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Topic 3. Modelling and Simulation

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Cost-Benefit Analysis using GIS: An Application to the Forest Bioenergy Sector

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This doctoral thesis introduces a novel methodology to optimize the use of forest biomass for energy purposes at regional scale, by means of GIS applications and economic tools. The procedure calculates, at first, the energy potential of a given forested area, as well as a reasonable location and dimension of a district heating power plant, based on local energy availability and energy demand. In a second step, it runs a cost-benefit analysis (CBA) to assess the economic feasibility of the plant. The CBA considers financial costs and benefit, social benefits and environmental costs, estimated by means of market and non-market valuation techniques. Financial, social and environmental flows are combined to produce four different scenarios, for which the net present value is calculated. Afterwards, a probabilistic sensitivity analysis is carried out, to assess the stability of the results when different assumptions of input values are included. Such procedure have been tested in an Italian case study, the valleys of Gesso and Vermenagna in the Piedmont region. These alpine valleys are interesting, because forests are at present under-utilized. At the same time, the presence of the Alpi Maritime Natural Park provides constraints to the use of natural resources; for these reasons, a carefull planning of the activities is fundamental to assure sustainability. The GIS methodology has been developed in GRASS GIS and automatized in python, while econometric computations were carried out in R. This procedure may facilitate energy planning and increase the efficiency of the forest-timber-energy chain.

Gianluca Grilli is a PhD candidate at the department of Civil, Environmental and mechanical engineering of the University of Trento. Gianluca holds a M. Sc. In environmental economics and his main fields of interest are non-market valuation and public policy evaluation, both with ex-ante techniques, such as cost-benefit and cost-effectiveness analysis, and ex-post techniques, in particular propensity score matching and difference in differences analyses. In addition, he is interested in spatial analysis with GIS software. For his doctoral studies, Gianluca obtained a scholarship from the Institute of Renewable Energy of Eurac Research, Bolzano.

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Abstract

The necessity of reducing energy dependence on fossil fuels is stressed by the European Union (EU), with the main objective of reducing greenhouse gases (GHG) emissions and contrasting climate change. The Directive 2009/28/EC (climate and energy package) goes in this direction, foreseeing three main targets to be reached by 2020 (20-20-20 targets). Forest bioenergy could play an important role to achieve these goals and, in particular, an interesting source of bioenergy is represented by residuals of wood processing. Usually, forest activities aim at harvesting trees to produce high-quality timber. Tops, branches and other residual biomass are considered waste and abandoned but, in many cases, they could be used to produce energy.
However, planning the exploitation of forest biomass requires considering several variables, in order to be effective. In particular, the economic feasibility of building a power plant is always uncertain. In some cases, the power plant is oversized and the locally available biomass is not enough for an efficient running. In addition, harvesting biomass may have negative consequences on forest environment, negatively affecting the provision of ecosystem services.
In an attempt to tackle these cited important issues, this thesis provides a Decision Support System (DSS) to help decision-makers in planning the use of forest biomass for energy efficiently. The DSS is designed by means of Geographical Information Systems (GIS), to account for the spatial effects of energy planning, and implemented in GRASS GIS, an open source and free software, to facilitate the diffusion among decision-makers.
The DSS has three main objectives: (1) identifying the energy potential from forest biomass of a given area, (2) hypothesizing a reasonable place to settle a power plant and (3) run a cost-benefit analysis to investigate the economic convenience of the project. The procedure is tested in a case study in the Italian Alps, the valleys of Gesso and Vermenagna in the Piedmont region. The area is interesting because forests are at present underexploited, thus it

is possible to increase efficiency in the forest-timber-energy chain.
In principle, different economic actors might be interested in exploring the possibility to build a new DHP, both private and public. For this reason, four scenarios are proposed, based on different assumptions of the interested costs and benefits to be included, in order to cover a wide range of hypothesis. A baseline scenario is a situation in which the potential investor is only interested in the financial performance of the DHP, i.e. a private entrepreneur (financial scenario). Another scenario likely to be explored by privates is called financial and environmental scenario, in which the investor is interested both at the financial performance and at the value of forest natural capital. In this scenario, the change in the values of forest ecosystem services is also included This situation might be explored by forest owners that are also interested in building the DHP. On the other hand, public actors, such as public institutions, might be interested at the welfare effects that a DHP provides. For this reason, willingness to pay (WTP) for renewables is included to account for preferences of the target population. WTP is used as a proxy of the perceived social benefit. A first scenario includes only financial flows and social benefits (called financial-social scenario). Another scenario, which might be interesting for public administrations owning local forests, presents also the change in forest values (social-environmental scenario).
Results show that the energy potential retrievable from local forest is about 13,000 MWh per year, corresponding to a DHP of about 1.6 MW of capacity. Concerning economic performances, the financial and social scenario was proved to be the most interesting one, conversely the financial-environmental scenario the least profitable. From this result it is possible to see that a DHP seems to be convenient if created by public institutions, because it appears to be a welfare increasing solution. On the other hand, private actors would be less attracted from such a solution, because the economic performance is uncertain.

