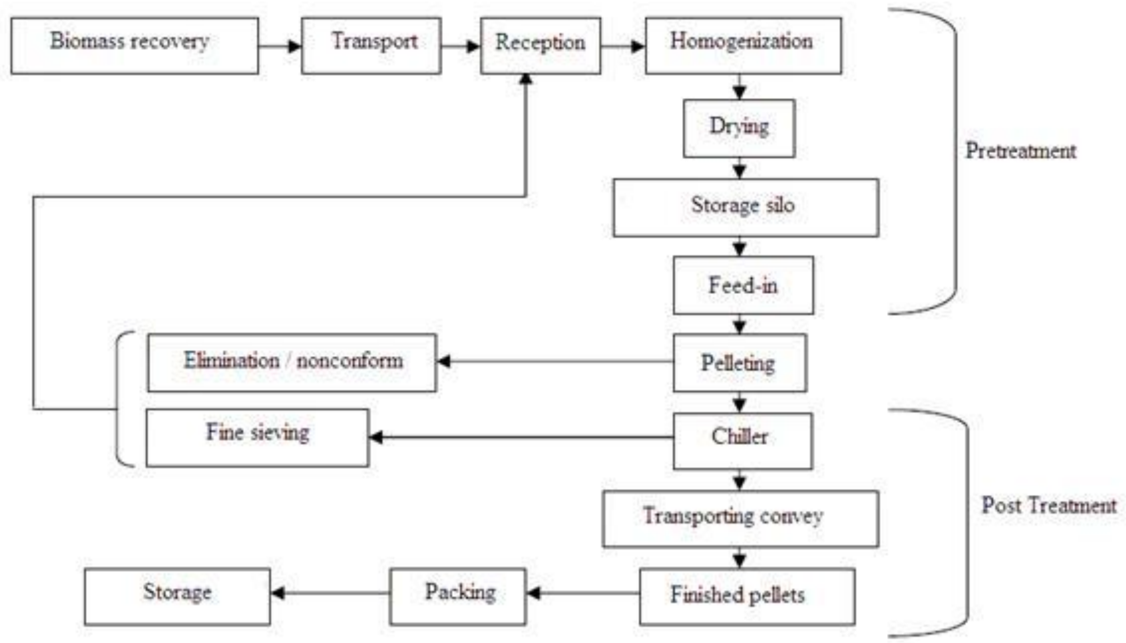

Figure 20 - Pelleting process.

Pretreatment

Upon material receipt, FB passes through a preparation phase, i.e., remove most of the larger impurities found to make the combustion as clean and free of impurities as possible, because, impurities may destroy or obstruct the boiler. Thereafter, and if not already come in the form of chips, the raw material undergoes a process of chipping in order to provide an all matter uniform appearance. This is performed in two different ways in the material, as previously explained - knives or hammers chippers.

The homogenization of the material is not always necessary, depending on the degree of chipping in which the matter arises. The mixing if applied results in a product with constant characteristics required by the market.

Before entering in the storage or feed-in stage, the homogenized material is subjected to a drying process so the final product (pellet) is present with a degree of m. c. inferior to 12% (Alakangas, Wood pellets in Finland – technology, economy and market 2002).

After this stage, the wood material is sieved again to assure that no mechanical parts in the pelleting process are obstructed. If any material is founded that is not conforming to the requirements, is retrieved to the stage of reception and enters again in the pre-treatment stage from beginning.

Post treatment

This second stage is where the particles, after drying, are compressed to achieve pellets (or briquettes), according to costumers demand, respecting always norms and standards. As such, the particles enter pelleting matrixes are mixed usually with steam (or corn flour) in order to bond and connect particles, and in this process, the matrixes are heat, removing remaining m. c. (5 - 10%) so that final product has good combustion characteristics, followed by a cooling stage in chiller(s), where the pellets are introduced into a vertical counter current flow chamber (Alakangas, Wood pellets in Finland – technology, economy and market 2002).

