DEVELOPMENT OF A FOREST BIOMASS SUPPLY MODEL FOR A DEMONSTRATION COGENERATION PROJECT IN CHILE

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Development of a forest biomass supply model for a demonstration cogeneration project in Chile.

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Summary

Although there is a great forest biomass potential in Chile and bioenergy could become a relevant energy industry in the country, its development has been prevented mainly by the lack of proper business models that can fit into the Chilean reality.

Chilean forestry sector is characterized by small-scale ownership, a situation that requires the implementation of associative business models to provide a reliable supply for a cogeneration plant. Currently, small owners of biomass resources are not interested in developing bioenergy projects since they do not have enough feedstock to make a profitable project by their own. On the other hand, industries and project developers are not attracted to develop such projects because they do not have a secure and reliable long-term biomass supply. This is a vicious circle hard to break just leaving the market act by itself.

The present project presents the development of a supply chain model for a small demonstration CHP plant located in Chiloé Island. The idea of this $2MW_{el}$ installation is to promote these types of projects, that can provide heat and power to processing industries located nearby the biomass resource and replace conventional fuels currently used. According to calculations made, the amount of feedstock needed is available in a short distance from the energy demand point, which was ratified by a field trip made to the chosen plant site.

The proposed business model to supply the plant was a cooperative model, based on the formation of a forest-owner cooperation. This model was chosen in order to empower small owners and provide them the appropriate management and technical tools to improve their income and quality of life by developing a sustainable and profitable business. There are several successful international experiences with this type of business model and also there are some small initiatives in the country that can be taken as a starting point for a novel industry in the energy sector.

Since the Chilean energy matrix is strongly dominated by imported fossil fuels, it is only logical that the country should follow the path of developing its renewable energy sources and biomass is one of the most promising alternatives currently technically and economically feasible.

Abstract

Chile has a heavily fossil fuel dependent energy matrix, based mostly on imported oil, gas and coal. Renewable energy sources are an alternative to diversify the energy matrix with local resources and biomass is one of the most promising sources in the country. Although biomass represents a 16% of the primary energy supply, most of it is used in low efficiency processes. Therefore it is important to review more efficient conversion processes, as cogeneration, and their barriers of implementation.

The problem tackled in this project was the forestry biomass supply model for a 2 MW_{el} cogeneration plant located at Chiloe Island. The plant size was established according to the power demand of four fishing companies located in the nearby area. The annual biomass requirement was calculated in 19.000 ton, which will mainly come from Canelo forest, an abundant native specie not commonly used as residential firewood due to its lower heating value than traditional species.

The main barrier identified for establishing a proper supply chain in Chile is the small-scale ownership of the forests, with more than 80% of the total area in hands of owners with lands smaller than 200 ha. The model proposed to gather the supply was a Forest Owner Cooperation (FOC), commonly used in countries in Europe and North America. By having larger supply and lower transactions cost, industry pays FOCs higher prices for wood products that it does to a single small-scale producer. Therefore, it is an attractive business for small owners and it guarantees a secure supply to the CHP plant.

In addition, the lack of accurate information about the forests, such as ownership, management plans and locations, was an important barrier identified to establish a more advanced model, which may have included the optimum location of the plant and transport logistics. This barrier was acknowledged during the project, especially throughout a field visit to the island, where it was clear that the natural resource was extremely abundant and close to the energy consumptions areas, but there were no clear information about its real fuel potential (management plans).

On the whole, the following situation is occurring in the Chilean reality. Small owners of native forests are not interested to manage their forest because they do not have a market where to sell the biomass obtained. On the other hand, industries and project developers are not attracted to develop bioenergy projects because they do not have a secure and reliable long-term supply. This is a vicious circle hard to break just leaving the market act by itself. Therefore, government actions are expected to take place if there is a real interest to develop such industry.

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Acknowledgment

The present thesis project was developed in the Renewable Energy Center (CER), located in Santiago, Chile. The Center is a novel organization and has a mission to promote and facilitate the development of the renewable energies industry, articulating public and private efforts to optimize the use of Chilean natural resources, thus contributing to ensure a sustainable energy supply, in economic, social and environmental terms.

For 2010, the Center identified two energy sources that were the most promising for Chile. The first is Concentrating Solar Power (CSP), due to the enormous potential in the northern part of the country, especially in the Atacama Desert. The second one was Biomass because there is large potential in the southern regions of Chile.

The Center had already identified that one of the main barriers to develop biomass projects was the establishment of a reliable supply chain of feedstock, no matter which type of biomass was used. Therefore, the CER wanted to study this area more deeply and requested the development of the present work.

1 Introduction

Chile is a country located in South America that occupies a long, narrow coastal strip between the Pacific Ocean to the west and the Andes mountains to the east. According to the last census carried out in 2002, its population reaches 15.116.435 inhabitants (INE, 2002).

Chile has experienced a steady economic growth in the last decades, resulting from sound economic policies maintained consistently since the 1980s. This development has allowed Chile to increase the quality of life of its inhabitants, reducing poverty rates by over half, and tripling its GDP in just two decades. A consequence of this progress has been the increase in the overall energy consumption, both in the industrial and residential sectors. Between 1970 and 2002, the country's energy consumption more than tripled, following the same trend as economic growth, as shown inFig.1.

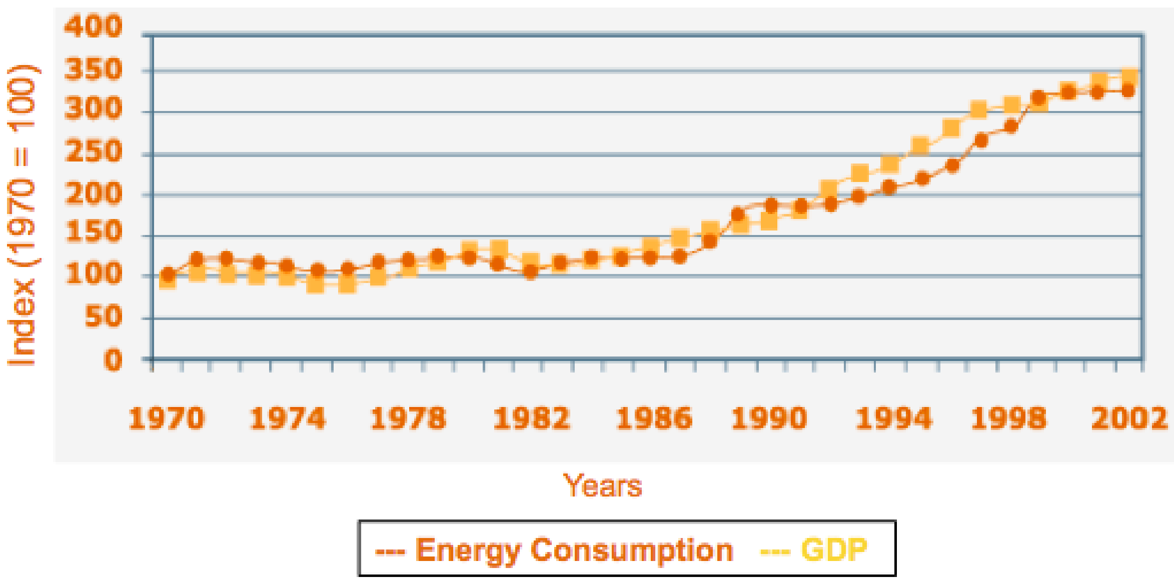

Fig.1: *Energy consumption and GDP between 1970 and 2002,* (Programa Chile Sustentable, 2010)

This trend has continued in the last years. A very representative figure is the following; between 2002 and 2007, the energy consumption per inhabitant grew by 82,94% (INE, 2008)

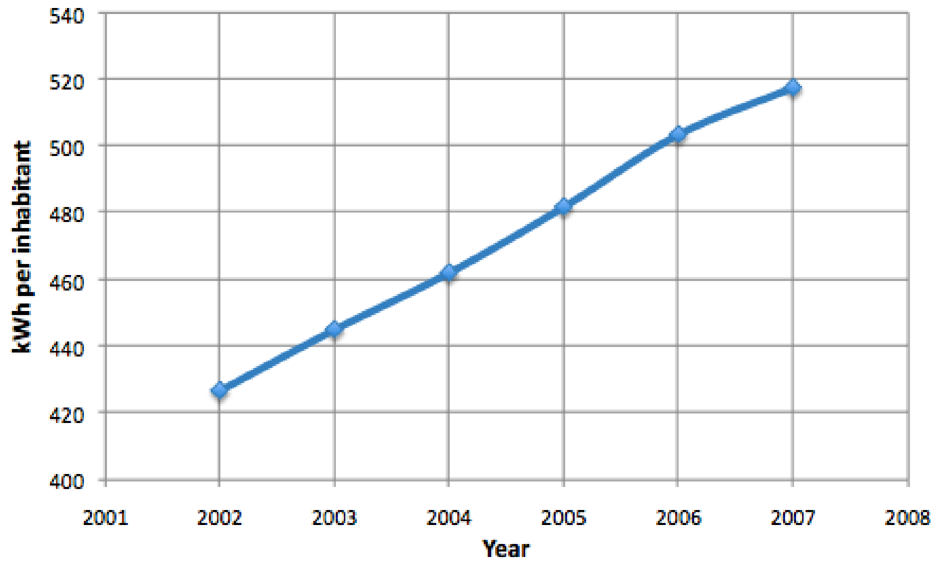

Fig.2: *Electricity consumption per inhabitant between 2002 and 2007* (INE, Distribución y consumo eléctrico en Chile, 2008)

In order to provide the energy needed to meet the rising demand, conventional sources have been used throughout the years, especially oil, coal and gas (Fig.3).

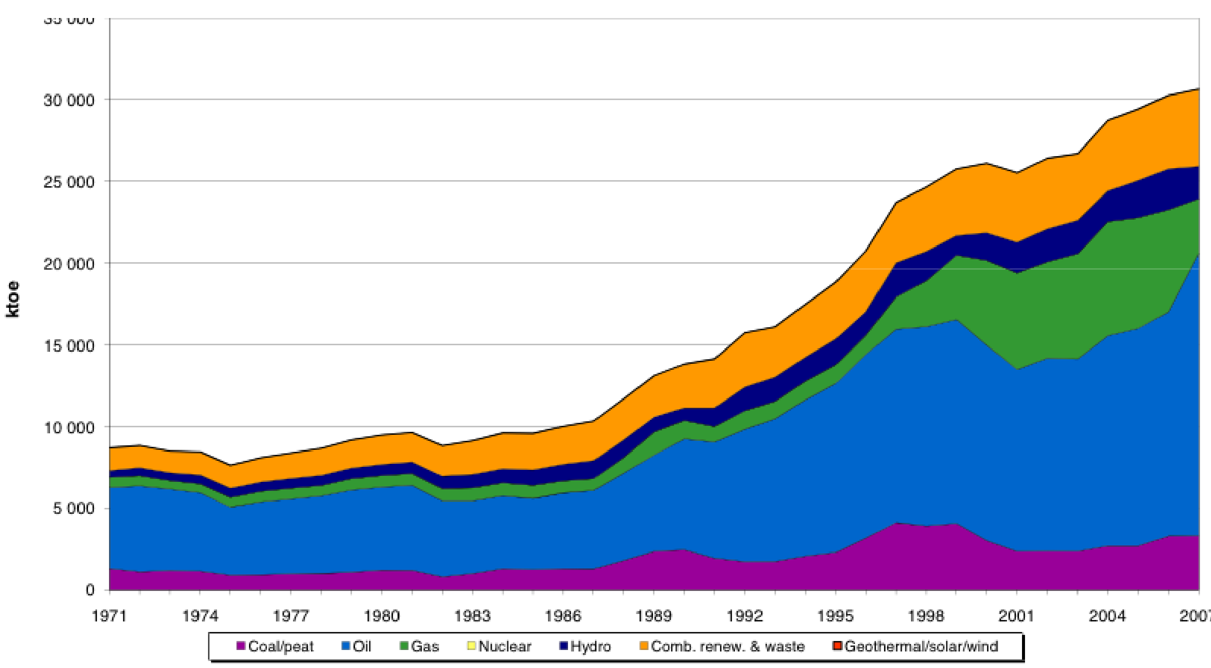

Fig.3: *Total primary energy supply between 1971 and 2007* (IEA, 2007)

One of the main problems with this energy matrix is that it strongly relies on foreign supply of fossil fuels (Fig.4). According to information from the National Energy Commission (CNE, Balance Nacional de Energía, 2008), 99% of the oil used in the country is imported, as well as 80% of the natural gas and 96% of the coal. The only sources that are available within the country are hydropower and biomass, which combined represent a 22 % of the total energy supply and also correspond to the only renewable sources currently being used.

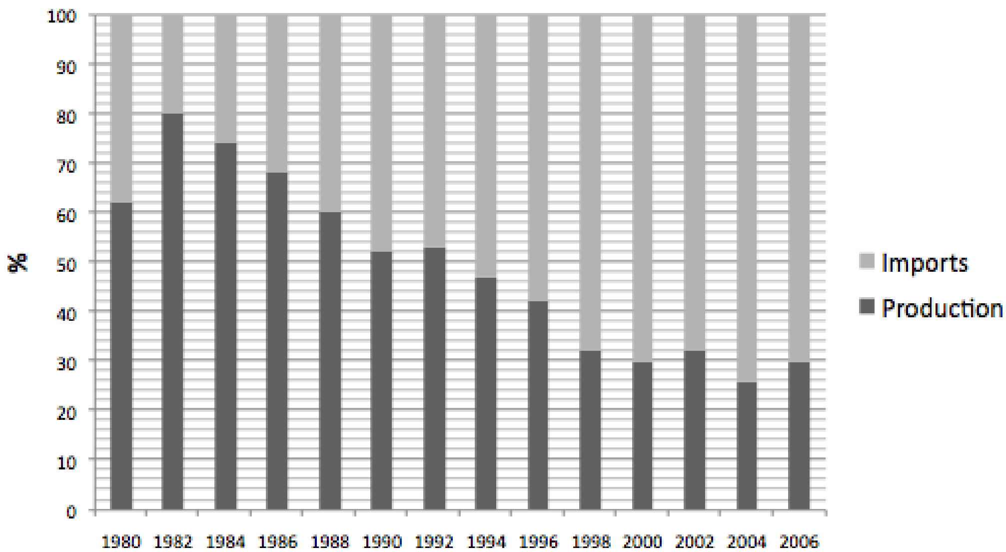

Fig.4: *Energy dependency of Chile*(CNE, Balance Nacional de Energía, 2008)

Hydropower has a vital role in electricity generation (Fig.5), where almost 50% of the power is produced by this source. Due to the particular shape of Chile, all hydropower plants are concentrated in the central/south part of the country. In other parts of the country electricity is produced from conventional sources, such as coal, oil and gas.

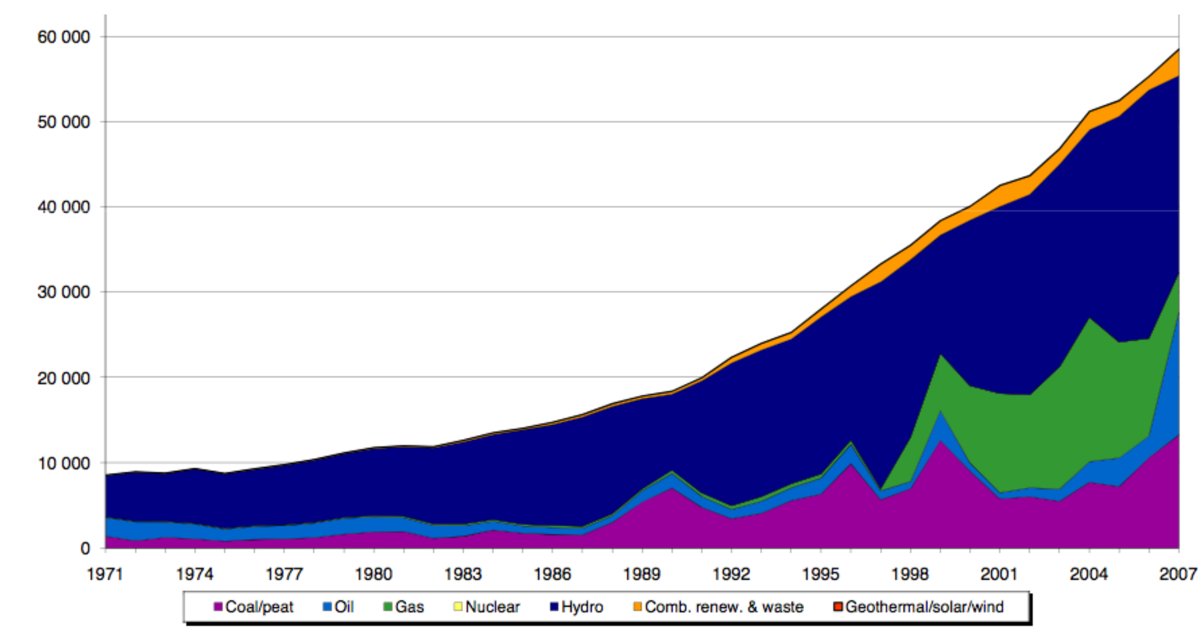

Fig.5: Electricity generation by fuel (IEA, 2007)

Biomass has a significant share in the energy matrix too; however its use is mostly concentrated in the residential sector, where firewood corresponds to 58% of the total energy consumption.

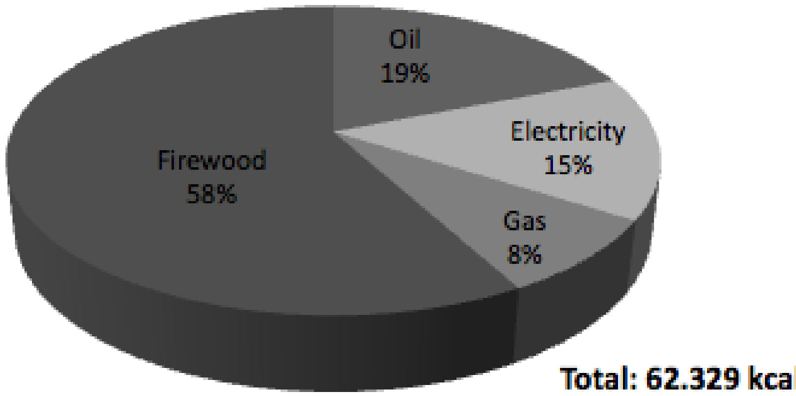

Fig.6: *Energy consumption in residential sector in 2008,* (CNE, Balance Nacional de Energía, 2008)

In terms of power generation, the contribution is small and mainly comes from cogeneration plants located at large forestry and pulp mill complexes, where the biomass supply is constant and reliable.

One of the main issues of the current use of biomass in Chile is that the efficiency of most processes being used is very low (around 10%). Since the biomass potential in the country is rather large, there is a need to study in depth different sources and technologies for various applications suitable in order to make most out of the available and valuable raw material (UTFSM, 2008).

2 Objectives

The main objectives of the present project are:

- Identification of barriers for the development of cogeneration project using raw biomass, residues and byproducts from the forestry and agriculture industry.