Dedication

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Statement of Originality

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due references are made.
The contents of this thesis are partly published in the following contributions:

- Chapter two:
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- Grilli, G., Ciolli, M., Garegnani, G., Geri, F., Sacchelli, S., Poljanec, A., Paletto, A. (2017). A method to assess the economic impacts of forest biomass use on ecosystem services in a National Park. *Biomass and Bioenergy*, 98, 252263.

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Chapter 1

Introduction

1.1 Background and Historical framework

Energy is one of the most critical and important resources that has always conditioned anthropic activities, without energy life on earth would not be possible. Sources of energy may be renewable or non-renewable. Renewable energy (RE) can be defined as energy collected from natural resources that can be regenerated in a human time-scale (Perman, 2003). The most common RE sources are biomass, water, wind, solar and geothermal heat. RE sources differ from fossil fuels because the latter are the result of anaerobic decomposition of dead organisms, which are processes lasting millions of years and not compatible with human lifetime. Energy obtained from fossil sources is therefore considered depletable, non-renewable and non-recyclable (Tietenberg and Lewis, 2016). Thus, an intense exploitation of fossil fuels in a short time-span may severely deplete their pools and jeopardize future availability. Most common fossil fuels are petroleum, coal and natural gas. Fossil fuels exploitation not only affects the possibility for future generations to use them, but their combustion also causes a release of carbon dioxide and other Green House Gases (GHG) that were stored in carbon pools for ages (Statheropoulos et al., 1998). Given the high levels of GHG emissions, fossil fuels are considered one of the main drivers of climate change (Jotzo, 2004). Conversely, an intelligent use of REs allows sources to regenerate with a reasonable timing, eliminating (or, at least, reducing) the menace of future energy shortages. At the same time, most of REs do not need combustion to produce energy, thus the release of GHG is much lower. Combustion is necessary to produce energy from biomass, however polluting emissions are naturally captured by the regeneration of new biomass. Therefore, even biomass energy is thought to be carbon neutral (Zanchi et al., 2012). According to the global renewable energy policy network, called REN21, at present the share of renewables in the final energy consumption is estimated to be 19.2% worldwide, the share of non-renewables is around 78.3 %, while the remaining 2.5% comes from nuclear power (Ren21, 2010).

The interest toward RE has started in the early nineties, with the Conference on environment and development, held in Rio in 1992. In that occasion it was decided to establish the United Nations Framework Convention on Climate Change (UNFCCC), with the objective of stabilizing the levels of GHG at a non-dangerous level for the climate system (Bodansky, 1993). After the establishment of the UNFCCC, another important milestone in mitigating

climate change was the Kyoto protocol, signed in 1997 and officially entered into force in 2005, when Russia became a member state of the agreement. The Kyoto protocol bears from the premise that climate change exists and that it is caused by humans, so humans have to provide actions to contrast or mitigate its effects (Protocol, 1997). Concretely, the treaty commits member states to reduce GHG, the target goals are costumized for each country, in order to reflect the contribution of each nation to GHG emissions, wealth and actual capacity to undertake concrete actions for reaching such objectives. Each country has certain objectives of reduction for each anthropogenic GHG emission, out of which carbon dioxide (CO_2) is the most important one.
The principal features of the Kyoto protocol may be summarized as follows:

- Binding committments to reduce GHG emissions for each State Party;
- Implementation: each state has to prepare policies and concrete actions for GHG reductions;
- establishment of a climate change fund for developing countries to facilitate policy implementation in less wealthy states;
- Accounting and reporting of the activities;
- establishment of a Compliance Committee to assure integrity and conformity of the policies with the protocol commitments.

In order to reduce GHG emissions, REs represent important tools because they allow generating clean and non-polluting energy. RE has become a priority for the European Unions (EU) energy policy, to counteract climate change at global level and the scarcity of fossil fuels in the EU member countries (Moula et al., 2013). EU has been active in the field of energy policy for many years, even though only in 2005 it was introduced a mandatory and comprehensive legislation for European countries. EU policy agenda foresees a more intense development of REs in order to increase energy efficiency, to reduce GHG emissions, and to decrease the dependence on fossil fuels(Jäger-Waldau and Ossenbrink, 2004; Tol, 2012). In the last decades, a series of policy documents and directives have been developed by the EU in order to achieve the above mentioned objectives (Rietig, 2013). In 1996 the European Commission adopted the Green Paper (1996), aiming at increasing the share of RE sources in the primary energy supply from 6% to 12% in

2010 (Uusi-Rauva, 2010; Ericsson and Nilsson, 2006). Subsequently, the Renewable Energy Directive 2009/28/EC has defined the 20-20-20 target with the aim to raise the share of energy consumption produced from renewable resources to 20% in 2020 and to reduce GHG emissions by 20% compared to 1990 levels. Recently, the Energy Strategy 2020 of the European Commission highlighted the need to increase the share (30%) of RE sources by 2020 and to drastically reduce GHG emissions by 2050 (Bentsen and Felby, 2012) (Bentsen and Felby 2012). The potential future benefits of the EU energy policy will be a diversification of the RE market and an improvement in both energy security and workplaces (Demirbas, 2009b,a; Mathiesen et al., 2011; Nishizono et al., 2005).