Cooling is considered the most important step of the pelletizing process since this is where lignin reaching its maximum binder potential allowing the pellets to maintain the new shape. At the end of process, the fine particles that escaped the densification are collected again being reintroduced at the beginning of the process.

Finally, there is the need of the field of distribution - storage, transport or packing - being necessary to take into account the distance to which the pellets need to be moved away because it turns more expensive as well the more emissions are emitted during transport. Another preoccupation is that pellets are subjected to conditions which cause the increase of moisture, thereby altering its characteristics, the longer the journey needed to delivering them to the customer (Alakangas, Wood pellets in Finland – technology, economy and market 2002).

Considering Reed *et al.* (2008), the pelletizing process is very efficient from an energy efficiency point of view, making it an opportunity to business nowadays because fossil fuel prices fluctuations.

ANNEX B - DENSIFIED BIOMASS STANDARDS

Towards the use of various forms of FB as well as the existing need for competition in the energy market and modernization of combustion, arises on the market the concept of densified biomass. As its name implies, densified biomass is an agglomeration and junction of FB (although other biomass materials are allowed) previously chipped.

There are currently two different types: pellets and briquettes. Pellets (Figure 21) come in small condensed parcels (usually 20 mm long and 8 mm width) while briquettes (Figure 22) have a similar shape like tree logs (usually 250 mm long and 80 mm width).

Figure 21 - Pellets. Source: www.sp-co.ru

Figure 22 - Briquettes. Source: www.sp-co.ru

The densification of biomass in the form of pellets made possible to increase the homogeneity and transporting to the destination, allowing these to have a high bulk density and be competitive with the combustion of coal, and through a more efficient combustion due to low particulate emissions (Kanury 1994, Werther, et al. 2000).

Like other fuels available in the market, pellets are covered by rules and minimum requirements which must meet to be sold. The main parameters concerned face the amount of moisture present, the calorific value, ash content, and the values of bulk density per unit and concentration of substances such as nitrogen, chlorine, among others (ECS 2010).

Table 16 - Comparison between pellets and chips. Source: (CBE 2002)

Parameters	Pellets	Dry chips
LHV - GJ/ton	17,0	13,4
kWh/kg	4,7	3,7
kWh/m3	3.077	744
Moisture - %	8	25
Density - kg/m3	650	200
Ashes - %	0,5	1

From the analysis of Table 16 it is found that the use of chips as a fuel becomes less favourable since it occupies three times the space of pellets, produces more ash during combustion and contains about ¼ of the energy in equal quantity (volume) of pellets.

Since pellets are a recent product emerging on the Portuguese market, several countries established rules and regulations. The main standards are the ÖNORM M7135 from the Austrian Pellets Association, the Germans DIN 51731 and DINplus, from Switzerland the SN SS166000 and the SS18 71 20 from Sweden, mainly because these countries are the largest pellet producers. A comparison between DINplus, DIN 51731 and ÖNORM M7135 is presented in Table 17.

Table 17 - Comparison between DINplus, DIN 51731 and ÖNORM M7135. Source: (Pellet@las 2009)

Parameters	Unit	DINplus	DIN 51731	ÖNORM M7135
Diameter	**mm**	4-10	4-10	4-10
Length		< 5 x D	< 50 mm	< 5 x D
Density	**kg / dm3**	> 1,12	1,0 - 1,4	> 1,12
Water content	**%**	< 10	< 12	10
Abrasion	**%**	< 2,3	-	< 2,3
Ash content	**%**	< 0,5	< 1,5	< 0,5
Energy content	**MJ / kg**	> 18	17,5 - 19,5	> 18
Sulphur content	**%**	< 0,04	< 0,08	< 0,04
Chlorine content	**%**	< 0,02	< 0,03	< 0,02
Nitrogen content	**%**	< 0,3	< 0,3	< 0,3
Heavy metals		Regulated	Regulated	Not Regulated

Between the presented, the main standards used in Europe are ÖNORM M7135 and DINplus, which are very important to guarantee the final quality of the product at the stage of delivery to the end consumer (Hahn 2004).