- Design of a supply chain model for a demonstration cogeneration project for a given location, using the type of biomass most feasible in the given region. The model will be done considering the following issues:

    - Biomass availability, including location, ownership, quality, etc.
    - Demand for energy: current primary energy sources, steam process demand.

3 Methodology

The overall methodology to identify the barriers that biomass projects face is to develop a theoretical concept of a demonstration project and recognize which the most relevant variables are that can affect the development of the biomass projects. This project will also consider factors which could prevent the progress of this industry in Chile.

The organization of the work has been set using the following approach:

- Identify the most promising biomass source in the country, by using current biomass resource assessment studies

- Based on this decision, the characterization of the biomass resource (quality and spatial distribution) will be matched with the energy demand on the area (both thermal and power demand) in order to identify an attractive area where to develop a CHP demonstration plant. The size of the plant will be set according to specific data of the energy demand currently supplied by conventional fuels.

- By having a specific location chosen, a supply chain model will be developed, studying several aspects such as:
    - Biomass availability and ownership.
    - Technology and workforce
    - Transport logistics

- Finally, the identification of the most relevant barriers will be made, so the information gathered can be summarized for policy makers. In this way, the design of support schemes and policies that tackle the identified barriers can be aimed at the relevant aspects that could boost the development of the bioenergy industry in the country.

4 Biomass Potential in Chile

There are several sources of biomass available in Chile. This includes firewood, crops, and waste from food, agriculture or industrial processes. In this study, four sources (Table 1) will be considered since they are identified as the most attractive alternatives (UTFSM, 2008).

In 2008, a study was carried out by the Federico Santa Maria Technical University called "Biomass potential for power generation in Chile for 2025"(UTFSM, 2008).In this report, the net potential of each source was calculated according to several factors, such as biomass availability, the biomass physical and chemical characteristics and the energy conversion technology to be used.

Biomass source	Technology
Manure from pigs and poultry, Energy Crops	Biogas plant
Waste from agricultural crops	Gasification
Waste from forestry industry	Direct combustion and cogeneration
Firewood from sustainable management of native forest	Direct combustion and cogeneration

Table 1: *Biomass source and the energy conversion technology considered* (UTFSM, 2008).

The net potential of power generation for each source is shown in Table 2. The information is given within a range of minimum and maximum values, due to the uncertainty level or the confidence interval of certain parameters used in the calculation procedure.

Biomass source	Net Potential		Share of total
	Min [MW]	**Max [MW]**	**%**
Manure from pigs and poultry, Energy Crops	2.027	4.106	31%
Waste from agricultural crops	280	600	5%
Waste from forestry industry	319	927	7%
Firewood from sustainable management of native forest	2.319	4.723	36%
Other	1.367	2.795	21%
Total	**6.312**	**13.151**	**100%**

Table 2: *Net Potential of different biomass sources in Chile,*(UTFSM, 2008).

Not only is the net potential important to consider when choosing a specific type of biomass to work with, but also the viability to develop successful projects has to be taken into account. This analysis was done taking into consideration the following factors(UTFSM, 2008):

- Type of biomass and whether its availability is constant, intermittent, seasonal or random.
- Geographical location and concentration of the natural resource.
- Level of accessibility of the resource from the generator entity. For example, if the owner of the biomass is also in charge of the power generation process, this is considered as a factor of 100%. If this is not the case, there are different percentages applied according to the distance between resource and generation facility and the supply chain that is created.

The final percentage of feasibility for each source is shown in Table 3.

Biomass source	Feasibility
Pig and Manure Waste, Energy Crops	21%
Waste from agricultural crops	53%
Waste from forestry industry	20%
Firewood from sustainable management of native forest	20%

Table 3: *Feasibility of development of power generation projects from different biomass sources*(UTFSM, 2008).

At first, biogas from manure and energy crops and combustion/co-generation of firewood from a sustainable management of native forests seem to be the most attractive alternatives, just in terms of the final power output that they can have. However, it is appropriate to analyze all factors around each option in order to make an adequate decision on what biomass source to focus on. Next, a few relevant aspects of each source will be mentioned, in order to justify the final choice.

4.1 Pig and Manure Waste and Energy Crops for Biogas Production

The feasible potential of biogas for power generation is estimated around 400 MW, by both the UTFSM study and reports from the National Energy Commission (CNE, 2007). This amount corresponds to 2,7% of the total installed capacity in the country.

The biomass sources considered in the study were residues from poultry and pigs along with energy crops, such as roots, barley, tubers, grains and fodder. From the sources studied, the most interesting ones are the waste from animals, due to their geographical concentration and proximity to the end consumer(UTFSM, 2008). However, the spectrum of sources considered in this study is limited, taking into account that worldwide, there are numerous successful biogas production endeavors from residential organic waste and biomass from wastewater treatment facilities which can further increase the potential.

In Chile, more than 80% of natural gas is imported. Most of it comes from Argentina, but due to a financial crisis, the neighboring country reduced gas exports and between May 2006and December 2008 there was no gas available for the industrial sector(Metrogas, 2009).Due to this shortage, industries were forced to use other fossil fuels, such as coal, oil and liquefied natural gas as a quick solution to the problem. Meanwhile, biogas started to become an attractive option for several industries that had the raw material to produce it and had not previously taken advantage of it.

Thanks to this situation and other incentives, biogas projects are already being developed by the private sector. Among the conditions that can encourage biogas production we can mention: the possibility of getting extra funding from the Clean Development Mechanism, the use of cogeneration technology to reduce fuel costs in industries, and the fact that biogas production is an economically competitive alternative to treat wastewater.

Fig.7: *Biogas plant in La Farfana, Santiago* (Metrogas, 2009)

4.2 Waste from Agricultural Crops

The main crops grown in the country are wheat, corn, and oats (Fig.8). The plantation fields are concentrated in the south-central part of the country (between regions VII and XI).It was considered that the waste production varied within a range from 150 to 320 kg/ha/month, depending on the type of crop(UTFSM, 2008)

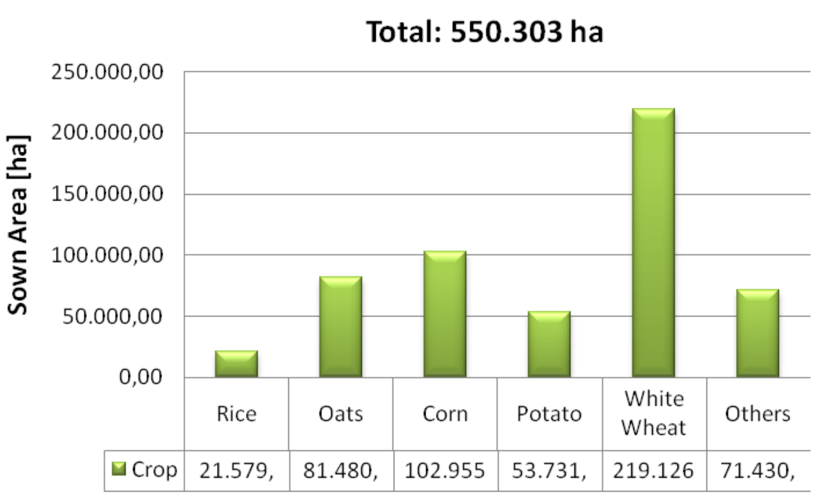

Fig.8: *Area of main crops in Chile,*(INE, 2007)

Although its potential seems to be small compared to other sources, waste from agricultural crops has certain advantages, such as its low moisture content. On the other hand, the main restrictions around the use of this source are its low energy density, its seasonality and the fact that there is already a demand for this product, for example as animal feed.

4.3 Waste from Forestry Industry

This is an activity that is already in progress in the country, undertaken mainly by private companies. One example is Arauco, one of the largest forestry enterprises in Latin America. This company owns several cogeneration plants, where they use waste biomass obtained from sawmills and processing plants (mainly from forests of pine and eucalyptus) as fuel.

The heat and electricity produced are consumed inside their own plants, although the surplus of electricity is incorporated to the National Power Network (SIC).

Plant	Installed Capacity [MW]	Power to Grid [MW]
Arauco	101	15
Constitucion	40	15
Licancel	30	6
Trupan	30	13
Valdivia	140	61
Nueva Aldea (phase 1)	29	14
Nueva Aldea (phase 2)	140	37
Total	**510**	**161**

Table 4:_Installed capacity and surplus to grid of cogeneration plants from Arauco (Arauco, 2006)._

Table 4 shows that there are several plants already in operation, and currently there are plans to open even more(Arauco, 2006). Since these large forestry complexes have the biomass supply ensured, this practice has become a business-as-usual situation for them. Moreover, several of these cogeneration projects have been presented as Clean Development Mechanism projects, receiving extra funds that can finance up to a 30% of the initial investment of a cogeneration facility (Arauco, 2006).

Being this the current scenario, it is extremely complicated for companies that do not belong to the forestry industry to have access to waste biomass for independent cogeneration projects.

4.4 Sustainable Management of Native Forest

From all the existing forests located in Chile, 81% of them correspond to native forests(CONAF, 1999).This number only exemplifies the enormous potential that this type of biomass has, which is estimated between 5 and15millions of cubic meters of firewood per year[1](CORMA, 2010). This

[1]This number varies according the amount of hectares considered to be available for exploitation.

amount would ensure the sustainability of the resource, considering that its annual growth is estimated in 5 cubic meters per hectare(CORMA, 2010).

However, due to years of improper management, the native forest is very degraded, especially those in the hands of small farmers. A very common and damaging practice performed across the years is the extraction of the best quality species, leaving the forest with low value species, and threatening the sustainability of the forests. Given this situation, currently the only alternative that owners have to market native forest is as firewood, since its low quality does not allow producing other products, such as lumber and boards.

In 2008, the "*Recovery of Native Forest and Forestry Promotion"* law was passed in Congress. The aim of this law is the promotion, recovery and improvement of native forests, in order to ensure the forests' sustainability and environmental policies. Within this law, there are funds available for forestry management plans that are aimed to recover native forests for timber production, with an economic contribution of up to USD 72 dollars per hectare(CONAF, 2008).Also, there is a National Firewood Certification System (SNCL), which can certify that the firewood comes from a sustainable managed forest which increases its commercial value.

Considering that at present90% of the firewood market is informal (precarious work conditions, tax evasion and the non-fulfillment of consumer laws) and lacks any regulation regarding the origin of the timber(SNCL, 2010), these kinds of projects can be a contribution to start a formal firewood market. Also, using the cogeneration technology can drastically increase the efficiency of the overall conversion process, since most firewood is currently used in traditional stoves and boilers.

Among the disadvantages that this biomass source has, the most relevant one is the lack of experience in establishing a successful biomass supply chain (producer, intermediary and end-consumer). Also, the cultural change needed from all parts of this supply chain is important to take into account. This item covers several issues, ranging from the training needed from producers in order to learn proper and new practices to deal with their forest, to the preference of the consumer towards this sustainable firewood rather than the previous one, even though it may have a higher cost.

4.5 Choice of Biomass Source

After the analysis of the advantages and disadvantages of the different sources presented, it was decided that the current project will focus on the use of the sustainable management of the native forest as a biomass source. The reasons for this choice are the following:

- It has the biggest potential for power and heat generation.
- Firewood is already a commonly used form of biomass.
- It could improve the quality of life of the small owners of native forest plantations, which currently have no or very low income from the forest itself. Thus, there will be a promotion of sustainable rural development as a remarkable consequence of the power generation from a renewable source.
- With the application of the Native Forest Management Law, there are capitals available for programs of sustainable management of native forest that can include the utilization of this biomass as an energy source.
- It opens a new and serious market for firewood from native forest, with regulations and certification standards.

- The sustainable management of native forest will help restore the level of degradation that it presents and also to preserve its biodiversity.

5 Characterization of Native Forest in Chile.

To formulate a sustainable energy solution based on the forest sector, it is indispensable to have a reliable estimate of the locally available biomass sources.

In 1999, the National Forest Agency (CONAF) published a complete land registry of native vegetation resources in the country. Below, a brief summary of the results from this study will be discussed, in order to give an estimation of the amount and location of native forests in Chile.

5.1 General Characteristics

The total area of forests in the country in 1999 was 15.637.232,4 ha, divided into three different categories, as presented in Fig.9.

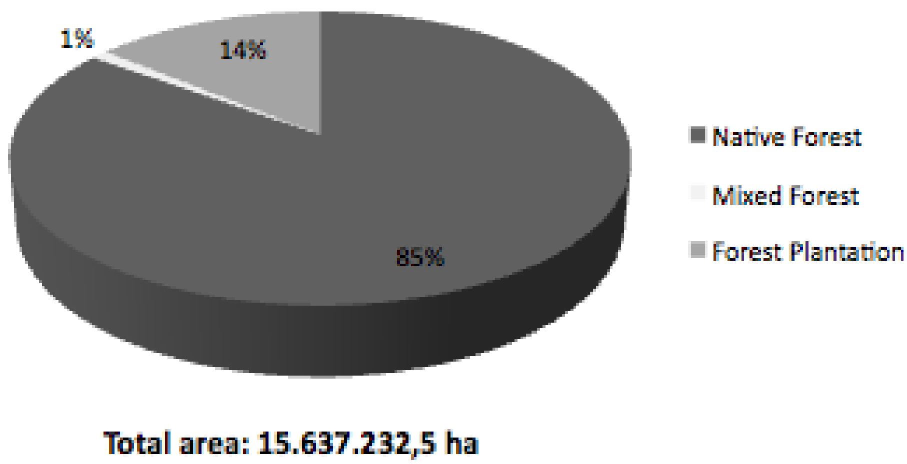

Fig.9: *Total area of forests*(CONAF, 1999)

As the diagram shows, the great majority of the forests available in the country are native forests (13,1 million ha), but within this type of forest there are subcategories that are divided according to the structure of the trees that belong to it. These categories are:

- Primary Forest: a forest that contains trees which have reached great age remaining in its original condition. This forest has been relatively unaffected by human activities.
- Secondary Forest: a forest which has re-grown after a major disturbance (fire, insect infestation, timber harvest)and where a long enough period has passed, so that the effects of the disturbance are no longer evident.
- Krummholz Forest: a particular type of forest that has been continuously exposed to fierce and freezing winds, causing the trees to become stunted and deformed.

The percentage of each structure available in the Chilean native forest is shown in

Fig.10.

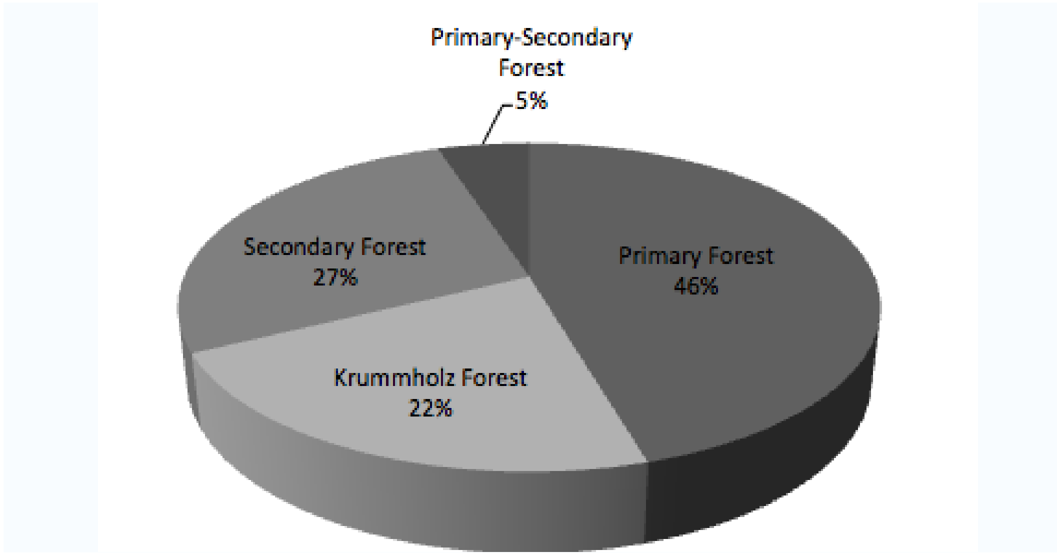

Fig.10: *Area of native forest according to structure*(CONAF, 1999)

Within each category, there is available information about area coverage and height distribution, which is relevant when estimating the available firewood potential. (see Table 5)

	Height	Area ha	Share of subtotal
Primary and Primary-Secondary Forests	8-12 m	1.659.978	14,6%
	>12 m	4.874.498	36,3%
Secondary Forest	2-12 m	2.766.865	20,6%
	> 12 m	818.881	6,1%
Krummholz Forest	2-8 m	3.004.719	22,4%
Total		**13.430.558**	**100%**

Table 5: *National area of native forest divided by structure and height*(CONAF, 1999)

Although the area of native forests seems to be vast, in reality there are areas that cannot be exploited in the short term, due to technical, environmental and ownership constraints. These areas are:

- National Parks and National Reservoirs.
- Native forests with heights lower than 8 meters.
- Native forests located in areas with a slope greater than 60 degrees
- Native forests located in protected areas.

Considering these restrictions and taking into account the forestry types that have low technical complexity for its management, the available area of native forest for sustainable management is estimated at 3.007.665,2 ha (Conaf/GTZ, 2006)

5.2 Geographical Distribution

For the purpose of a better understanding of the geographical distribution of the native forest in Chile, Fig.11shows a political map of Chile, with its distribution by regions.

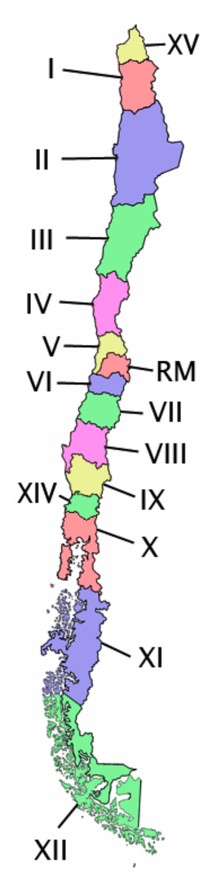

Fig.11: *Map of Chile, with its regions identified.*

The regions XIV and XV were created more recently, which is the reason why most of the official information is not updated. Therefore, when the X region is mentioned, it will correspond to the X and XIV regions together.

Of the 13.430.602 ha of native forest available in the country, 84% is concentrated in the 3 southernmost regions(X, XI, XII). This is a key fact, since these regions present constraints related to connectivity and proper access to the rest of the country. This situation may lead to a major challenge regarding the collection and supply of the biomass, which will be tackled later in this report.