1.2 Sustainability of Renewable Energy

Despite many positive aspects people can derive from an enhancement of REs, an intense and uncontrolled production of energy from renewables may also have drawbacks (Grilli et al., 2016b). Negative aspects of REs development are connected with environmental, social and economic spheres, i.e. the three pillars of sustainability. According to the Brundtland report, the sustainable development (SD) is the process of meeting the needs of present generations without affecting the possibility for future generations to satisfy their own needs (Brundtland et al., 1987). In other words, the present use of natural resources for humans' benefit should not deplete the integrity of the environment and its resources, in order to assure a long-lasting life on earth. In economic terms, SD is a different concept from economic growth (Stern et al., 1996). Growth implies a non-negative variation of income levels every period, which is possible only assuming an infinite availability of resources. The concept of SD, on the other hand, acknowledges that resources on earth are limited, thus it is impossible to grow undefinitely and the focus is to provide an efficient use of them. During the years, the definition of SD shifted its attention, from a mere environmental concern to a wider spectrum of issues.The modern definition of SD aims at balancing environmental, social and economic sustainability; the need to consider these three perspectives simultaneously is widely recognized (Goodland, 1995; Moussiopoulos et al., 2010). Environmental sustainability refers to a condition of balance and resilience of societies, in which humans can satisfy their need to consume natural resources, while ensuring that ecosystems have the capability to fulfil their function. This definition of environmental sustainability is strictly linked to the concept of ecosystem services (ES Ehrlich et al., 1983). ES are benefits people derive from nature and are fundamental to assure life on earth, thus ecosystem management should strive to maximize the provision of such services to society. A more formal definition and additional information on ES will be provided in chapter five. Social sustainability is related to a life-enhancing condition within local communities and to the process allowing communities to achieve this condition (McKenzie, 2004). A participatory approach in decision-making processes is crucial for the implementation of social sustainability (Pitt and Bassett, 2014). Economic sustainability is defined as the ability to maintain productivity and generate income (Conway and Barbier, 2013). In a broader perspective, SD enables the realization of a social and economic system ensuring the increase of real income and improves the general quality of life (Ciegis et al., 2015). The use of renewables for energy may interfere with all these three cited aspects, bringing in some cases negative consequences.

The withdrawal of resources for human needs always imply an environmental impact, including using REs source for energy. A recent review of the literature about REs impact on ES, published by Hastik et al. (2015a), showed that each source of RE somehow affect the natural environment. For example, ground-mounted photovoltaic panels lower landscape aesthetics. Wind power has similar impact on landscape and may involve habitat depletion, because of interference with migratory routes and habitat alternation. Collecting solid biomass to produce energy reduces the organic material in the habitats, thus diminishing fertility and causing a general disturbance in the environment. Specifically concerning forests, cutting trees may affect negatively the hydrogeological protection of the slopes.

Social impact is related to the effects of REs production on society. Such effects may be both positive and negative. Positive consequences of increasing RE production are related to the fact that energy is produced locally, thus giving the possibility of generating income and increasing the number of workplaces. Nevertheless, it is well-known from the scientific literature that the development of REs may generate "green on green" conflicts between opposing groups of stakeholders. In particular, the NIMBY (Not In My Back Yard) phenomenon is particularly interesting (Van der Horst, 2007). The NIMBY effect appears when people are aware of the importance of a project, however they believe that such project may create negative conse-

quences locally and they dont want to realize it in their territory. Landfills are a very common example of a project affected by NIMBY opponents. Similarly, producing REs may be outraged by local communities, because of the perceived impact on the environment. For example, people may be against the construction of new hydropower plants because they are concerned with the quality of the rivers. Concerning district heating, a power plant fuelled with forest woodchips might be perceived as a source of polluting emissions. Within this framework, planning and communicating activities effectively is essential for the success of a REs project.
Eventually, economic impacts are related to the capability of generating new income and stimulating entrepreneurship (Grilli et al., 2015a). Given the cited effects of REs on the spheres of sustainability, it is clear that activities should be carefully planned, in order to maximize positive impacts as much as possible and minimize (or at least reduce) the drawbacks (Grilli et al., 2016d).