The European Union also joined efforts to standardize the pellets market through the establishment of standards by CEN (European Committee for Standardization or *Comité*

Européen de Normalisation) creating labels, such as “ENplus” which covers not only quality issues but also criteria for sustainability and supply security - crucial for the development of the existing and future pellet market - EN 14691 (technical specifications) and EN 15234 (quality assurance for solid biofuels) (Pellet@las 2009, Alakangas, New European Pellet Standard - EN 14961-1 2010).

ANNEX C - RETURN OF INVESTMENT

The Return Of Investment (ROI) was made to both industries. The several considerations taken are presented next.

The Thermoelectric power station is presented by the following table.

Table 18 - Thermoelectric power station considerations to determine the Return Of Investment.

	Scenarios		
Parameters	**Conservative**	**Regular**	**Optimistic**
Factory cost (€)	50.106.645€	79.019.168€	118.487.069€
FIT (€/yr)	16.114.297€	25.343.602€	37.915.862€
FB Acquisition (€/yr)	3.118.546€	4.904.663€	7.337.730€
General Maintenance Costs (€/yr)	3.105.332€	6.976.438€	14.633.578€
Sales (€/yr)	1.861.201€	2.927.186€	4.379.282€
Return Of Investment (yr)	**3,08**	**3,59**	**4,31**

The values present in Table 18 were obtained using the following considerations:

- **Factory cost**: Obtained using cross-multiplication from the values from the thermoelectric power station of Mortágua, which cost 25 M€ and produces 67GWh. As such, the values estimate ranged from 134 to 316GWh.
- **FIT (Feed-In Tariffs)**: Assumed as 120€/MWhe given the time that pass from the launch of *Decreto-Lei* no. 33-A, which was in 2005, with a maximum time of 15+10 years.
- **FB Acquisition**: The value was achieved by multiplication of the amount of FB to be processed and Table 11.
- **General Maintenance Costs**: Personal, ashes clearance, O&M, personal for the first year. Remain value to be considered in the entire life-time is O&M.
- **Sales**: Present in Table 14.
- **Return Of Investment**: Estimate for thirty years of life-time.

The ROI for the pellet factory is presented in Table 19.

Table 19 - Pellet factory considerations to determine the Return Of Investment.

Parameters	Scenarios		
	Conservative	**Regular**	**Optimistic**
Factory cost (€)	11.039.918€	21.703.652€	38.964.280€
FB Acquisition (€/yr)	1.670.650€	2.627.498€	3.930.927€
General Maintenance Costs (€/yr)	1.500.000€	2.800.000€	5.050.000€
Sales (€/yr)	2.450.286€	3.853.664€	5.765.360€
Return Of Investment (yr)	**5,16**	**8,60**	**10,06**

As previous, the values present in Table 19 were obtained using the following considerations:

- **Factory cost**: Achieved through cross-multiplication considering a study performed in Ontario[7], Canada, which indicates that a pellet factory ranges from $100 to $150 per annual tonne produced.
- **FB Acquisition**: The same method as the thermoelectric power station.
- **General Maintenance Costs**: Emission control, pellet storage, bagging equipment, personal and O&M for the first year. To the rest life-time, the only value to be considered is O&M.
- **Sales**: Present in Table 14.
- **Return Of Investment**: Estimate for thirty years of life-time.

The results of Table 18and Table 19 are an estimate according to existing facilities and the estimate production this thesis.

Several differences can be observed. The first major difference is that the pellet factory does not receive Feed-In Tariffs. DL 33-A/2005 only consecrates RFB thermoelectric power stations that supply the national grid, and is according to the amount of MWhe achieved. The value considered (120 €/MWhe) was reached with the original value (107 €/MWhe) and inflation.