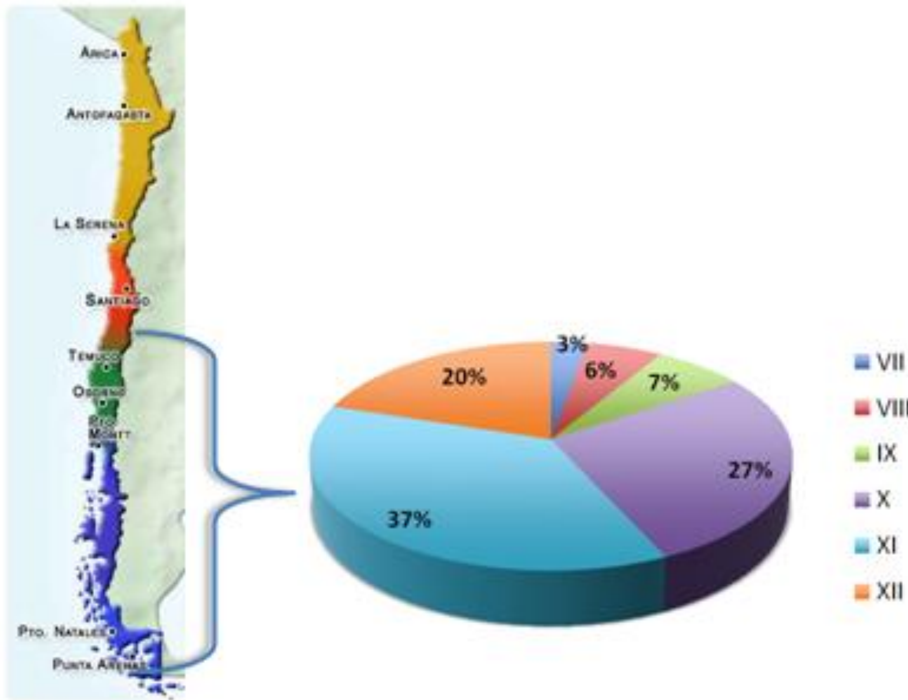

Fig.12: *Distribution of native forest by regions,* (CONAF, 1999)

Regions X, XI, XII are the areas where native forest is concentrated. Therefore, these regions will be analyzed in depth to find a suitable location for a theoretical project.

Using available maps for these three regions, that illustrate the different use of land, it is possible to allocate more specifically the areas were native forest is situated. The maps' key is as follows:

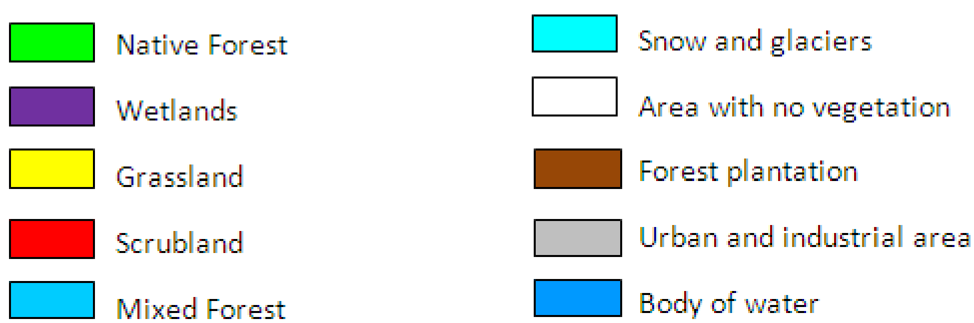

Fig.13: *Maps Key*(CONAF, 1999)

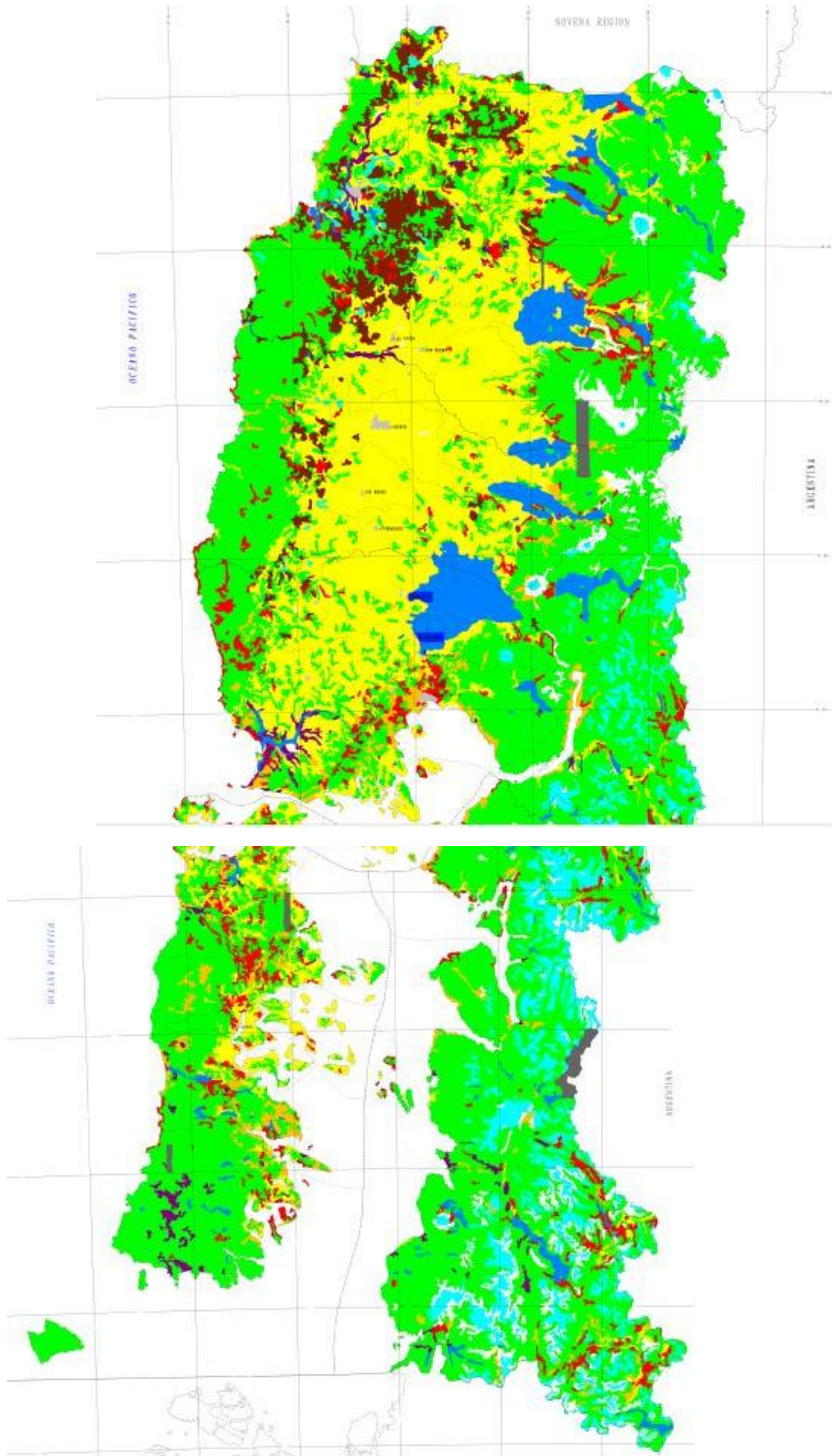

Fig.14: *X Region with different land use identified*(CONAF, 1999)

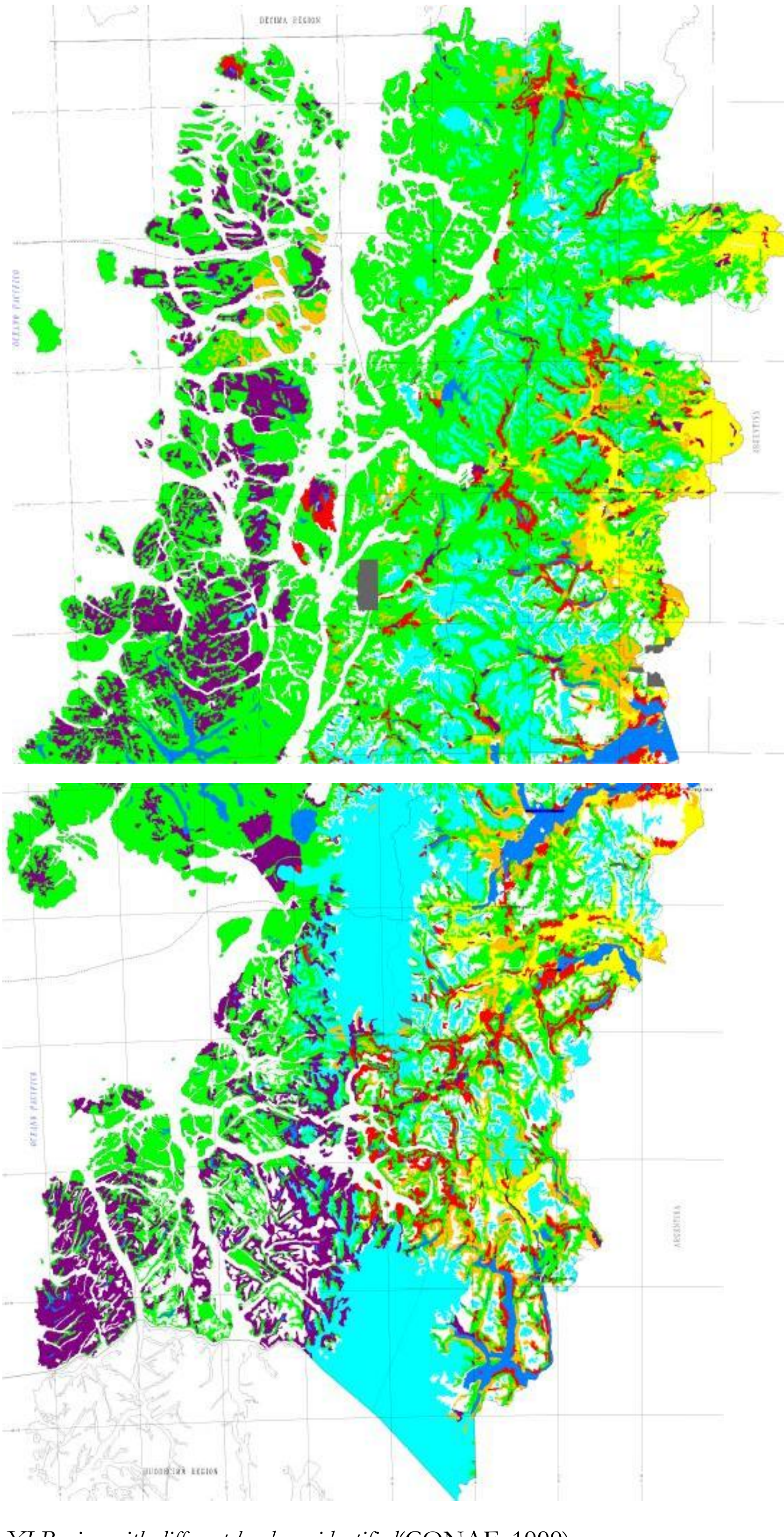

Fig.15: *XI Region with different land use identified*(CONAF, 1999)

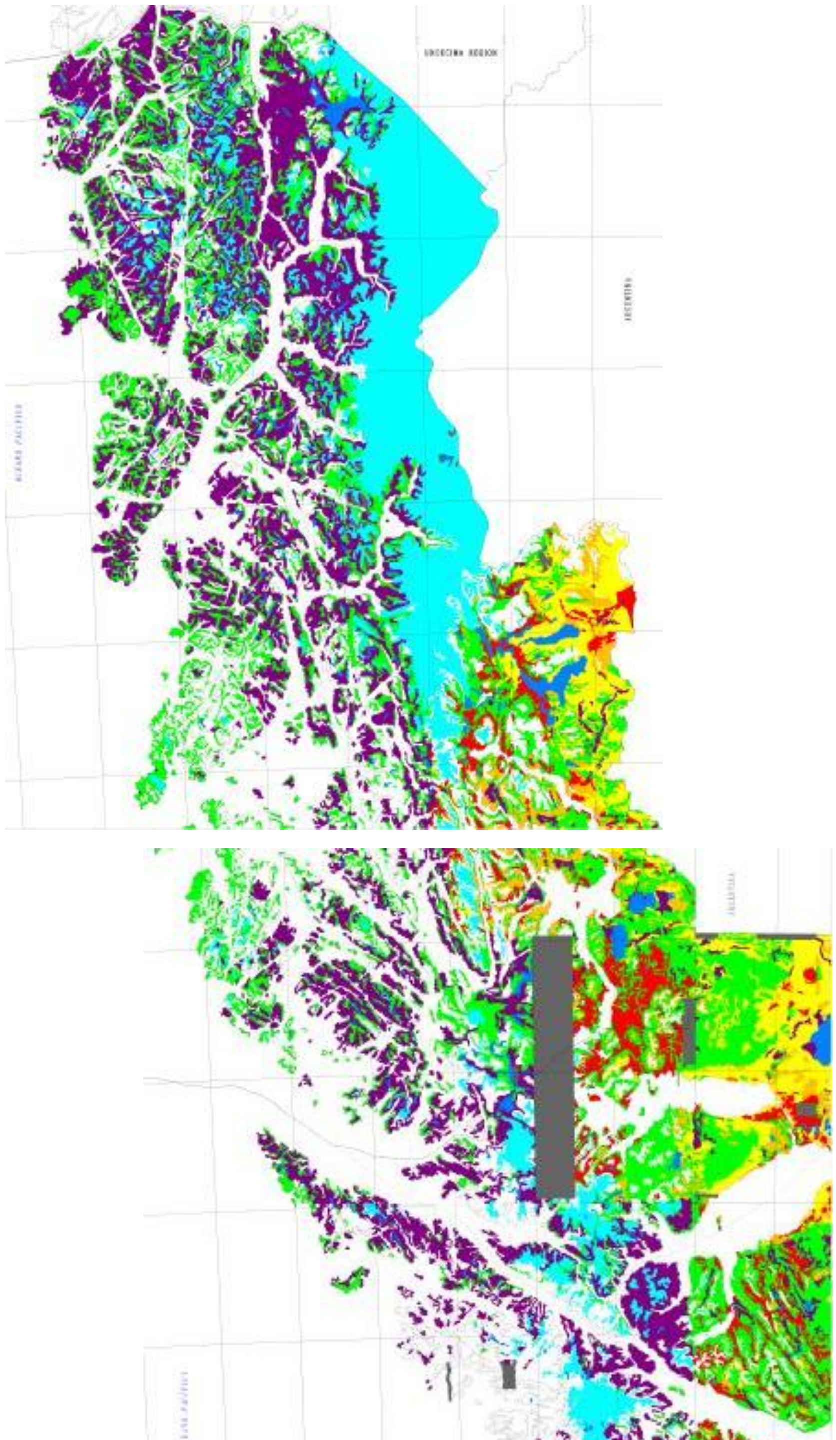

Fig.16: *XII Region with different land use identified* (CONAF, 1999)

From

Fig.***14***, Fig.15 and

Fig.***16***, it is clear that in regions XI and XII the biomass resource is more scattered than in X region, where the native forest areas are concentrated. This is a key issue for choosing an appropriate location in terms of access to the site, logistics needed to collect the biomass and transport it to the generation plant.

5.3 Owners of Native Forest

It is estimated that 80% of the total forestry property in Chile is in the hands of small owners, which corresponds to approximately 200.000 farmers. Another 40% of the forestry lands belong to large owners, with sizes bigger than 5.000 hectares. The rest is classified as medium sized owners, with land ranges varying from 300 to 5.000 ha(Conaf/GTZ, 2006).

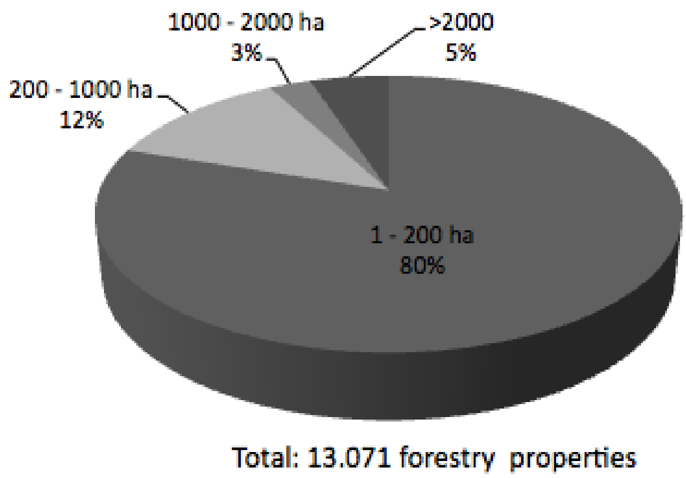

Fig.17: *Number of forestry properties, divided by its size* (Conaf/GTZ, 2006)

Roughly 50%, or less, of the income of the small owners comes from activities related to the native forest itself, where the main sources of income are jobs, such as workers at forestry plants, salmon fisheries, household chores and tourism(Conaf/GTZ, 2006). This fact reflects the sub utilization of this valuable resource and the potential to transform it into a profitable good.

Another important point to be taken into account is the socio-economic characteristics of these farmers, which may be relevant in terms of establishing new marketing alternatives. These are(Conaf/GTZ, 2006):

- High level of poverty
- Low level of education
- Low availability of work force
- Low ability of productive management

Due to the lack of knowledge about sustainable forestry management, the forest in the hands of small owners is much degraded in terms for productive purposes. Until its quality can be improved,

the most attractive alternative for its marketing is as combustible material, for residential or industrial use.
In contrast, medium sized owners do not depend on the forestry resource for living and most of them do not even live on their lands, but in the city. Moreover, the native forest owned by them is not as degraded as the one in the hands of small owners, since the forest is not used unless there are real and profitable marketing options for their products. Besides, a vast majority of these owners have enough financial resources to undertake actions aimed at the sustainable management of their forest, if there is an interesting marketing proposal(Emanuelli, 2006).

Due to the difference of management ability in the different type of owners, it is considered that the biomass supply for any kind of wood business (energy, pulp mills, sawmills, etc) should come 20% from small owners and 80% from medium and large sized owners (Emanuelli, 2006).

6 Location for Demonstration Project

Considering that native forest areas are highly concentrated, which will facilitate the overall biomass supply chain; it was considered that the X region was the most suitable area to focus the project on. This region is divided into four main provinces; Llanquihue, Chiloé, Osorno and Palena, with the following area of native forests in each of them.

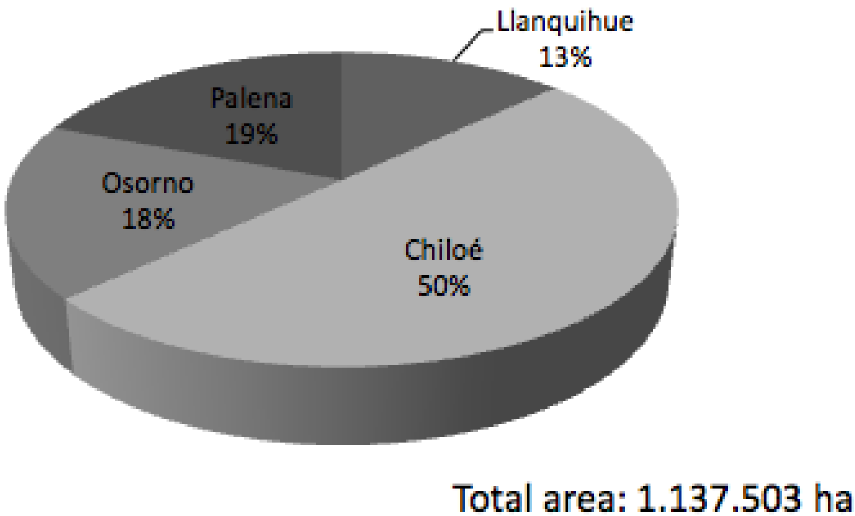

Fig.18:*Native Forest Plantation in each province of X region.* **(**INE, 2007)

The province of Chiloe concentrates 50% of all available native forests, which can be seen as a high energy potential, making it an attractive place to focus on. Also, this province is an island, condition that underlies several concerns regarding its energy security supply. These characteristics make Chiloé an appropriate place to develop a possible project of biomass cogeneration.