1.2.1 Planning the use of forest biomass

The use of forest biomass for energy purposes is an interesting case. Usually, forest contractor cut down trees in order to obtain income from timber (Röser et al., 2008). After stem delimbing and debarking, a relevant quantity of residual wood is abandoned in forest because it is considered a waste. The resulting dead wood left in forest is important for soil fertility and habitat for micro-organisms (Viana et al., 2010). However, such residuals might be used as woodchip to produce energy and there is a growing trend to collect and use forest biomass residues. This practice started in northern European countries (Röser et al., 2008) and it is gaining attention even in other places. The utilization of harvesting residuals is particularly interesting because they are considered to have no production costs, given that harvesting costs are all attributed to the main product, i.e. timber (Sacchelli et al., 2013a). For this reason, an efficient collection of residuals might represent a new source of income for forest workers with a relative small amount of additional cost, connected with transportation and collection. This possibility is even more interesting in southern Europe and in Italy in particular, because forests are under-utilized and in constant expansion (Marchetti and Blasi, 2010). The annual harvesting rate in Italy is less than a half of the annual increment, thus the negative impact of collecting residuals instead of leaving them in

forests as dead wood can be considered negligible. Moreover, another reason for the growing attention towards residuals is the enhancement of district heating power plants (DHP), fuelled with forest biomass. At present, the main source of fuel for those DHP is represented by sawmill waste, which is also the source of raw materials for other industries, including pallet and panels producers (Zambelli et al., 2012). Wood sources from sawmills are limited, thus increases in the demand may lead to future shortages. For this reason, increasing also the supply of such biomass is fundamental. In particular, to assure a sustainable use of biomass, an efficient planning of all the activities is of primary importance. First of all, an uncontrolled withdrawal of forest resources might lead to a depletion of the ecosystem quality, thus leading to unsustainable practices (Sacchelli et al., 2013b).
Secondly, DHP should be supplied by local biomass. If biomass is imported from distant areas, the benefit of using RE to contrast GHG emissions might be counterbalanced by transport pollution. At the same time, importing fuel increases transportation costs.
For the cited reason, many variables and expected effects have to be considered and decision support tools might be of extreme help for decision-makers, to carry out an effective planning.
In the recent years, computed-based Decision Support Systems (DSS) have gained attention, as important tools in many different areas (Sharda et al., 1988). A DSS is a system of procedures, able to consider and process a large amount of data and generate indicators for helping decision-makers. DSS are used in different types of organizations in management, planning and even operational activities. In many cases the spatial extent of the effects are important, thus DSS may be based on Geographical Information Systems (GIS). Given the ability of dealing with a large amount of inputs, DSS are helpful tools when planning RE development, in particular concerning forest biomass use for energy (Voivontas et al., 1998b). As already mentioned, an effective planning of biomass use should take into account several effects, including the impact of resource withdrawals on the environment, the social consequences of having new power plants in a destination, the economic feasibility of the project (Cai et al., 2009). For this reason, tools incorporating all these aspect in a holistic framework are helpful to obtain a clearer idea about opportunities and threats to forest biomass use.

1.2.2 Review of the literature and knowledge gaps

The scientific interest towards DSS for energy planning is quite recent, but the number of published papers on this subject is growing rapidly. Table 1.1 shows the most common topics addressed in the scientific literature, together with the tools and some references. Early works on DSS mainly focus on list of procedures for an efficient planning (Sharda et al., 1988). For example, (Voivontas et al., 1998a; Angelis-Dimakis et al., 2011) provide a collection of databases and procedures to estimate the energy potential from different renewable sources. Those authors suggest a top-down approach, through which the real energy potential is estimated starting from the theoretical potential and adding constraints to its full exploitation recursively. For example, concerning solar power, the theoretical potential refers to the entire solar irradiation on earth. The full irradiation cannot be completely harvested, because of losses due to present efficiency of technologies, land use and other limiting factors. Similarly, the theoretical upper limit of forest biomass exploitation is the total amount of wood in forest. However, a complete harvesting of all the avalaiable biomass in a single solution is inefficient, because it would imply the loss of the forest for future use. Forest management plans, when present, already incorporate this historically consolidated long term vision, at least under the wood production point of view. In order not to affect the wood stock of forests, no more than the annual increment should be harvested. In addition, there are several issues to consider, including technical limitations, sustainable good practices, legal constrains, opportunity cost of producing timber and other factors limiting the use of the forest resources for energy. Angelis-Dimakis et al Angelis-Dimakis et al. (2011), in particular, propose a scheme for the evaluation of energy potential, which is proposed in figure 1.1. The idea of describing declining levels of energy potential as additional constrains are added is interesting, because it is possible to create several scenarios to understand how the quantity of harvestable energy varies as different assumptions about limitations to energy withdrawals are included.