Other difference is that in Portugal, the pellet factories are absent of corporate taxes, which in 2009 was €8.470.400[8].

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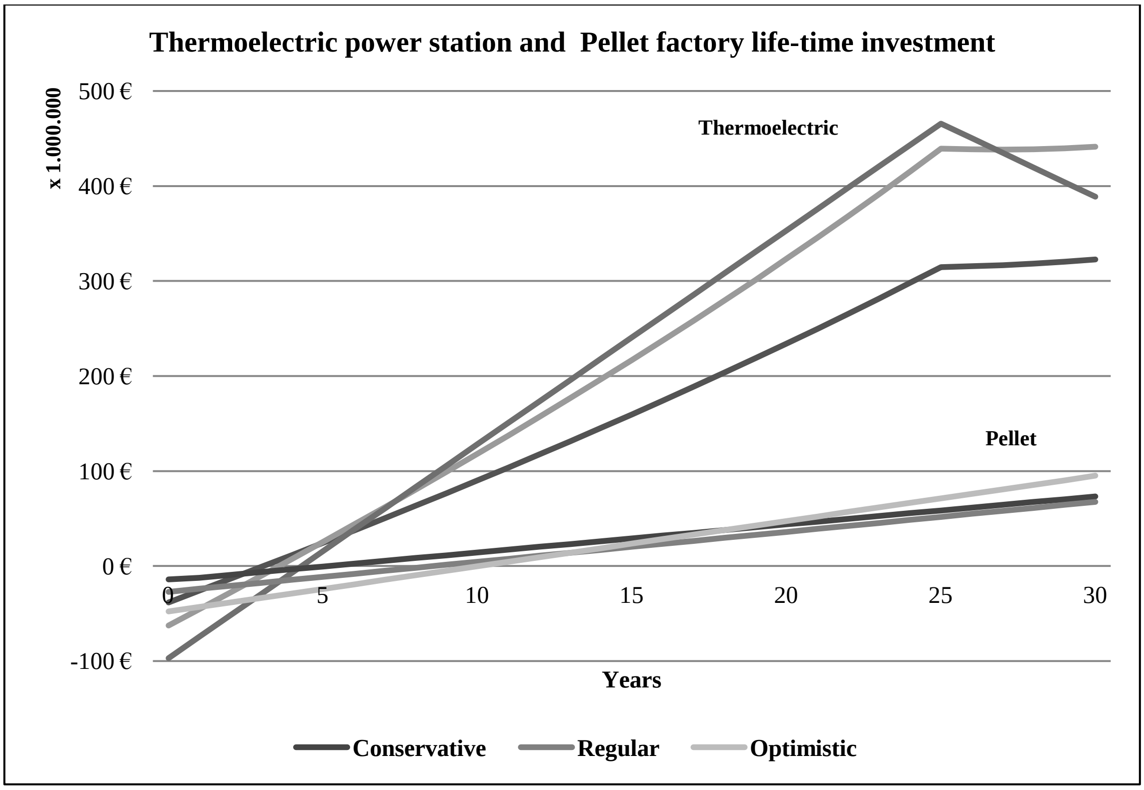
[7] Deloitte (2008).

Although the thermoelectric power station presents reduced ROI, these may not be accurate, because this type of industry has more complex systems than a pellet factory, requiring major investment in O&M to maintain proper functioning. Pellet factories have fewer problems, and, as such, the maintenance costs are inferior due to the simplicity, as observed in Figure 17.



Graphic 1 - Thermoelectric power station and Pellet factory life-time investment.

Graphic 1 represents of the yearly values expected to each factory. In the thermoelectric power station analysis is possible to see that after the end of FIT (25 years = 15+10 years), there is a maintenance or reduction in profit. The pellet factory does not have a diminishing in profit in the three scenarios, but, these are small in comparison to the thermoelectric power station.

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[8] *Resolução do Conselho de Ministros* no. 51/2010, *Diário da República*, 1st series, no. 140 of July 21.