6.1 Chiloé Island

Chiloé is the second biggest island in Chile, with a population of 120.000. Most of them are located in the four main cities of the island; Ancud, Castro, Chonchi and Dalcahue.

Chiloé is connected to the central grid of Chile, known as the SIC (Interconnected Central System), via power lines that run over the Chacao Channel. Currently, its electricity is derived from fossil fuel burning plants located mostly on the mainland.

Fig.19: *Map of Chiloé Island, highlighting the main communities (Chiloé, 2009)*

6.2 Biomass Availability and Geographical Distribution in Chiloé

In the latest agricultural census done by the National Institute of Statistics (INE, 2007), there is accurate information about the exact amount of available native forest in each of the communities within Chiloé island. This information is presented in the next Table.

Province		Area ha
Chiloé		**565.950**
	Castro	16.089,8
	Ancud	39.871,2
	Chonchi	74.466,4
	Dalcahue	59.289,7
	Queilén	10.712,6
	Quellón	359.332,6
	Quemchi	6.163,8
	Others	24,3

Table 6: *Native Forest Area in the Chiloé province, X region,*(INE, 2007)

The structure of native forests in the island is mainly primary and secondary type(Fig.20). This last type of forest is the most useful in terms of productivity for energy purposes due to their physical characteristics(Conaf/GTZ, 2006).Therefore,it is the one considered as the real biomass potential available in the island.

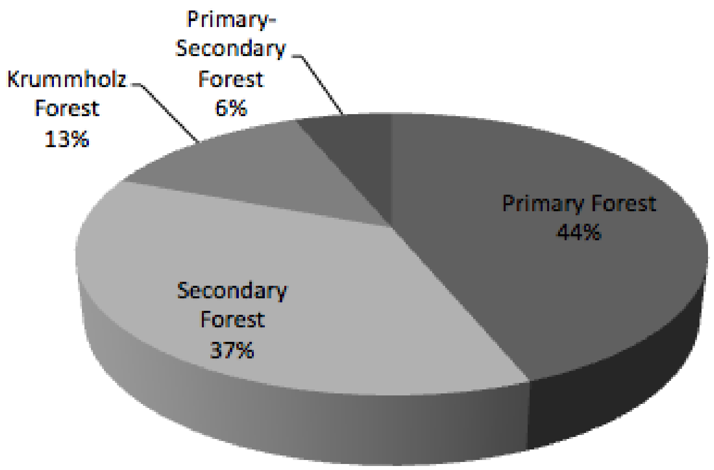

Fig.20: *Structure of native forest in Chiloé*(Milla F, 2006)

Considering that 37% of the native forest in Chiloe is secondary forest, there is an available area of 209.402 ha. The basic condition of sustainable management is to extract resource below the forest growth rate. Therefore, if the annual growth of the forest is 5 m^3 per hectare(CONAF, 1999), theoretically there are 1.047.008 m^3 of wood per year in the island that can be converted into useful energy.

A more realistic approach to estimate the biomass potential is to consider the biomass providers, the landowners registered in the local forestry authority (CONAF), instead of estimating it with all-existing forest area. In this registry(Milla F, 2006), there are two different types of owners; beneficiaries of the grants developed by the new framework to promote sustainable management plans and also, private owners who have presented management plans to the authorities. The owners by community and the area available to be exploited are presented in Table 7.

	Number of landowners	Manageable Area ha
Ancud	116	3651,2
Chonchi	40	2467,8
Quellón	62	2193,8
Queilén	2	216,3
Total	**220**	**8529,1**

Table 7: *Registered owners in four communes of Chiloé and its manageable area* (Milla F, 2006)

According to these values, in a year there could be 42.645,5 $m^3$of wood that can be used for energy production, considering the four communities where information is available. But this number could easily be greater, considering that each year there are new grants given and the statistics used are not updated to the present year. On the other hand, currently there are no direct incentives for forest owners to register with the forest authority, so there is the high risk of not having updated and proper land ownership information as long as this situation continues.

In the following section, an analysis of the energy consumption in the area will be done, in order to do a proper match between supply potential and demand.

6.3 Profile of Energy Demand in Chiloé

Once the location of the biomass supply and the offer available is determined, it is important to evaluate the energy demand in the area and decide whether it is more suitable to focus on a combined heat and power facility or if it is better to focus on a simpler heat generation project. This issue is a key component for the development of a proper biomass supply model.

In 2006, a survey was conducted by CONAF(Cordero, 2006), with the aim to characterize the energy demand in the island. From the 47 companies and organizations located in the main communes of Chiloe (Castro, Chonchi, Queilén and Quellón), 37 of them were interviewed in order to obtain their energy consumption patterns. The productive sectors which these companies belong to are mainly the food and fishing industries and also educational organizations.

The results of this examination showed that oil is the most consumed energy source, followed by electricity, which was also considered as a primary energy source, assuming that it was purchased from the grid and not generated in situ[2].

[2]Conversion used for electricity: 860 Kcal/Kwh,Source: CNE

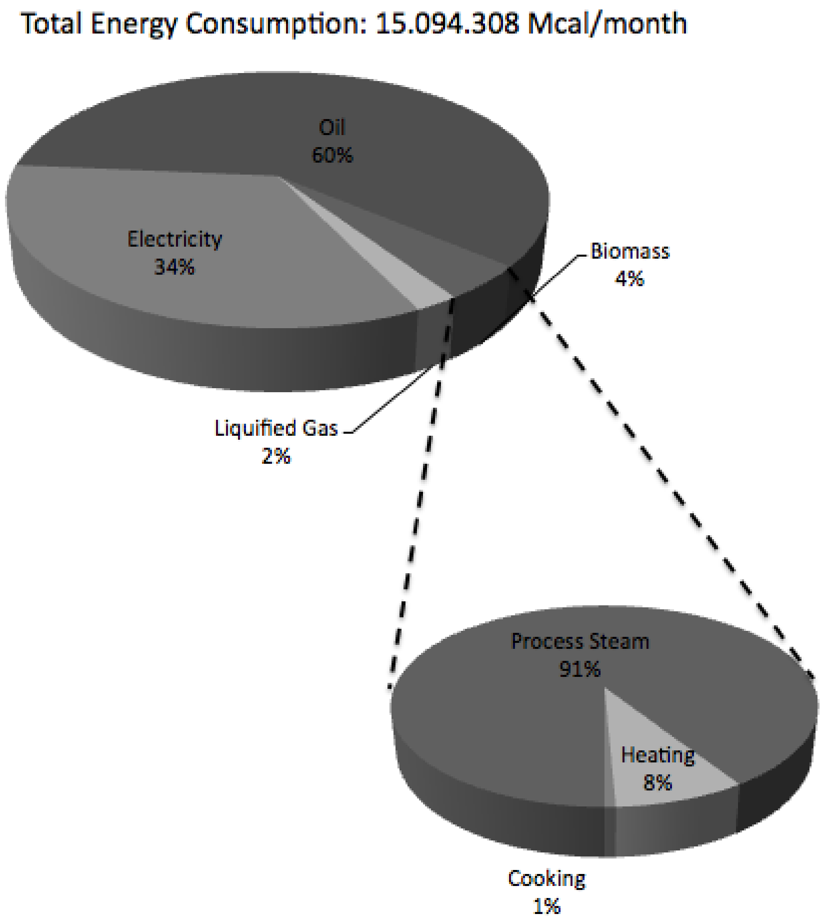

Fig.21: *Energy consumption in Chiloé*(Cordero, 2006)

Figure 23 also shows the final consumption of biomass, the generation of process steam being the main practice. This information was expected considering the type of institutions surveyed. The fact that power generation using biomass is not an implemented is interesting. A cogeneration facility would be a pioneering initiative in the island.

The oil consumption is a key factor in this analysis, since biomass could be the option to replace it, both in heat and power generation. For that reason, the breakdown of the final use of oil by communes is shown in Table 8

	Castro	**Chonchi**	**Queilén**	**Quellón**	**Total**	**Share of total**
Boiler	618.204	106.264	2.167	34.260	760.895	82,2%
Dryer	0	0	0	22.417	22.417	2,4%
Power generation	18.600	60.008	0	64.000	142.608	15,4%
Total	**636.804**	**166.272**	**2.167**	**120.677**	**925.920**	**100%**

Table 8: *System of oil consumption by commune in liters per month*(Cordero, 2006).

According to Table 8, most of the oil consumed is used for the production of process steam in a boiler, but there is a significant amount that is intended for power generation.

In a further analysis, the communes of Quellón and Chonchi present an interesting condition, due to its energy needs and the biomass availability. As portrayed in Fig.22,in both towns the use of oil and electricity from the grid is predominant, leaving biomass as an irrelevant source in their energy matrix. Therefore, the use of biomass in an efficient technology, offers a real opportunity, but also a major challenge to tackle.

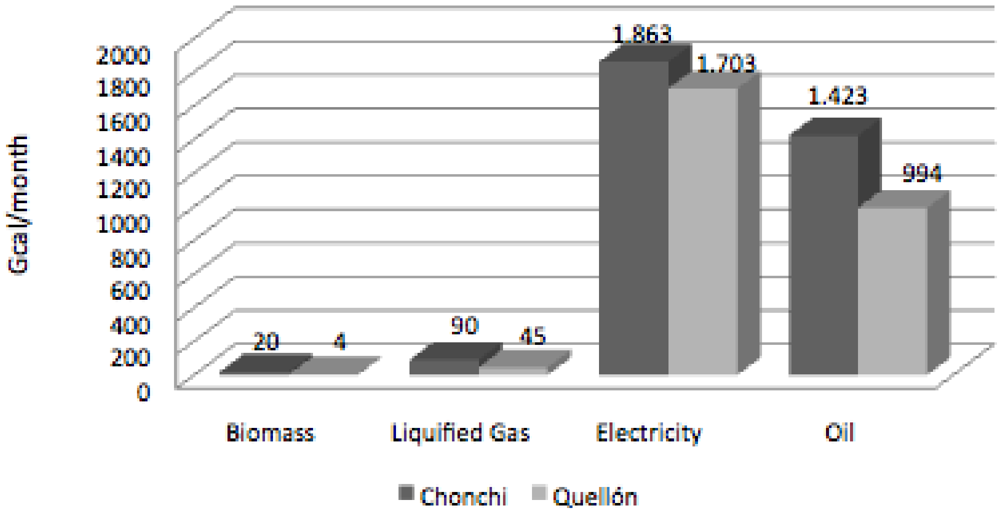

Fig.22:*Primary energy consumption of industries surveyed in Quellón and Chonchi*(Cordero, 2006)

Table *6*andTable 7show that both communes have, by far, the most native forest area available and there are already sustainable management plans in progress, which indicates a clearly sub utilization of the resource. However, the most attractive fact reflected in the information gathered is that there is a significant amount of oil used for power and steam generation (also liquefied gas in the steam case), making Quellón and Chonchi ideal sites for a combined heat and power facility.

A rough initial estimation, calculated with the information available from the survey conducted by CONAF, indicates that around 2.800 MWh per month could be produced with biomass instead of fossil fuels.(seeFig.*23*)

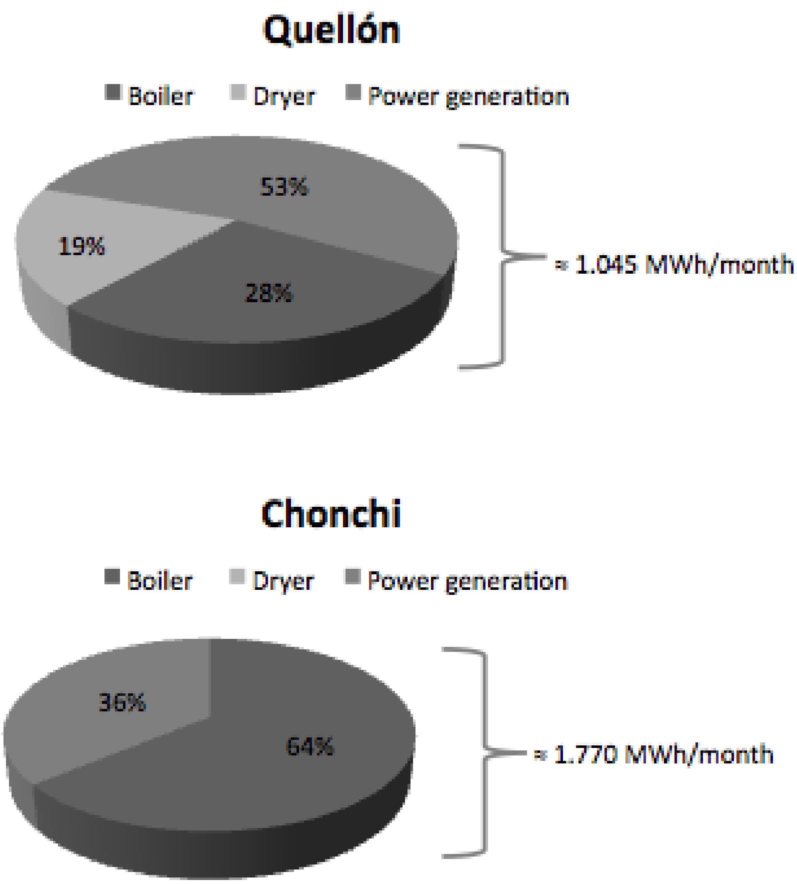

Fig.23: *Theoretical amount of energy from oil that can be replaced with biomass in Quellón and Chonchi*(Cordero, 2006).

It is relevant to mention that in the residential sector, 91% of the population in the island use firewood for heating and cooking purposes(Siemund, 2004). This is done in individual stoves, which are low efficiency equipment and usually use biomass with a high content of moisture(Fig.*24*). Nevertheless, there is no district heating network in Chiloé and building one would involve changing ancient customs and the coordination of far more participants than a few industries. This is, among many, a disadvantage that makes the project focus on the industrial sector as the initial target for a cogeneration facility and as a starting point.

Fig.24:*Traditional stove used in Chiloé for heating and cooking purposes*(Chiloeweb, 2010).

7 Biomass Supply Chain Model

One of the main problems that the sustainable management of native forest currently faces is the lack of proper marketing channels for its products (Emanuelli, 2006). The demand for them is scarce, since the wood market is strongly dominated by pine, and the offer is not highly rated, in terms of quality, location, price and homogeneity (Emanuelli, 2006). This situation has led to the search of new markets where this resource can compete and the energy sector has arisen as one of the most promising, due to the current situation in the energy sector.

To successfully market timber from native forests, a proper supply chain needs to be established. In this chapter, international experiences and models will be reviewed, aiming at achieving a preliminary supply chain model, according to the information available for the chosen location.

7.1 General supply chain model

The basic marketing model is such where there is an available supply of a certain product and a demand for it that needs to be satisfied. In general, the Chilean firewood market is very informal, with a supply characterized by a scattered and degraded resource and the demand is mostly intended for residential use for heating, with low efficiency technologies. Actually, if the demand is considered as the need for wood for heat and power generation, it is only fair to say that this does not exist.

To overcome this disconnection between offer and demand, it is necessary to incorporate a new key role in this model; an intermediary entity. Although, at present something similar does exist, a trader, this role does not contribute to the proper expansion of the native forest market. The appropriate actor should have the tasks to promote the demand for native forest timber, give a professional character to its marketing and also have a technical knowledge about biomass treatment.

Fig.25: *Basic marketing model*

It is well known that before designing a new supply model, it is important to review and understand the existing one, to identify its weaknesses and strengths (Rauch & Gronalt, 2005). Next, a brief diagnosis of the current market is presented.

7.2 Current model

7.2.1 Supply

As it was mentioned earlier, one of the main issues regarding with the biomass supply is the small-scale ownership. Currently, the small-scale forest owner handles forest activities such as felling and selling directly, most of the time, to a trader, who is in charge of the transaction with the final user.

Small owners face problems of access to wood market, due to their location (generally outside the cities) and the lack of proper roads. Other important barriers are the need for initial investment capital and the poor information handled by them related to the prices and volumes required by the end consumers of their products.

7.2.2 Intermediary

In the native forest market, not only that intended for energy purposes, the intermediary entity that currently exists is usually a person, who performs the roles of trader and stocker. This individual fixes the price of the feedstock with almost no negotiation with the producer, pays in cash and offers different services to the small owners, such as medicines and money, which later are charged in the prices that farmers pay (Conaf/GTZ, 2006).

This situation can be classified as an oligopsony(Conaf/GTZ, 2006), where the number of buyers is small while the number of sellers in theory could be large. In this case, the intermediaries are receiving most of the benefits of the market, leading to a diminished situation for the producers, who are not receiving a fair price for their products. In this distorted market, neither the suppliers nor the consumers are important enough to modify the price of the product; consequently the situation has kept on going throughout the years.

7.2.3 Demand

At present, there is no industrial demand for firewood intended for heat and power generation, since such a facility does not exist in the island. However, it is important to study the behavior of the large consumers of firewood in the area.

According to a survey performed in 2004to study the behavior of firewood consumption, a few characteristics of the large consumers (public institutions and industries) were identified (Siemund, 2004). Among them, three are worth highlighting:

1. Almost no consumers require a certificate of provenience from the provider, which would also require an adequate forest management plan (Siemund, 2004). This fact reflects the lack of interest among the consumers about the origin of the product and the potential barrier that this situation represents, in terms of accepting a higher price for a certified timber.
2. State-owned consumers have to buy firewood through a special channel, called ChileCompra. This issue has to be taken into account at the moment of analyzing the marketing strategy. The rest of the large consumers buy directly from the rural producers.
3. Chiloé is a rainy area; therefore the firewood used has a high content of moisture, which reduces the efficiency of the combustion process. Among consumers, there is the perception that “wet firewood” is better, since it lasts longer inside the boiler, but a few of the interviewees were interested in using biomass with adequate content of moisture, if this were available.

7.3 Alternative Model

The need for a new marketing model is clear, mainly in the supply and in the intermediary side. Experience in the forest field with small farmers in Chile has revealed the need for forming a basic network of producers and owners of forests linked to large companies in the surrounding areas. These companies can be seen as another network, which joined to the producer create a horizontal economy characterized by the long-term productive linkage between them (Burschel & Rojas, 2005).