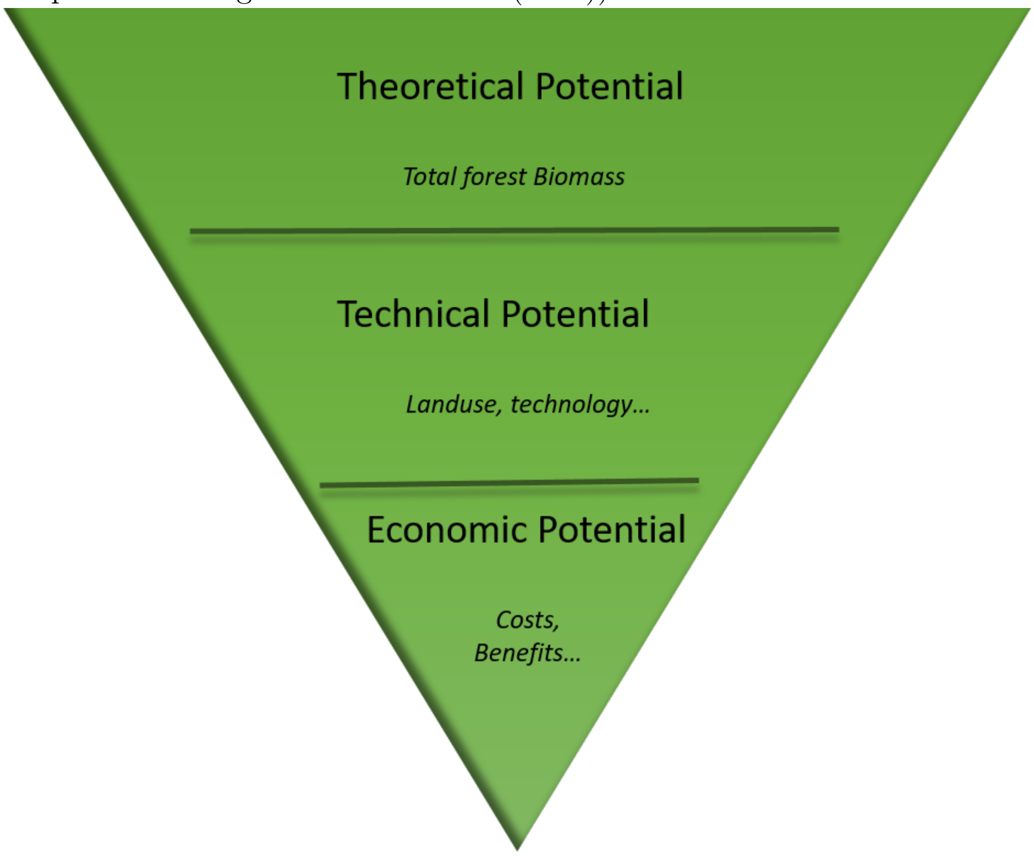
Another broadly discussed topic in the literature is the choice of the most viable alternative among a portfolio of REs options (Stein, 2013; Grilli et al., 2016b; de Oliveira et al., 2016; Portugal-Pereira and Lee, 2016; Wanderer and Herle, 2015). Multi-criteria (MCA) and Life cycle Assessment (LCA) are the most common techniques in alternative appraisal and such tools, although they cannot be considered DSS, take into account several relevant factors in

Table 1.1: Main topics and tools covered in the Literature

Topics	Tools	References
	Map Overlay	Angelis-Dimakis et al. (2011)
Energy potential	Statistical models	Voivontas (1998)
	Top-Down models	Sacchelli et al. (2013)
Choosing alternatives	MCA	Stein (2013)
	LCA	Wanderer and Herle (2015)
		Portugal-Pereira et al. (2016)
	MCA/AHP	Shabani and Sowlati (2016)
Planning and siting	Optimization tools	Gambino et al (2016)
	Linear programing	Zhang et al. (2015)
Economic Assessments	Direct calculations	Basso and Botter (2012)
	Cost functions	Aggidis et al. (2010)

order to identify the best solutions.
Concerning planning and siting power plants, most common tools are represented by MCA, and Analytical Hierarchy Process (AHP) in particular, optimizing procedures or linear programming applications (Radics et al., 2016; Gambino et al., 2016; Shabani and Sowlati, 2016; Sen et al., 2016). There are only few procedures, documented in the literature, attempting to consider all these aspects into a unique decision support tool. An interesting work was published by Frombo et al. Frombo et al. (2009), who introduced a GIS-based software (called "Biomass Management System") for the optimal planning of forest biomass use for energy. The software was created by means of Visual Basic and Lingo 8 software. Another interesting contribution dealing with DSS in forestry was published by Fiorese and Guariso Fiorese and Guariso (2010). The aim of the paper is to provide a procedure to maximize energy production from dedicated crops. However, this manuscript introduces a list of command and procedures and not a piece of software as in the case of Frombo et al. Zambelli et al. (2012) also provideed a DSS to explore the technical availability of forest biomass for energy purposes. In this case, the energy potential was estimated considering local biomass availability and technical limits, given by harvesting technologies (cable crane and harvester/forwarder technologies). ToSia (Lindner et al., 2010) is another