Next, a successful model of association widely used in North America and Europe and its application to the Chilean market will be presented. It is used to create formal organizations to handle the wood supply from small owners.

7.3.1 Ownership Model – Forest Owner Cooperation

Background

A Forest Owner Cooperation[3] (FOC) is an organization of forest owners in charge of bundling harvested timber and selling it to the processing industries (energy plants, sawmills, pulp mills, etc). Because of larger supply and lower transactions cost, industry pays FOCs higher prices for timber than it does to a single small-scale producer(Rauch & Gronalt, 2005).

The main processes of a standard supply chain in a FOC are shown in Fig.*26*, arranged according to their frequency and their chronological order. This kind of process maps provide an overview of all business operations and define the most important ones (core business). This specific map is thought to handle large customers, such as energy companies and mills, not individual clients.

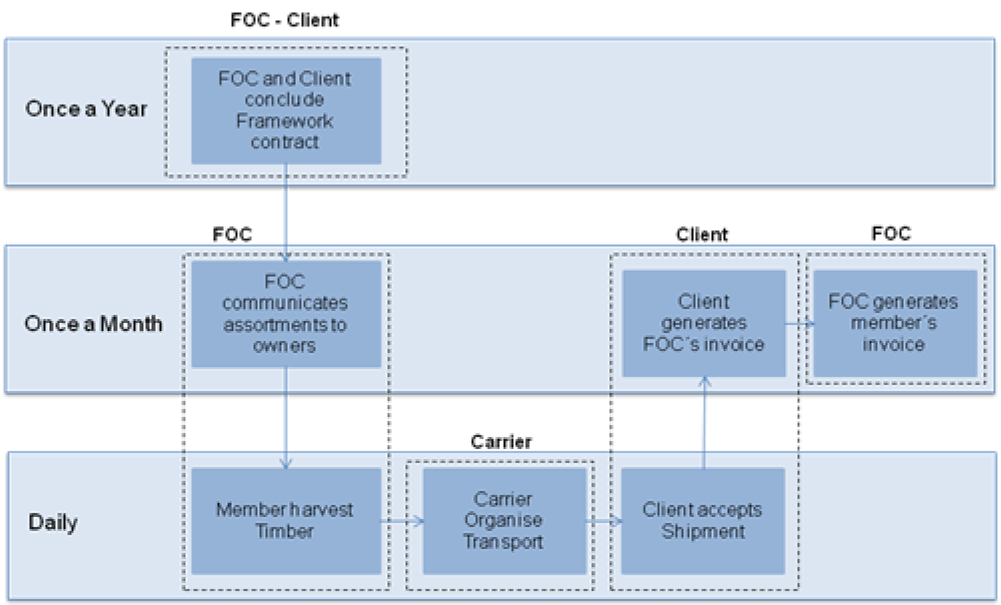

***Fig.26**: Standard process map of the supply chain, FOC to end consumer*(Rauch & Gronalt, 2005)

The key advantage of a FOC is that the control of the business is kept with those who utilize it, since the business exists for their benefit. This situation could transform the suppliers from passive price takers to active price setters, which is precisely one of the main problems in the current Chilean firewood market. However, for the success of a FOC, or any kind of cooperation, a large, active and involved membership is a critical requirement.

An additional important advantage of FOC is that since this business model increases the revenue retained by the producers, the local economy receives a positive impact. This is because locally owned projects tend to source administration, debt and supplies in the area; therefore more value is retained within the local community(Bowman, 2007).

As every business model, FOCs have also several disadvantages. Democratic decision-making can be a slow process. Additionally, many landowners lack an understanding or knowledge of the benefits of planned sustainable management of their forests. Therefore, they may not be naturally drawn into a business that seeks to increase value to their land (Bowman, 2007).

[3]In some countries, Cooperation is known as Cooperative.

In the past, cooperative enterprises have failed mainly because members perceived the cost of membership (lost or diminished property rights) exceeds the benefits. A solution to this problem has been applied in some cooperatives in the United States, where the management of the FOCs encourage members to hire their own experts to plan forest management actions. However, the FOC expects access to timber when promised, supported by legal contracts, membership fees and professional–quality forest plans.

Vertical integration of forest industry operations (silviculture, harvesting, gathering, sorting, processing, selling, etc) is a common practice within the cooperative business, although it adds considerable complexity to management. There are different means of integrating services; one extreme is when the FOC handles all parts of the supply chain, whereas the other extreme is when partner business are hired to delivered specific quantity, quality and timing of products flow along in the supply chain. According to literature reviewed, it is unclear which strategy is most likely to succeed or fail in the long term(Hull & Sarah, 2008).

One of the biggest challenges that FOCs face is the lack of initial capital to create the infrastructure for a local forest industry serving niche markets, such as bioenergy. Is in this aspect where government, and nongovernmental, forestry organizations can support FOCs, providing financial aid, such as low interest loans, start-up grants and space at industrial parks (Hull & Sarah, 2008).

<u>International Experiences of FOCs</u>

Forestry cooperatives currently thrive in at least 17 countries, such as Japan, Australia, United States and several countries of Europe, involving over 3.6 million people. Next, three cases will be reviewed.

- Sweden

Södra is a FOC based at Växjö, Sweden. It was founded in the 1930s around 51.000 members, with 2.3 million hectares (average holding of 50 ha). Due to its size, Södra has split in five different divisions: Södra Timber AB (sawmills), Södra Cell AB (pulp mills), SödraSkogsenergi (bioenergy, pellets),SödraInteriör(interior wood products) and SödraVindkraft AB (windpower)(Södra, 2010).

Södra is a cooperative organization that is run in a democratic way, regardless of the size of the land each member owns or the size of the contribution he makes. Its main objective is to help forest owners to develop forestry operations that are profitable and sustainable, by making available several services for them, such as the Green Forest Management Plant. This Plan offers professional advice on how to develop a method of effective, high-yield forestry combined with environmental objectives.

SödraSkogsenergi is the division that is most attractive to the present project. It supplies biofuel mainly to large customers such as thermal power stations, combined power and heating plants, as well as industry and pellet factories. There are two sources of the biofuel sold; from industry (bark, shavings and chips) and forest (branches, tops, small trees, etc).The residues from the industry are converted into pellets, since they are easier to handle, store and transport. Residual forest products are transported to terminals for processing to chips, in order to improve logistics and reduce transport costs.

- United States

Oregon Woodland Cooperative (OWC) is a group of 43 forest owners formally organized into a cooperative, formed in 1980(OWC, 2008). Through the concept of "members helping members", the ability of each member to manage their woodland and market its products over the long term is improved.

Bundled firewood is the most important product offered by the Cooperative, since it represents a premium, value-added product for low value logs, which are sold to supermarkets, convenience stores, and campgrounds. The entire marketing program is coordinated by the Cooperative, from the manufacture to the delivery, and invoicing of the firewood. Processing (cutting and splitting), bundling, and transportation can be handled directly by the landowner, or can be contracted out to a third party (OWC, 2008).

OWC offers several services to their members, such as access to a range of services related to forest management and certification and discounts in chemicals and fertilizers, through the association with different companies in the field.

- Australia

SMARTimber Cooperative is a cooperative located in Central Victoria, Australia. It was formed with the aim of selling timber from small-scale landholders and farmers, in order to maximize their returns. Strategic alliances were established between the cooperative and other small scale, local processors, to ensure that control is maintained over quality, while boosting job creation in regional areas.

SMARTimbers aggregates regionally-sourced timbers and sells associated wood and non-wood products using a single desk cooperative marketing structure. The cooperative facilitates stewardship planning for member's plantations and forests, ensuring that all products handled by SMARTimbers are produced in a sustainable and environmentally responsible manner using current best practices(SMARTimber, 2010).

<u>Experience in Chile</u>

Energía del Bosque is the first and only Forest Owner Cooperation that currently is operating in Chile. It is located in Valdivia, a city in the X region and it is composed of 30 small famers. It was created to trade certified firewood, mainly for heating purposes. The Association of Forest Engineers for the Native Forest (AIFBN) provides technical assistance to the cooperation through a program funded by the Inter-American Development Bank and AVINA, an organization focused on the sustainable development in Latin America(Rain, 2010).

The general idea behind a cooperative is the democratic self-management of an economic activity. In this case, the main activity of the cooperation is the wholesale of raw wood and its products, and the retail trade of charcoal, firewood and other fuels for residential use. This scope is not fixed, since there could be other areas where the cooperation can expand if there is the need and opportunity.

The administration of the cooperation is done through different entities that are described below(Rivas, Rain, & Reyes, 2009):

- <u>General Board of Members</u>: Maximum authority that gathers the investors, who take the main decisions, for example, the price of selling of the firewood.
- <u>Administration Council</u>: In charge of the legal representation of the cooperation and choosing the members of the commissions.
- <u>Auditing Board</u>: Has the tasks of checking the accounts and the administrative situation of the cooperation.
- <u>Manager</u>: Chosen by the Administration Council, has to watch over the fulfillment of the agreements reached by the members, the marketing of the firewood and the general management of the cooperation.
- <u>Commissions</u>: Work in three areas to improve the management of the cooperative; Production and Marketing, Communication Formalities and Organizational Strengthening.

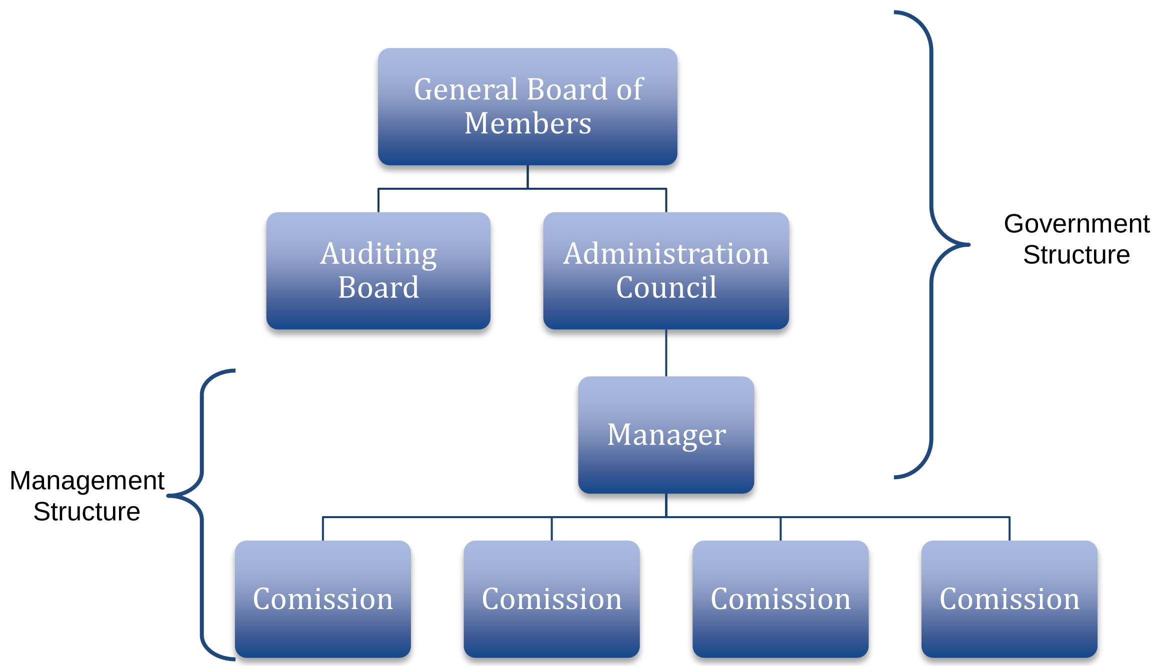

***Fig.27**: Administration model of Energía del Bosque Cooperation*(Rivas, Rain, & Reyes, 2009)

The firewood is sold in different formats, depending on the specie and the length of the log. The supply chain model consists of several interactions between producer, FOC administration, carrier and client, which are summarized in Fig.28.

The process starts when the FOC member informs the Manager of the existence of certain volume of firewood, endorsed by a sustainable management of the forest. Upon this call, the FOC is in charge of performing measurements of the timber in situ and if this is approved, the transportation to the collection center is arranged[4]. The logs are placed alongside a forest road, to be picked up by a truck hired by the FOC to an outsource company.

Once in the collection center, a quality control is done to the incoming firewood and the payment to the producer is issued by the Manager. The logs are later classified by specie (wood density) and stocked in piles according to their characteristics, which are monitored to measure the moisture content.

When an order is placed by a customer, the date and hour of the delivery are set. The firewood is delivered at customer's location by a hired truck and the final payment is done. Among the clients that the cooperation currently has, there are several public organizations, such as the municipality of Valdivia and the local headquarters of the Army and the Civil Police.

[4]The transportation could be directly done from producer to client in special cases.

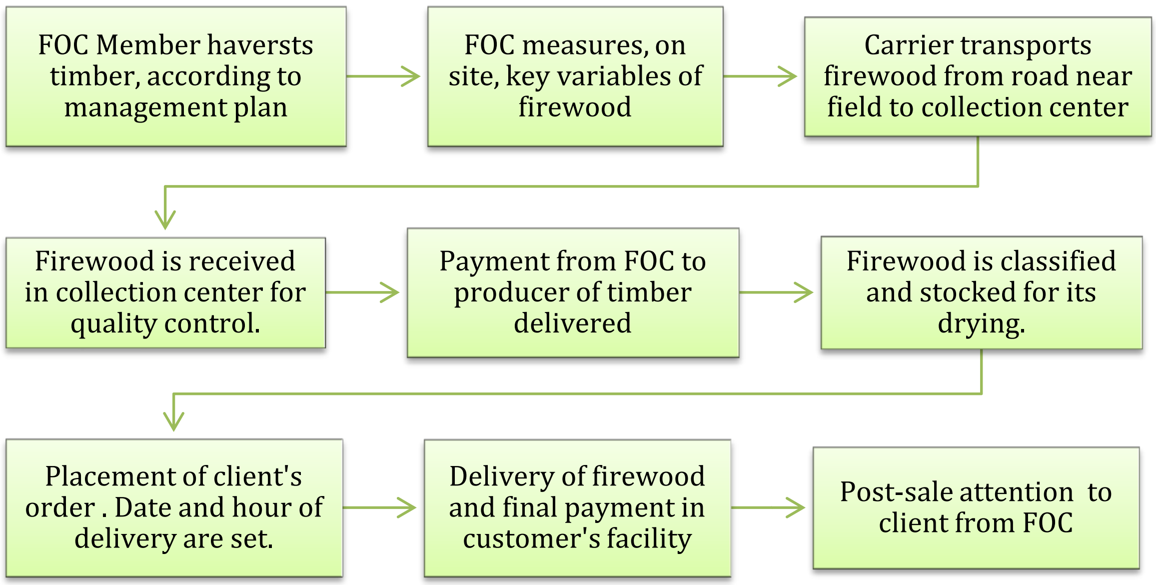

Fig.28: *Supply model of Energía del Bosque Cooperation*(Rivas, Rain, & Reyes, 2009)

According to the cooperation's manager, Fernando Rain (Rain, 2010), this scheme has worked out in terms of having a constant supply from the producers, and offering a proper marketing channel for their products. Also, the customers have had a good acceptance of the products as they are willing to pay more for high quality firewood with a sustainable origin. However, there has been an issue with the drying of the biomass, which is done naturally. This process takes considerable time and sometimes it has produced shortage of firewood, since it has not achieved the proper content of moisture for marketing. This is a topic that has to be taken into account for further projects.

The volume of firewood that the FOC handles is about 1000 cubic meters, which come from 500 hectares of managed forests. The price of the product varies from USD 35 to 45 USD[5] per cubic meter according to different criteria, like the seniority of the client and the volume purchased(Rain, 2010). This value is substantially higher than the one trade in the informal market in the same city, which is around USD 18 to USD 225(Uach, 2007).

Under the same model of Energía del Bosque, a cooperation is being created in Chiloé, named Cooperativa Huilliche Coihuin de Compu. This organization will work with the indigenous community of the zone in order to provide a proper marketing channel for their wood products. Currently the cooperation is formed by 19 members, with a total area of forest of 190 hectares. However, it has not started to trade due to unfinished legal proceedings.

The scheme of a cooperation, or cooperative, is a successful model of handling small-scale forest ownership. Since it has already started to be applied in Chile, it could be an efficient form of managing part of the supply coming from small owners needed for a heat and power plant, following the same model of Energía del Bosque. Taking in consideration the international examples, it is vital that besides the bundling of the products to increase the price of the product offered, the

[5]Currency rate used 1 USD = 533 CLP, March 23, 2010.

cooperation entity also provides technical assistance to the owners, in order to boost the business in the long term.

7.4 Supply network for chosen location

In order to design a demonstration supply chain model, specific locations and a specific demand where chosen among the information presented in Chapter n°5.

7.4.1 General Network

The universal fuel network flow is shown in Fig.29.As it has been already stated, the biomass supply not only should come from small owners gathered in organizations like FOCs, but also should include other providers, such as private owners with larger lands and resources, and the beneficiaries of funds from the National Forestry Corporation, for forestry management plans that are aimed to recover native forests for timber production. The last group includes different type of owners, being small-scale ownership the most important one, which in that case is recommended that they should also gather in a FOC, to improve their marketing ability.

The location of the chipping and/or storage facilities is essential in designing the optimal system structure (Gronalt & Rauch, 2007).Terminals are needed in order to balance the seasonal fluctuation in demand at the heating plants and in the supply from forest activities. If fuel is stored at a terminal, this does not significantly affect total cost, whereas storage at landings markedly increases costs due to smaller volumes and the need for moving chipper between stands (Gronalt & Rauch, 2007).

The general network should consider more than one power plant or final user, but since there is no cogeneration facility in the area, the model will be based on only one CHP plant, as a demonstrative project. As it is only one plant, it will also be considered that the terminal is going to be located next to the plant and no transport would be needed from one place to another.