Figure 1.1: Scheme of the top-down approach to potential estimation (Source: Adapted from Angelis-Dimakis et al. (2011))



available tool, which is based on the concept of sustainability.
Differently from other contributions, authors of ToSia provide a set of indicators for the sustainability impact assessment of the Forest-Wood chains, including environmental, social and economic indicators. More recently, Sacchelli et al. (2013b) provided a free and open source software to estimate the energy potential of forests from a given area. The potential estimation is based on forest data obtained from forest management plan and allows including in the computation technical, environmental and economic constrains. More recently, the Brusa model was born as a result of the project Renerfor (Valente, 2014). The Brusa model requires users to enter the typology of power plant (district heating or electricity generation) and the desired location, returning as output the energetic potential of the local forests. However, this model is mainly designed for the use of the Piedmont region, in

Italy.
Despite the cited interesting models, there is something lacking in the literature that might be of interest for decision-makers, while planning the use of forest biomass. In particular, the knowledge gaps are:

- The energy potential of a given area depends not only on biomass volumes but also on the economic convenience for forest contractors to harvest the whole quantity of prescribed yield. Therefore, each forest management unit should be harvested only if expected income for forest contractors exceeds the costs of cutting;

- In many cases, decision-makers are interested in the value of forest ecosystems. An effective planning, should not negatively affect the total economic value of forests but rather assure the maintenance of natural capital stock. This is important in particular when the owner of a power plant is also the owner of forest where fuel comes from;

- Increasing the share of REs is usually a decision made not considering efficiency criteria but rather social needs, such as decreasing GHG emissions. For this reason, the social effects of increasing the use of forest biomass should be included, in terms of welfare change for the interested local population. In particular, this issue is crucial when the owner of a new power plant is a public administration deciding to invest public money;

- The increase in the share of REs, has been so far possible only by means of subsides. Without such subsides economic convenience of a new power plant is not always assured, because investment costs are usually high and the net revenue uncertain. For this reason, considering the expected economic output of a power plant is important as well;

- Designing DSS based on proprietary software do not facilitate the diffusion of such tools among practitioners.

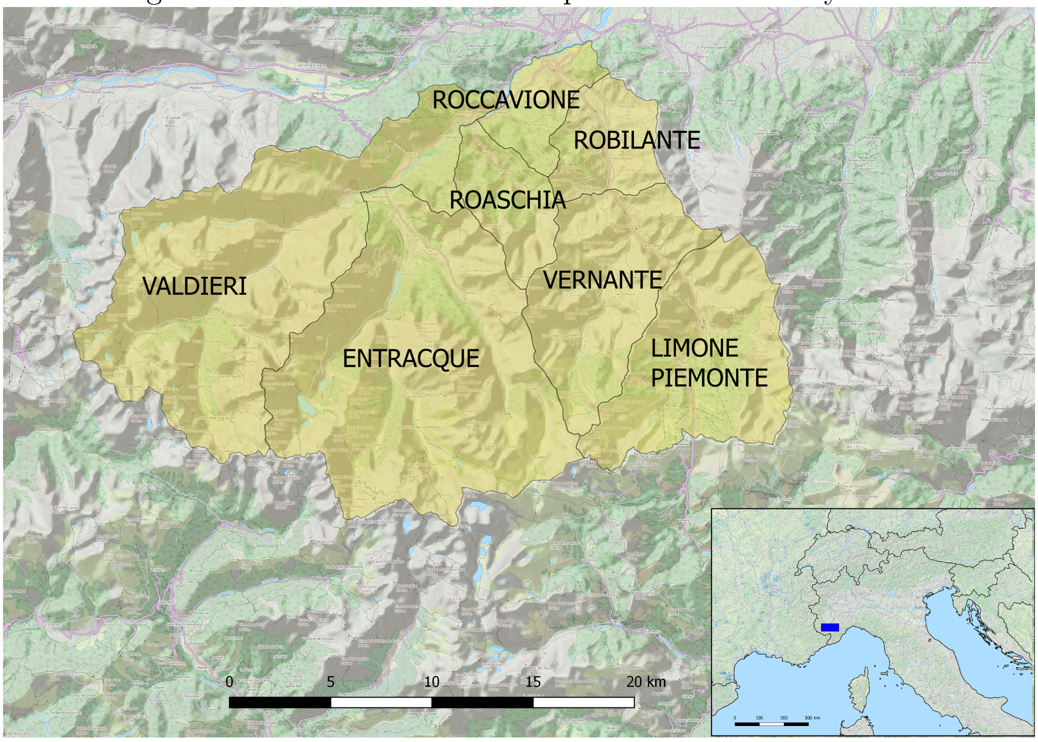
In the event of addressing these important issues, this thesis propose a methodology to correctly estimate the energy potential of a given area, effectively locate a new power plant fuelled with local forest biomass and run a cost-benefit analysis to foresee the expected economic convenience of such a project. In addition, given that an important aspect to assure the success of natural resource management is the involvement of local inhabitants in decision-making, the thesis suggests a simple methodology to identify the relevant group of stakeholders to involve in the process. The data computation is all implemented using open source environment, in particular GRASS GIS (Neteler and Mitasova, 2013) for the spatial analysis and R (R Core Team, 2013) for cost-benefit analysis and other econometric issues. In order to test the methodology, two alpine valleys in Italy were chosen as pilot areas. The GIS models and data collection was implemented in Gesso and Vermenagna vallys, in Piedmont region.

1.2.3 Description of the study area

Gesso-Vermenagna valleys are located in the north-western part of Italy (Piedmont Region), close to the Italian-French border. The study area includes seven municipalities. The Gesso valley is composed by the municipalities of Valdieri, Entracque, Roaschia and Roccavione. Vermenagna valley is instead constituted by the municipalities of Limone Piemonte, Robilante and Vernante (figure 1.2). According to official registers, the total population of the area is 10.000 inhabitants, but in practice the number of people permanently living in the territory is considerably smaller. In fact, like in many other mountain places, the valleys have faced an intense migration process, starting from the fifties. Piedmont region is an important industrial area for northern Italy, for this reason after the Second World War many inhabitants from remote areas moved to cities, looking for better employment. In particular, the relatively close city of Turin represents an important basin of employment in the industrial sector.

Gesso-Vermenagna valley is a mountainous area mainly based on the primary sector (about 22 % of total firms), while the secondary sector (industry) is poorly developed. The service sector is based on tourism with an average of 121 000 visitors per year. In particular, Limone Piemonte is an important destination for winter tourism. The land area is approximately 51500 ha, out of which about 32 000 ha are located in protected areas, included in the Maritime Alps Natural Park and Nature 2000 sites. The park is an interesting protected area, constituted in 1995 because of the presence of several threatened and endangered species. In particular, it is possible to find six different ungulates, such as chamois (*Rupicapra rupicapra*), wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), alpine ibex (*Capra ibex*), mouflons

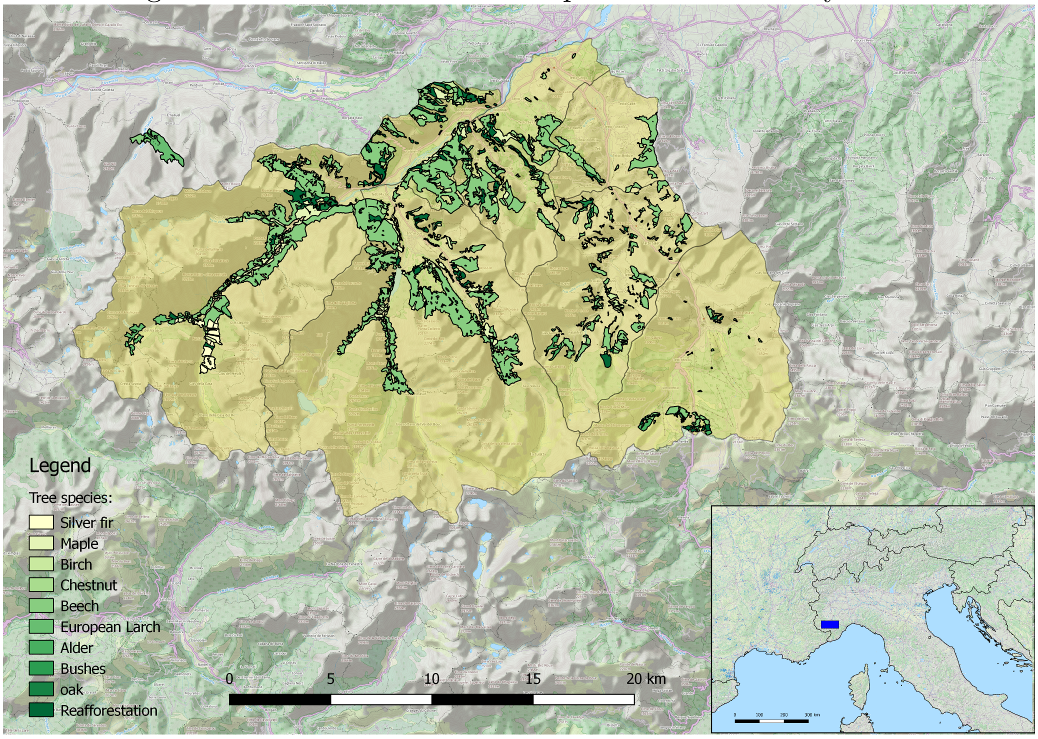
Figure 1.2: Location and Municipalities of the Study Area



(*Ovis musimon*) and the recently reintroduced red deer (*Cervus elaphus*). In addition, the area was interested by a natural coming back of the wolf (*Canis lupus italicus*), disappeared at the end of the nineteenth century. At present, a viable population of about 25 specimen lives in the area. Together with mammals, many important bird species inhabit the park, as well as reptiles and arboreal species. The species richness, together with legal restrictions to human activities provided by the protection regime, suggest that all the actions affecting the area should be carefully planned, in order not to deplete the habitat quality.