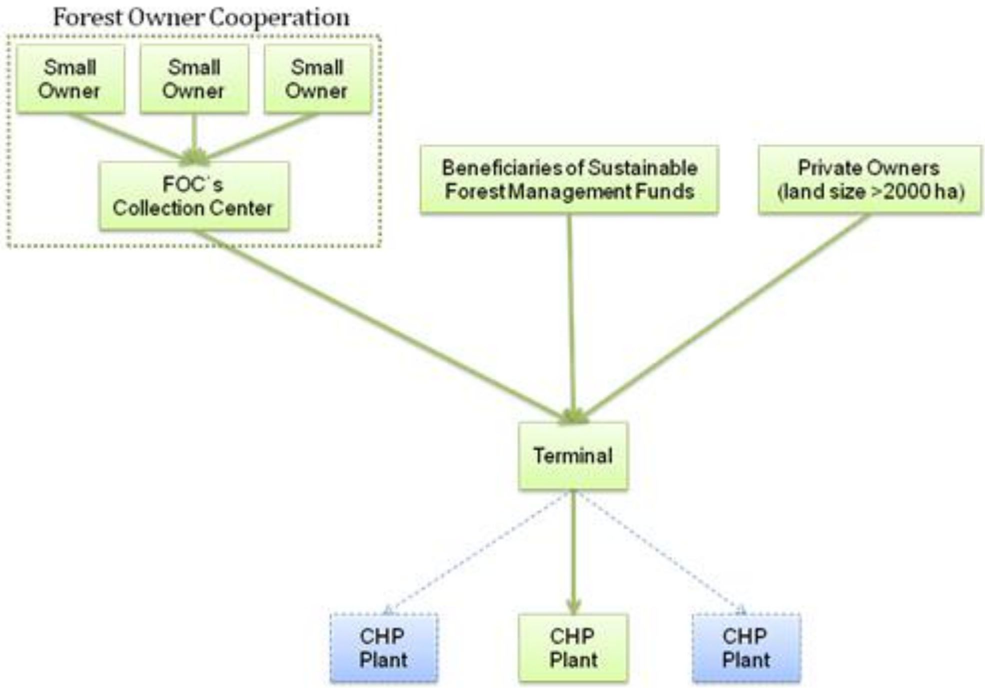

Fig.29 : *Forest fuel network flow*

Gronalt and Rauch(Gronalt & Rauch, 2007) propose a methodology to design and cost an optimal supply network for medium and large-scale energy plants. Although the plant of the present project is thought to be a small-scale plant, as a reference is an appropriate starting point. The methodology is the following:

1. Identify aggregate forest areas and other supply sources. Determine its Net Available Potential (NAP).
2. Calculate expected demand and forest fuel balance per region.
3. Determine system cost elements
4. Determine terminal catchment areas for both decentered and central terminal.
5. Find spatial allocation for terminals in forest fuel supply networks.

The first point was already raised in this report, when the biomass potential was estimated in the main communes in Chiloé. In the next section, the expected demand for a specific site will be calculated in order to match it with the biomass supply and develop the supply chain. Points 3, 4 and 5 will be tackled later, according to the requirements of the designed plant.

7.4.2 Expected Energy Demand

Transport of large quantities of biomass fuels from source to the site of use is one of the major obstacles to the development of larger biomass plants. On the other hand, small-scale biomass plants can be fuelled by local resources from small adjacent catchment areas. Therefore, it was decided to design a small scale as a demonstrative project in the area.

The demand was established as four companies chosen located close to each other at the town of Chonchi. These are:

- Pesquera Antarfood S.A
- Toralla S.A
- Pesquera Unimarc S.A
- Invertec Pesquera Mar de Chiloé.

These companies were chosen since its energy consumption levels are known in a certain level, due to a survey performed by CONAF in 2006(Cordero, 2006). Although this information is not as accurate and updated as it would be necessary to determine the small scale CHP plant capacity, it is enough to be taken as a reference. In any case, depending on the demand, the model would have to be similar as the one presented in this report.

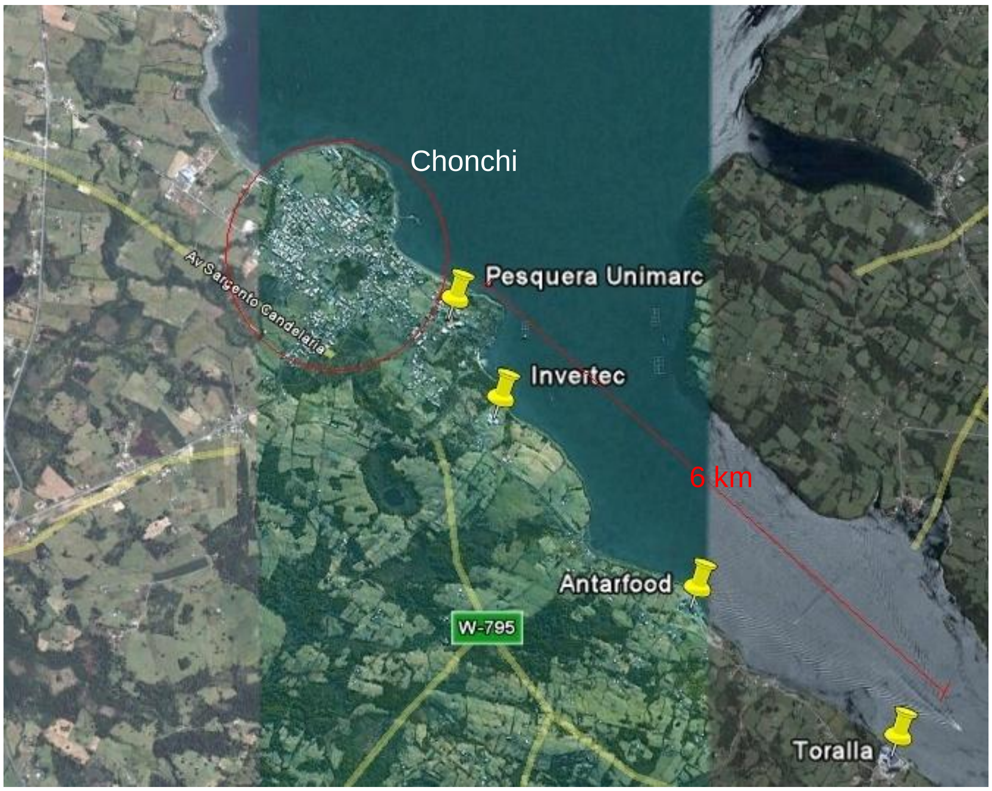

Fig.30: *Location of companies at Chonchi*(Image taken from Google Earth)***.***

The energy consumption of these companies to produce steam and power is shown in Table 9. This is the information that will be taken in consideration to estimate the installed capacity of the plant.

Company	Fuel	Equipment	End use	Energy Consumption [MWh/year]
Invertec S.A.	Liquefied Gas	Boiler	Heating-Hot Water	61,88
	Oil	Power generator	Power Generation	266,03
Toralla S.A.	Oil	Boiler	Heating-Hot Water	4.525
Antarfood S.A.	Liquefied Gas	Boiler	Heating-Hot Water	241,32
	Oil	Power generator	Power Generation	478,86
Pesquera Unimarc S.A.	Oil	Power generator	Power Generation	745,74
	Liquefied Gas	Boiler	Heating-Hot Water	459,99

Table 9: *Energy consumption of selected industries in Chonchi*(Cordero, 2006)

When designing a new cogeneration facility, there are three options in order to meet the heat and power demand, which are(Cogen3, 2004):

- Operate as an island, and meet both heat and power demands or,
- Meet the power demand at all times and generate associated steam or,
- Meet the steam demand at all times and generate the associated electricity.

In this case, due to the lack of information about the quality of the steam used in each process, it was decided that the plant would meet the power demand and produce the associated amount of useful steam. The following table shows the amount of energy consumed in each plant for power generation purposes and the installed capacity needed in each case, which was estimated according to the number of hours of operation of the generators.

Company	Hours per year	Energy Consumption (MWh/year)	Installed Capacity Needed (MW)
Invertec S.A	1200	266,03	0,22
Antarfood S.A	750	478,86	0,64
Pesquera Nacional S.A.	1200	745,74	0,62
Total			**1.48**

Table 10: Energy consumption (electricity) and installed capacity needed.

According to Table 10, the installed power capacity of the plant would be set in 2 MW, considering a margin of uncertainty, since the peak load is not known.

The technology chosen for the cogeneration facility is the Rankine Cycle, since it is the main technology used for small scale CHP(Kirjavainen, Sipilä, Savola, Salomón, & Alakangas, 2004). There are other technologies currently available such as biomass Stirling engines and organic Rankine cycles which still have to reach commercial maturity. Biomass gasification technology is evolving into a developed stage, but since combustion is the most proven technique, this is the one considered in the present project. Among the benefits of using a steam turbine are high overall efficiency, its long working life and high reliability and the ability to meet more than one site heat grade requirement(Cogen3, 2004).

To dimension the basic parameters of the CHP plant, the first factor to establish is the heat to power ratio, which sets the relationship between power and heat generated. Since the exact demand of energy is not available, a literature value was chosen, using as a reference Fig.31

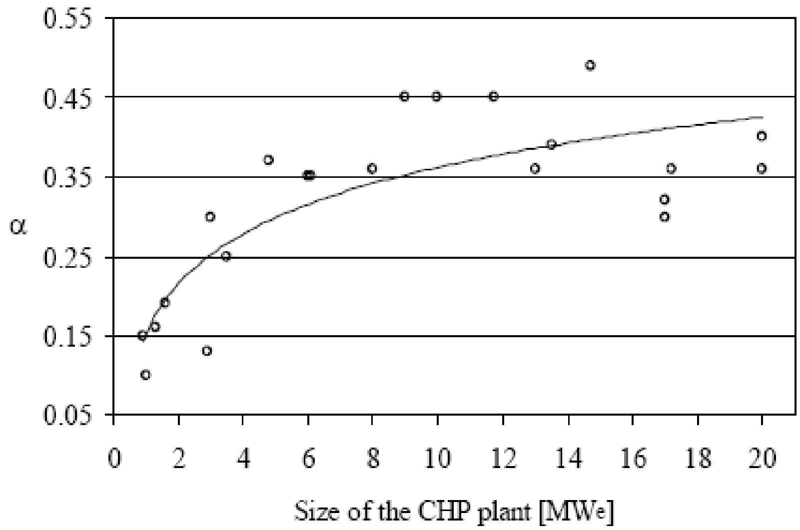

Fig.31: *Power-to-heat ratios versus the plant size of some Finnish and Swedish biomass-fuelled CHP plants producing 1-20 MWe.*(Sipilä, Pursiheimo, & Savola, 2005)

The power to heat ratio for a 2 MWel plant is 0,21 (or the equivalent 4,76 heat to power ratio). The biomass-fuelled CHP plants producing less than 20 MWe are usually based on a Rankine cycle with steam superheating, where the steam after the boiler is superheated at constant pressure to a higher temperature than the saturation point.

Next, a table summarizing the main results obtained for the CHP plant is shown, mainly the fuel requirement and the efficiencies of the plant. The net efficiency for the CHP plant was chosen at 90%, according to literature (Sipilä, Pursiheimo, & Savola, 2005). The wood considered for calculation is from Canelo re-growths (secondary forest), a species with low density and heating value compared to other species used in the area for heating purposes. According to information given by CONAF(Rojas, 2010), Canelo is a suitable wood to be considered as a fuel, since it is not desired by the firewood market and currently has no demand.

Parameter	Value	Unit
Power output	2	MW
Heat output	9,52	MW
Net efficiency	0.9	
Electric efficiency	0,16	
Fuel Calorific Value	9,6	MJ/kg
Fuel flow	4,8	ton/h
Operation hours	4.000	h/year
Biomass Requirement	**19.206,3**	**ton/year**

Table 11: *Main parameters for CHP plant*

The operation hours of the plant are a key factor for estimating the biomass consumption. For the base case it was considered that the plant will operate4.000 hours per year, (capacity factor of 0,5) although the operation time of the diesel generators currently used is 1.200 hours. This decision was made considering that literature and experience state that a CHP plant with less than 2.000 hours is not economically viable(Irish CHP Association, 2009) and that in countries such as Denmark, Finland and Sweden, most small scale CHP plants work between 4000 and 5000 hours per year (Kirjavainen, Sipilä, Savola, Salomón, & Alakangas, 2004). In any case, the amount of operating hours will be determined when the exact energy demand patterns are established in more advanced studies.

A feasible alternative for the plant operating more hours than the actual generators is that the surplus of power produced could replace some of the grid utilization that these companies have(Table 12). For example, if the plant operates 4.000 hours per year, there would be2.800 hours of surplus power, providing 5.600MWh per year to replace the energy consumed from the grid, which is based mainly on fossil fuels. The other possibility is that the surplus of electricity would be connected directly to Central Interconnected System (SIC)

Company	Monthly Power Consumption (MWh/month)
Invertec	240
Toralla	450
Antarfood	260
PesqueraUnimarc	615
Total	**1.565**

Table 12: *Electricity consumption from the grid of selected industries in Chonchi*(Cordero, 2006)

An important sensitivity analysis to be taken into account for further considerations is the variation of feedstock needed according to the hours of operations and the plant size. Both analyses are shown in the following tables.

Capacity factor	Biomass (loose m³)
0,2	38.413
0,5	76.825
0,6	96.032
0,8	134.444
0,9	153.651

Table 13: *Biomass requirements according to capacity factor of CHP plant*

Plant Size	Biomass (loose m³)
2	76.825,4
5	144.444,4
8	205.714,3
10	251.851,9

Table 14: *Biomass requirements according to plant size (Capacity factor of 0,5).*

These values were calculated just as a reference, in order to have an estimation of the amount needed. In case of plant size variation, the power to heat was also changed according to what is shown in Fig.*31*. An interesting fact is that the feedstock for a 10 MWe plant is only three times bigger than for a 2 MWe, which can be an alternative to the proposed plant if the biomass supply is available.

Biomass Drying

As it was mentioned earlier, the use of wet biomass in Chiloé, and in Chile in general, is widely spread. Beside the lower process efficiency of this practice, there is an important issue in terms of the supply of firewood, as it was mentioned by the manager of Energía del Bosque(Rain, 2010). According to him, there has not been any problem regarding the supply of biomass in terms of production, but there has been a shortage of fuel caused by the lengthy drying process, done by natural air-drying.

Drying biomass fuel improves combustion efficiency, and increases steam production,usually it also reduces net air emissions and improves boiler operation(Roos, 2008). If the fuel is too wet, it may be impossible to keep the flame lit without supplementary use of fossil fuels, while with dry fuel, the flame burns hotter and more evenly, facilitating complete combustion (Roos, 2008).

The natural drying of the biomass, specifically for Canelo wood, can take several months until it reaches an acceptable content of moisture, as it can be seen in Fig.32. From its raw state to moisture content of 25%, the process takes 4 months, which is done in the summer. Since Chiloé is a rainy area, if the firewood is left in an open environment, the moisture content increases

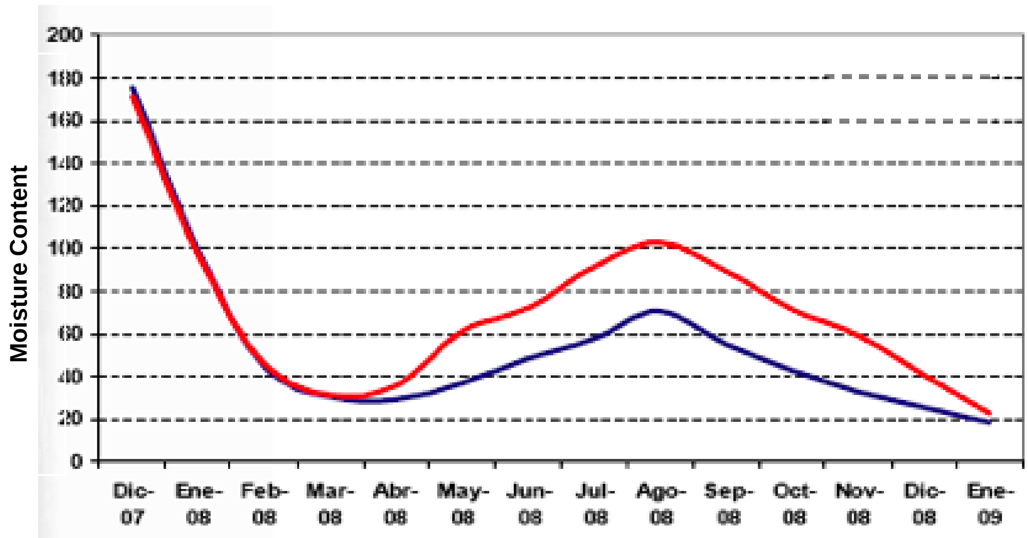

Fig.32: *Natural drying tests of Canelo (Drimyswinteri) in Chiloé. The blue line indicates the result of the test of firewood covered with a plastic shield and the red line is for firewood dried with no cover* (Neira, 2009)

According to these results, it is considered, that for this project, the cogeneration facility should include a dryer, to provide a steady biomass supply and avoid shortages.

The most interesting and efficient option for drying is the configuration widely used in cogeneration with bagasse from sugarcane, where the flue gases from the boiler are used to dry the raw biomass(Sosa-Arnao, 2004). The most efficient design is the parallel arrangement (Fig.33), where around 90% of the flue gases are used to dry the biomass and the rest is used to preheat the combustion air coming into the boiler (Sosa-Arnao, 2004).

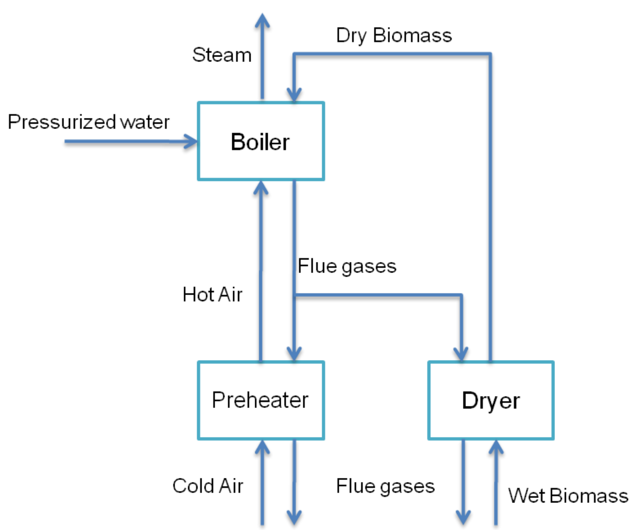

Fig.33: *Parallel arrangement flowchart for biomass drying using flue gases*(Sosa-Arnao, 2004)

Although this scheme is designed for bagasse, it could be applied to the case of Canelo, considering its physical and chemical characteristics. Reviews had been carried out to study the drying process of the wood (Perez, Ananias, & Hernandez, 2007). For pieces of 5 centimeters of thickness (the highest thickness studied) the following schedule was applied, since it was found to be one of the most suitable to preserve the wood properties.

MC (%)	T dry bulb (°C)	T wet bulb (°C)
Raw	44	44
Raw-30	44	40
30-25	48	42
25-18	52	44
18	52	52
20-15	60	50

Table 15: *Drying Schedule for pieces of Canelo wood of 5 cm thickness*(Perez, Ananias, & Hernandez, 2007)

The length of the drying procedure was between 272 and 444 minutes, depending on the initial moisture content (ranging from 80% to 140%). Considering that the temperature of the flue gases is around 200-300 °C and that working with moisture content of 25% is acceptable for combustion purposes, it is expected that this time could be reduced. Nevertheless, experimental tests need to be carried out to prove this fact. The information given in this section aims at giving a general idea of how the drying process should be performed.

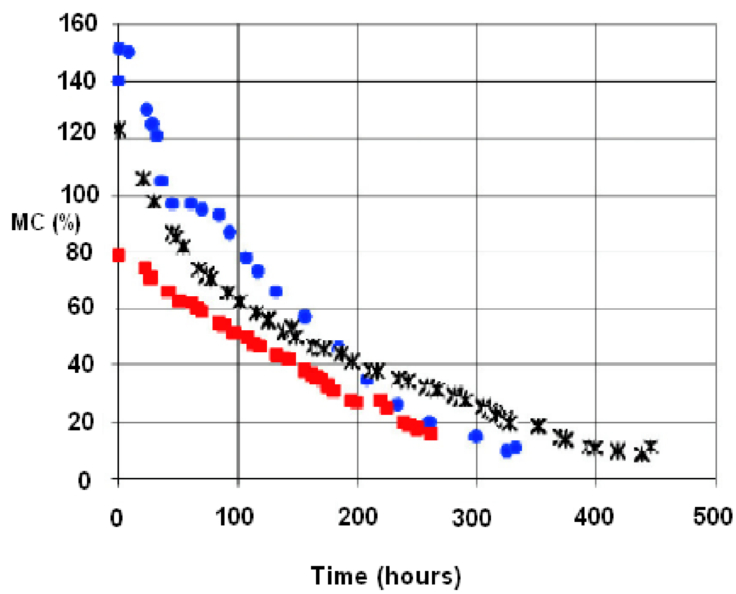

Fig.34: *Drying curve of Canelo re-growths of 5 cm thickness. (The different color lines correspond to different tests made)*(Perez, Ananias, & Hernandez, 2007)

The final layout of the CHP plant proposed, including the drying stage, is shown in the followingfigure:

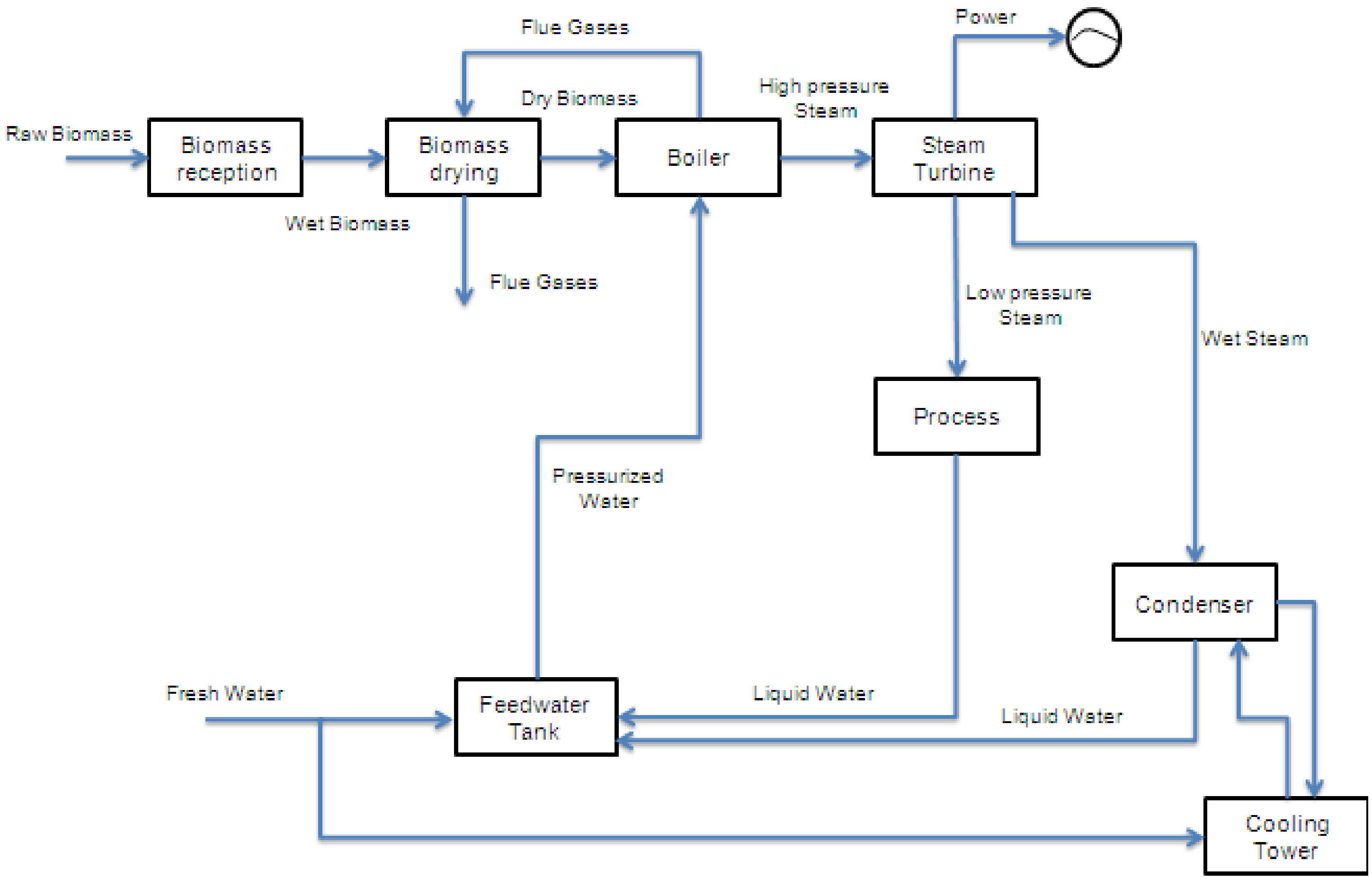

Fig.35:*Flow chart of CHP plant*

7.4.3 Biomass Supply

There are four main sources of forest biomass that can be used for energy purposes. These are:

- Slash (tops and branches) left after harvesting.
- Slash and small trees from thinning and cleanings.
- Un-merchantable wood
- Wood impacted by natural disturbance, such as fire or insect infestation.

In the case of the present project, the biomass considered to be used as fuel is from second-growths forests of Canelo, derived from forestry practices such as thinning and trimming as part of the sustainable management of the forests, activities supervised by CONAF. Possibly, other fuel sources can be included in the future.

Unfortunately, forest management plans on a regional level do not exist and no study has been made to estimate the potential of fuel wood with accurate information and projections in the long term. The information available is for specific management plans and expected deliverable volumes throughout its implementation. However, the implementation of these plans is very recent and not a common practice among forest owners. Thus, it is not representative of the real situation, but is the best approximation that is currently available.

To gather more data about the specific biomass availability and management plans in the island, during the last week of April, 2010, a field visit was made to the area. Interviews with actors that would play a key role in the project were also part of the agenda, such as the local offices of CONAF and forestry engineers working with the recently formed forest owner cooperative and also in the National Firewood Certification System. In addition, a visit to the industrial sector were the chosen companies are situated was made and some nearby forest areas were evaluated.

According to the literature(Gronalt & Rauch, 2007),for distances up to about 50 km, material can be transported in loose form. Therefore this distance was set as the action range. In Fig.37, the complete island is shown and the area located in a radio of 50 km from the chosen industrial zone.

Fig.36: *Radio of preferred biomass location to supply the plant.*

As it can be seen, the sources of biomass can be located almost in half the territory of the island and still be feasible to feed the plant.

Two were the selected forestry areas that were visited with personnel of CONAF. The first was located 5 km from the plant of Toralla, moving south in the road to Queilen. The other was next to the area of Pulpito, about 15 km away from Chonchi, along the highway to Quellón (Fig.37). Both areas are shown in Fig.*38* and in Fig.*39*, in a mixture of satellite images (taken with Google Earth software) and real pictures taken during the visit.

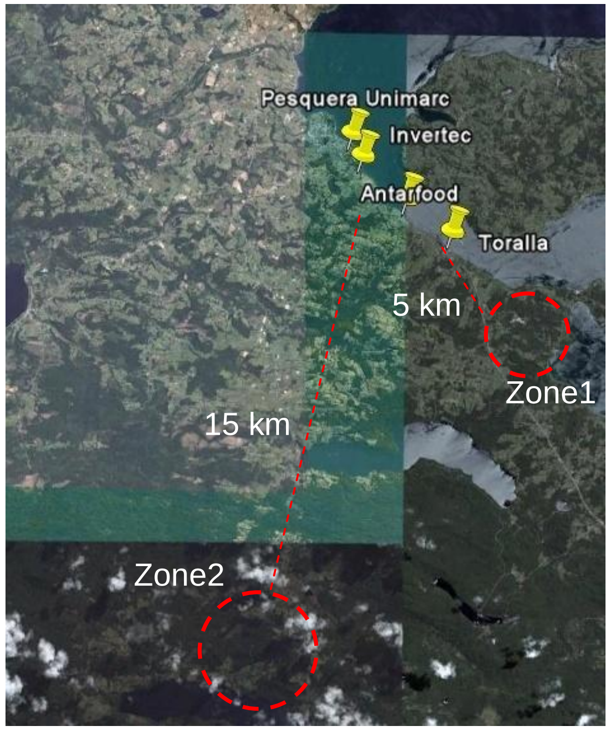

Fig.37: *First area visited during field trip.*

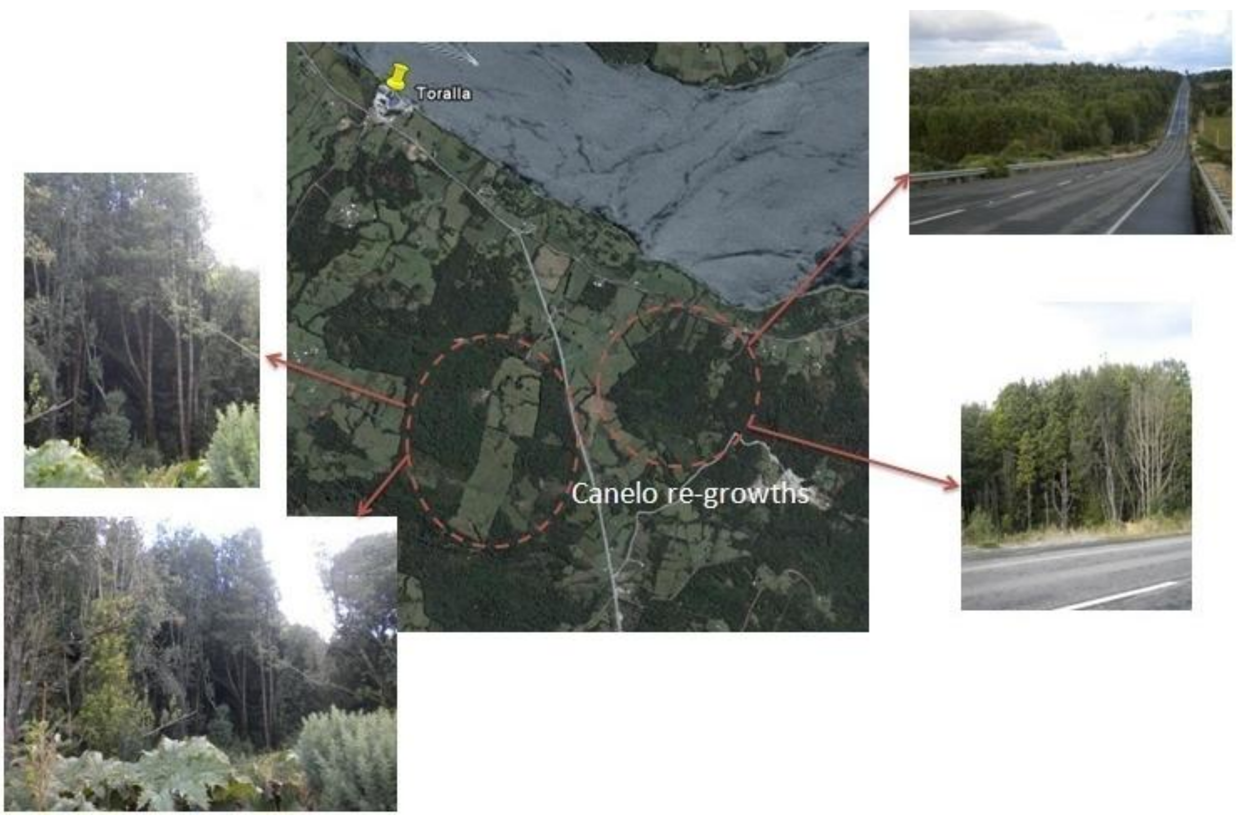

Fig.38: *First area visited during field trip.*

In the first zone, CONAF has estimated that there are more than 100 ha of re-growths of Canelo that can be managed in the short term. However, the management plans of these hectares have not been yet presented to the forestry authority. Therefore, the amount of deliverable wood volume can only be estimated.

CONAF´s personnel in Chiloé estimates that a conservative yield of deliverable wood volume is 80 m^3/ha. According to this parameter and considering the amount of biomass needed for the 2 MW_e plant would be around the 960,3 hectares intervened per year. Considering that there are 70.000 ha of re-growths of Canelo in the island, the amount needed to feed the plant seems feasible, statement ratified by personnel of the National Firewood Certification System.

Fig.39: *Second area visited during field trip, in the zone of Pulpito.*

Also it is important to remark that more optimistic yields for this region are found in literature referring to yields up to 200 loose m^3 per hectare. This case would only improve the plant supply scenario and would require less land intervened.

More detailed information was available for the second area visited. Along with two forestry engineers, a specific land was visited whose owner has presented a sustainable management plan to the authority. His land comprehends an extension of 180 ha, from which 169,4 can be managed. Such landlord is considered to be a medium sized owner.

Stand	Area (ha)	Productive Capacity [loose m^3]
1	68,7	5292,6
2	42,5	1142,4
3	4,4	126,24
4	8,1	1740,84
5	31,4	6744,72
6	14,3	2450,4
Total	**169,4**	**17.497,2**

Table 16: *Expected deliverable volume from forestry planning*(Rojas, 2010).

Considering that from all the wood recovered, 80% corresponds to Canelo species and that the management plan is expected to be carried out in 5 years, this specific land delivers a yearly volume of 2.800 loose cubic meters. According to the need of the plant, 30 landowners with similar characteristics would be needed to feed the plant. This scenario is an optimistic example, since they are medium sized owners and they are supposed to have more productive capacity and marketing abilities.

On the other hand, another example of the amount of owners needed to group is given by personnel of CONAF, from the beneficiaries of the funds for sustainable management plans for 2010 in Chiloé. For this year, 520 hectares were awarded with financing for management plans, which correspond to 82 owners(Rojas, 2010). The average land size is 6,3 ha per landlord, a considerable smaller number than the previously mentioned example. If it were considered that the CHP plant would be supplied with biomass from this type of owners, around 200landlordswould be needed.

With these two examples, it is clear that there is no unique manner to supply the CHP plant. A suitable solution would be mixing these two types of owners (as shown in Figure 31) in a network that can provide a market and promote the sustainable management of forests in hands of small owners, and also offer a secure supply to the plant. The small owners should be gathered in a cooperative and the medium sized owners could work by their own if they have the capacity.

A proposed model is the gathering of 30 small owners in a FOC, with an average land size of 10 hectares, since this number is suitable for a proper coordination within the cooperative. The FOC supply can be complemented with 10 or 12 medium-sized owners (average land size of 100 ha) as shown in Fig.*40*.

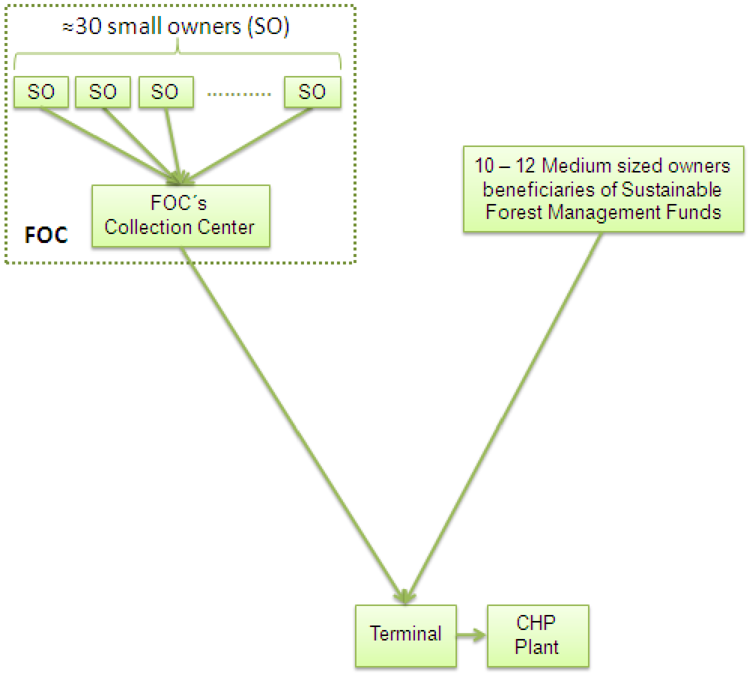

Fig.40*:.Biomass supply to CHP plant*

Workforce and Technology

Not only the biomass supply is important, but also the workforce to gather it is important to consider. According to studies performed in the zone(Marabolí, 2007), the availability of workers for forestry activities is scarce due to the migration of people to salmon and fishing industries since they offer a more steady income. Moreover, there are no qualified personnel to perform forestry related tasks, and the current workers only have the training gained from field experience.

This situation in the short term is an important barrier to be considered since simply there are not enough workforces to perform the forestry activities included in a management plan to supply the plant. Although this condition may indicate that there is a labor niche, in reality small owners are very reluctant of foreign people working in their lands. Therefore, a cultural change is also needed, beyond the technical training and assistance required.

In terms of the technology used in the forestry management in Chiloé, is it characterized by the utilization of basic equipment compounded by a chainsaw, an axe, a pair of oxen and a small cart. In a very few sites, tractors are used to drag the wood to nearby roads. The lack of technology and the knowledge to use it appropriately is translated into more time and cost of the forestry work, which can jeopardized the on-time supply to the plant.

Fig.41:.*Technology used to collect and transport firewood in Chiloé*(SNCL, 2010)

In countries where there is a developed bioenergy industry, there are two system used to harvest and collect the wood from thinning or small sized wood; a two machine system or a harwarder system (Fig.42). In the first one, a harvester and a forwarder are used to performthe tasks. The second one, which is a state of the art technology, sees the integration of the harvesting and extraction operational elements into a single processing unit, which uses an off-ground handling system. In this way, the timber does not come into contact with the ground from the point of felling until it is deposited at roadside.

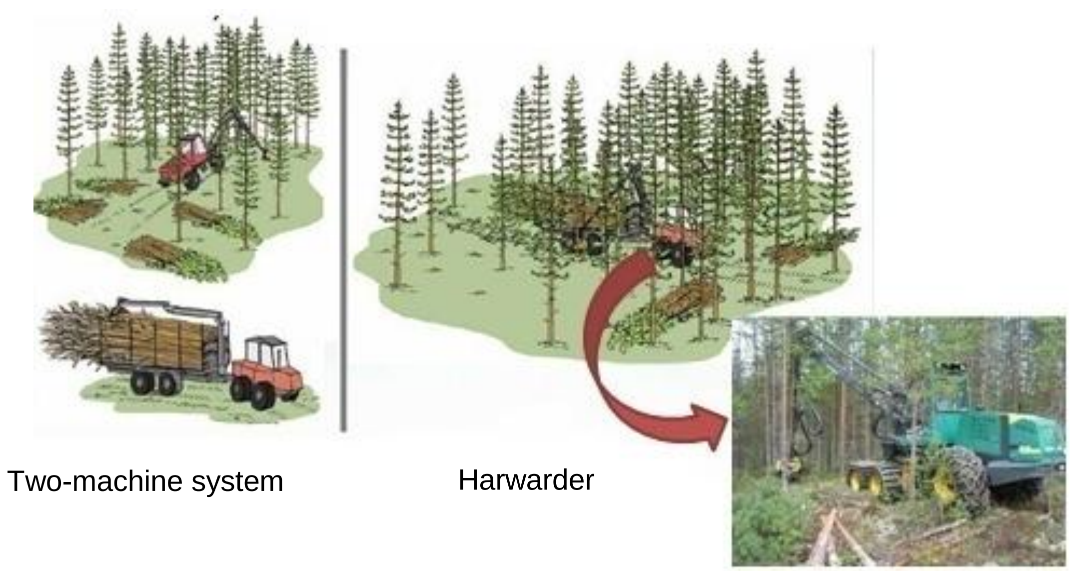

Fig.42: *Technology used to collect and transport firewood in developed industries*(Sikanen, Röser, & Asikainen, 2005)

The gap between the two technologies is such, that it cannot be expected that those kinds of equipment can be used in Chiloé in the short term. The improvement of mechanization is most of the times unaffordable for small owners, and cheaper alternatives have to be taken in consideration, such as faster an easy to handle chainsaws (Fig.43).

Fig.43: *Chainsaw with special handle used in Finland for manual felling* (Sikanen, Röser, & Asikainen, 2005).

In this area, the cooperative structure can be helpful to overcome this barrier. If the cooperative owns as an initial capital items such as chainsaws, tractors and a few trucks, it can provide access to this equipment as per requested by the owners. To have the initial investment, cooperative can gather resources from their members (difficult option for Chiloé), or have access to loans and credits from private institutions or financing support from government. For example, Södra offers this service to their members, encouraging the management of the forest and the production of sustainable bioenergy in a faster supply chain.

Transport Logistics and Storage

Transportation systems are a condition for the development of an effective bioenergy system. Currently, small trucks are used to transport loose logs and since the distance of the biomass source to the plant is smaller than 50 km, this characteristic is considered to remain the same.

A regular truck that delivers firewood in Chiloé Island can carry up to a volume of 20 loose m^3. Considering this parameter, the following assumptions were made to estimate the number of average trips needed to supply the plant.

Parameter	Value	Unit
Hours	4.000	h/year
Days	330	day/year
Hours per day	12,1	h/day
Daily fuel consumption	167,1	lm^3/day
Daily trips	**8,4**	**Trips/day**

Table 17: *Estimated trips to supply CHP plant.*

The above exercise is just a simple example to have an outline of the amount of trips needed and whether the road capacity of the zone will be able of holding such traffic. According to the field visit made, interviewed personnel at CONAF and the location of forest areas, it is estimated that the transportation of firewood from the roadside to the plant will not present major complications. The transportation of the wood from the felling site to the roadside is more complicated due to the lack of technology and workforce, topics that were already discussed.

A common experience is to have uneven deliveries of biomass and variations in the quality of forest chips (moisture content and heating value) have caused difficulties in optimal operation of power plants. An interesting solution to this problem has been adopted in some plants in Sweden, where the forest fuel is provided by companies which are obliged by contract to deliver a certain amount of bioenergy, specified in MWh, for each time period during the time of agreement(Gunnarson, Rönnqvist, & Lundgren, 2003).In this way, the energy supply is secure to the plant, but it requires a strong commitment and advanced technology use from the supplier, which currently does not exist in Chiloé.

Before forest residues can be used as fuel in energy plants, they have to be chipped. Chipping is a primary element of forest fuel supply chain remarkably affecting the whole system. There are several alternatives for performing this operation, the most commonly used being the following(Bradley, 2007):

- Roadside chipping: Biomass is chipped at roadside using either a mobile chipper or truck mounted chipper and transferred to a truck.

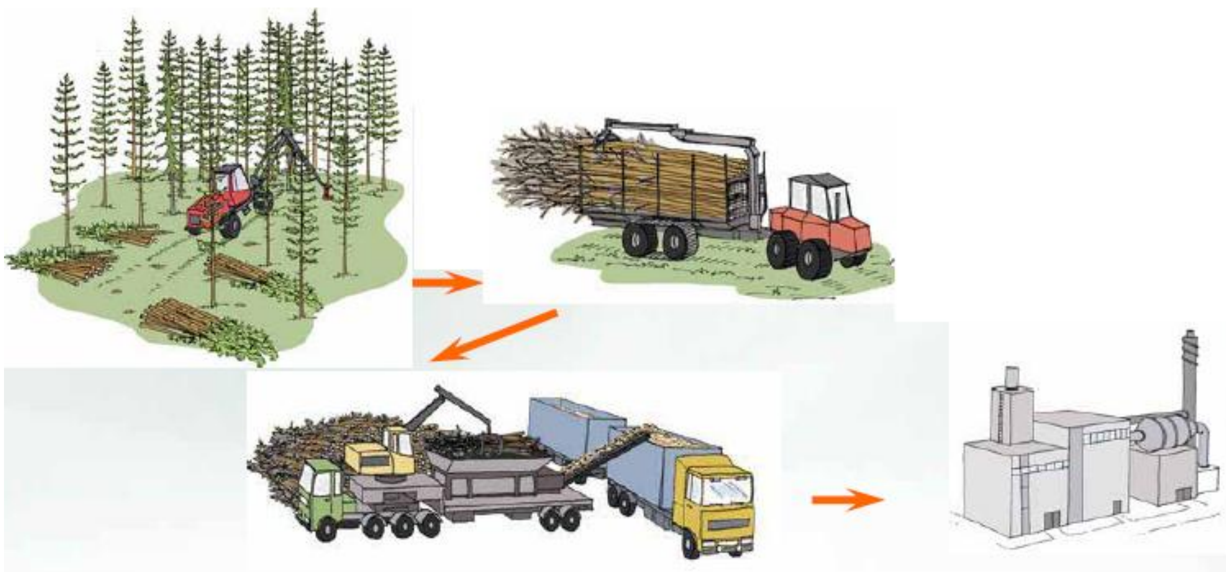

Fig.44: *Roadside chipping of small sized wood*(Backlund, 2007)

- Terminal chipping: Un-comminuted biomass is transported a short distance to a terminal where is chipped and loaded onto large bulk trucks.

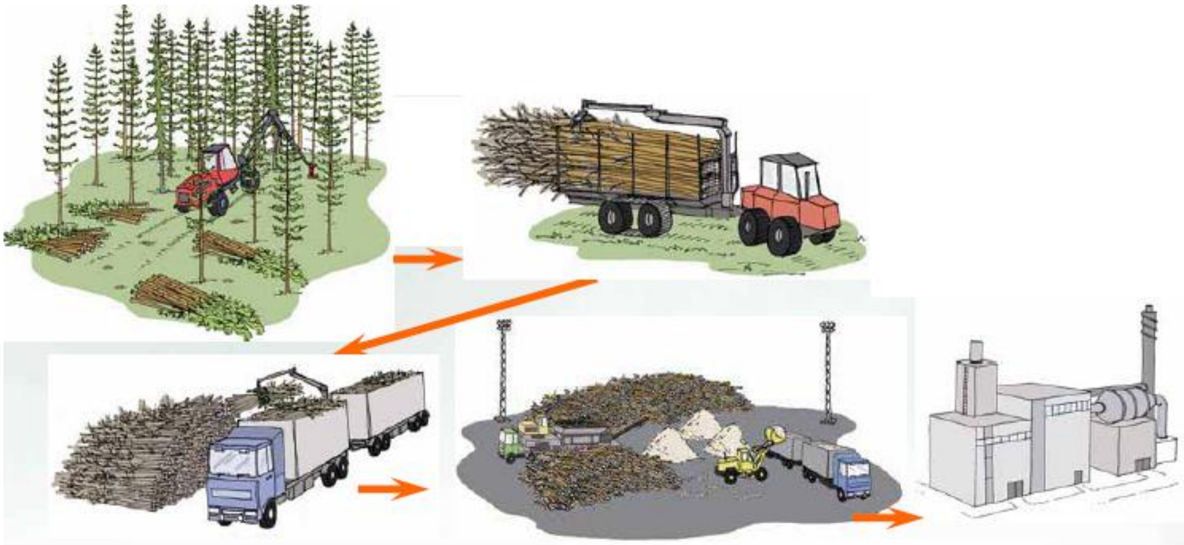

Fig.45: *Terminal chipping of small sized wood* (Backlund, 2007)

Both models have advantages and disadvantages and are aimed at different types of systems. Table 18shows characteristics of both models, which can be used to make the proper decision according to the specific plant location.

Terminal Chipping	Roadside Chipping
Simple to organize	High load volume
Low chipping costs	Possibility to use efficient chippers
Requires short transportation Distance for low density biomass	Need space for machines and trucks
Requires careful planning of logistics in order to avoid queuing of trucks	The chipper and the truck are depending on each other, creating a hot spot in the supply chain.

Table 18: *Characteristics of terminal and roadside chipping*(Sikanen, Röser, & Asikainen, 2005).

Several factors determine which supply system should be implemented, as the decision has to be made according to specific site factors, such as:

- Harvesting conditions,
- Roadside landing capacities,
- Road transportation distances,
- Operating volumes and storage capacities of energy plants,
- Availability of production machinery,
- The total costs of supply systems.

In Finland and Sweden, the most common supply chain model is roadside chipping. Although this fact might indicate that this is the model to follow in Chiloé, it may not be the most appropriate alternative given that in these countries there is already a bioenergy industry developed, with numerous plants and terminals and years of experience in the field. In the case of Chiloé, this will be a pioneer facility, so the organization has to be remains simple and has to use the available resources and technology (roadside capacity in the island is not high-quality and currently, mobile chippers is not a widespread technology in the zone). Also, the terminal would be located at the same plant and the distance from the source is not a limiting factor. Therefore, it is considered that the terminal chipping supply chain model is the most suitable option for the project.

As mentioned earlier, the terminal is used as a storage facility to avoid seasonal fluctuations and solve supply problems both at the plant and in the field. It is recommended that biomass should be stored as bundle firewood and that chipping should be done according to the plant needs. The reason for this choice is that once material is chipped, it is recommended to use it as soon as possible to prevent excessive microbial activity. The latter causes health hazards through spore emission, energy losses, and even spontaneous combustion. On the contrary, bundles do not display these drawbacks, and form a relatively uniform handling unit(Sikanen, Röser, & Asikainen, 2005).

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For the CHP plant in Chiloé, the sized for the storage facility should be large enough to cover at least one-month biomass consumption, which is equivalent to a volume 5.000 m^3. The wood has to be stored in a closed environment to avoid the increase of moisture content before it is consumed. Experience in storage has already been carried out in Chiloé, with the utilization of warehouses where firewood is stored during the winter season (4 months) above ground level. Results have showed that moisture content can be maintained or even reduced (Bertin, 2009)with this simple storage facility, situation that can facilitate the drying process proposed in the pre-burning stage in the plant.


Fig.46:*Warehouses in Chiloé to stored and dry firewood*(Bertin, 2009)

8 Discussions

There are several issues that can be discussed regarding the work done during this project. As an overview of the whole work, it is important to highlight that the main objective was to establish a supply chain model for a demonstrative cogeneration plant, was partially fulfilled. The reasons for this was the lack of accurate information about the location of the forest resources (geo-reference), which made impossible to define a precise logistics scheme and define the location of the plant in order to optimize the transport costs.

Other aspects of the project that are worth mentioning are presented in the next points. Most of them should be taken into consideration for further studies in the field.

- The biomass considered as fuel for the plant is firewood from native forests, but if other sources are available in the area, they also should be taken into consideration. These can be, depending on the location of the plant, agricultural crops residues, splinters available in the market, forestry residues, etc.

- The choice of biomass from native forest was made considering the current state of the resource, which is much degraded. In this situation, the only option to market products derived from native forests is as combustible material. However, an analysis has to be made for the long term, when the forests recover and improve their quality. By this time, it will be more profitable to sell other wood products (lumber, boards, etc) and only logging residues, bark, shavings, tops, branches and other by products shall be considered as the wood fuel available for the plant. To overcome this possible shortage of fuel, energy plantations can be used as alternative and that are not currently used.

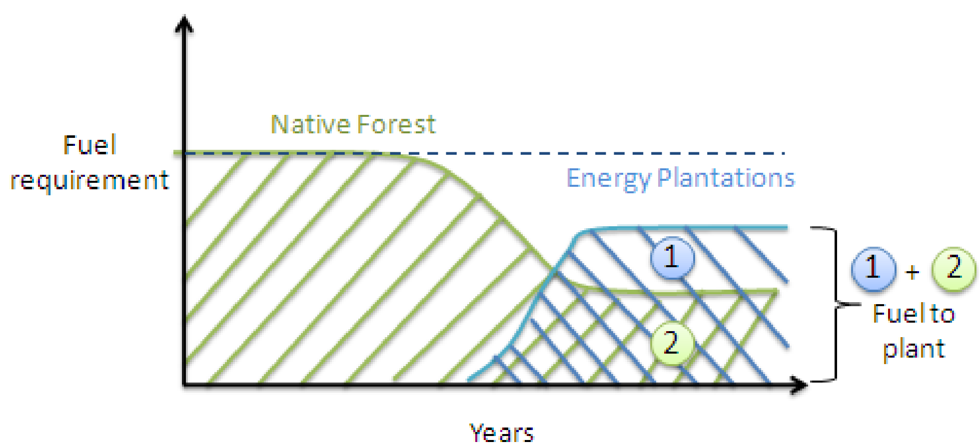

Fig.47: *Fuel supply to plant using energy plantations.*

A rough estimation for the renovation of the current forest is about 30 to 50 years(Rojas, 2010). Although it may seem like a distant future, it has to be thought that the energy plantations can take up to 20 years to grow in the southern climate. Hence, a proper planning has to be considered from the early beginning of the plant, to avoid shortage of fuel in the future.

- Chiloé was identified as a suitable location for the plant, for its biomass availability, its island condition and the energy consumption patterns (high fossil fuels consumption). However, in a meeting held with the National Firewood Certification System (SNCL), its director mentioned that Chiloé could be a difficult place to start a pilot initiative, due to its cultural characteristics and especially for the lack of awareness and interest for the use of sustainable management of the forest among owners of lands. He suggested that other cities of the X region, like Valdivia or Osorno, could be a better place to focus on, since the SNCL has already done an intensive job educating and informing about sustainable firewood and its efficient use. Therefore, people are more willing to participate in a project as the one presented in this work, with an appropriate disposition towards its implementation.

- The Forest Owner Cooperation model presented is just an alternative of business model to approach the supply side. It was thought as a model that would empower the small owners and provide them with tools and capacities to manage their forests, targeting to a sustainable rural development. There are other models available to approach the small-scale ownership problem, for example selling the forest canopy layer of the small owners to a larger company that can be in charge of the management and marketing of the products. Unfortunately, due to time reasons were out of the scope of the project.

- The Forest Owner Cooperation model is a suitable model to gather small owners who lack of marketing and managing abilities. Nevertheless, to successfully run a FOC, it is vital to have an active and involved membership, which is hard to accomplish if no additional services are provided by the cooperation. This is a key issue that can be tackled, for example, by proper government policies and funding. Providing an initial investment that can cover some basic technology items such as a truck, chainsaws and a storage facility, can be an alternative to get together small owners who lack the resources to access this machinery by themselves. Also, this action deals directly to the technology gap identified helping to narrow it and increasing the security of the biomass supply.

- The lack of supervision of the fulfillment of the management plans presented by the owners of the lands is critical and currently is inexistent. Even more, there is no interest from the owners in developing such, because it is time consuming, requires financing and there is lack of awareness of sustainable management. Therefore, the vast majority of forests interventions are done without a plan, although it is supposedly mandatory. At present CONAF, does not have enough personnel or the legal authority to control all the interventions performed in the forests, so it would be difficult in the future to ensure that the fuel of the plant comes from sustainable managed forests. This situation would jeopardize one of the main objectives of the CHP plant, which is the improvement of the current state of the native forest in the area. Also, this issue highlights the fact that CONAF requires a restructuration in the short term, where topics as bioenergy and the management of the forests have to emphasize has primary subjects in its agenda, since currently they are not being properly dealt.

- The economic aspects of the demonstrative project were not raised in this report, since it was considered there was no enough information to establish a significant analysis. It is definitely an aspect to have in consideration for further studies, given that there will be several barriers regarding financing, as all renewable energy projects face in Chile.

9 Conclusions

Chile is a country with abundant biomass resources, especially forests. This condition is very favorable for bioenergy projects, since the technology for the development of these projects already exists and it is normally used in developed countries. Therefore, it is considered that forestry biomass is one of the most promising renewable energy sources in the country that can be efficiently exploited with projects such as the cogeneration plant presented in this thesis.

Chiloé Island presents unique conditions to develop biomass projects, due to its natural resources, energy consumption patterns and its island condition. Several industries have oil consumption to produce electricity, fuel that is expensive to transport from mainland to the island. Using biomass to replace not only would diversify the energy source of the island, but also would promote local economy and provide more security of energy supply. After the earthquake Chile suffered in February 2010, this issue has gained major importance on any energy project to be developed in the future.

As far as the technical feasibility of the demonstration project is concern, the amount of biomass needed to fuel the plant is available in the area and the technology is already used in the country, therefore it is important to concentrate efforts on implementation barriers. To identify other obstacles biomass cogeneration projects may face, the establishment of a supply model for a theoretical pilot project was an adequate methodology. Two main barriers were identified and alternatives to overcome them were presented. The first was the small-scale ownership issue that prevents a secure supply chain to the plant. The business model of a Forest Owner Cooperative presented is suitable for the Chilean reality, considering that the aim was to promote sustainable rural development. However, it is important to remark that it is only an option and each case has to be reviewed individually.

The lack of adequate information on the biomass resource is another important obstacle identified, since there is no updated and accurate information about the current forestry management plans presented to the authority, nor the potential biomass that could be managed in the short term. A Geographical Information System (GIS) is needed in each major region of the country, to help project developers identify attractive areas where the biomass resources and the energy demand are the adequate for CHP plants and develop supply chain models that can be economically analyzed.

Overall, the following situation is occurring in the Chilean reality. Small owners of native forests are not interested to manage their forest because they do not have a market where to sell the biomass obtained. On the other hand, industries and project developers are not attracted to develop bioenergy projects because they do not have a secure and reliable long-term supply. This is a vicious circle hard to break just leaving the market act by itself. Therefore, government actions are expected to take place if there is a real interest to develop bioenergy industry. Since currently there is no institution leading this process, the Renewable Energy Center can establish itself as the leader and coordinate efforts ranging from high levels (Ministry of Energy and the Ministry of Agriculture, where policies are developed) to small owners who need basic training and technical assistance. Certainly, during this process, a few institutions from the government, especially CONAF, will have to be strengthened and reorganize to provide the support that is expected from them.

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