The main land uses are forests (42 %) and pastures (33 %). Figure 1.3 shown forest extension and the tree species composition. The main forest types are European beech forests (*Fagus sylvatica*) with 11 500 ha, chestnut forests (*Castanea sativa*) with 2 700 ha, and mixed forests (maple, linden and ash) with 1 850 ha. The average standing stock is 183 m3ha-1, with an average annual increment of 7.73 m3ha-1year-1. An interesting feature of such forests is the large diffusion of coppice management, which is unusual in Italy and in the area accounts for almost 50%. In fact, coppice provides timber of lower

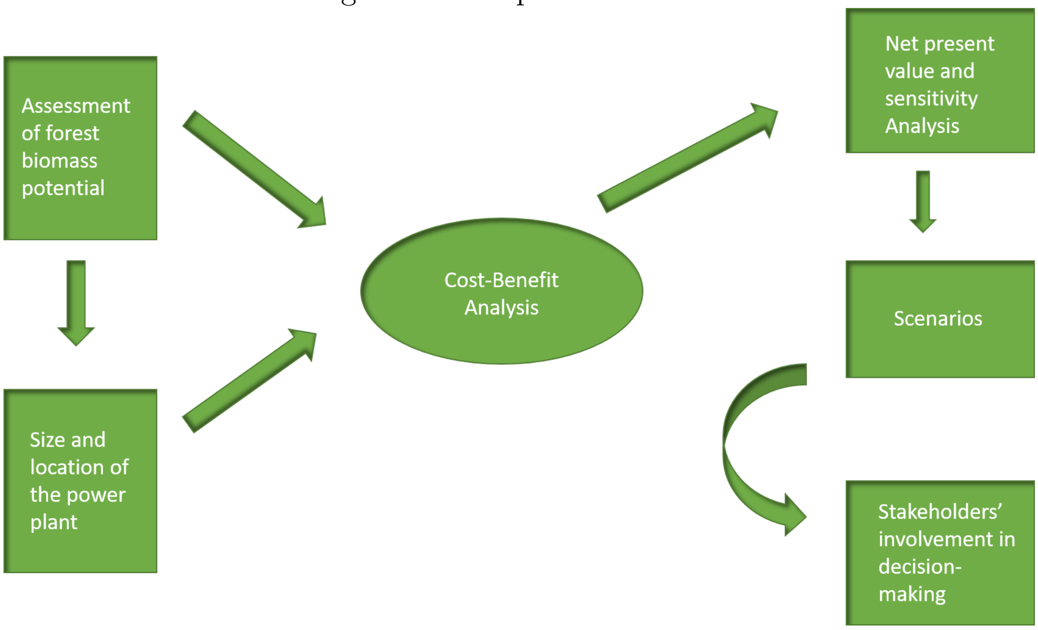
Figure 1.3: Location and Municipalities of the Study Area



quality compared to high stands and it is thus least preferred as management solution by forest managers and owners (Ciancio et al., 2006). Wood collected from coppice-managed trees is usually employed as woodchip for energy purposes.

Concerning energy, the Gesso valley hosts the biggest Italian hydropower plant, with an installed capacity of 1.3 GW, together with other smaller plants all around the valley, which were constructed before the birth of the Maritime Alps park. At present, it is very difficult to build new hydropower plants, because of both legal restrictions and opposition of local inhabitants. In order to compensate peaks of electricity demand, electric energy is seldom imported from the neighboring France, which is the supplier of low-cost nuclear energy. Other sources of energy are not developed and forest wood is used for energy only for domestic uses. For this reason, increasing the share of forest biomass may represent a good solution for heating purposes. With regards to individual energy consumption, the thermal energy demand of the households is around 15 MWh/year per household.

Figure 1.4: Steps of the thesis



1.3 Outline of the Thesis

This Doctoral project was thought to address the several issues that decision-makers have to face, when planning the use of forest biomass. In particular, the project has the objective to provide a DSS tool for planning a sustainable use of forest biomass to produce energy. The main purposes are the following:

- Estimate the energy potential from forest biomass in a given area;
- Identify an effective location of a power plant in the area, based on local energy demand, locally available biomass potential and efficiency of the district heating network;
- Assessing the economic feasibility of such a project by means of a Cost-Benefit Analyis (CBA);
- Understand how the Net Present Value varies when the expected investor is a private of a public economic actor.

The procedure is summarized in figure 1.4 and starts with the identification of the energy potential of the area. The information retrieved from this initial phase is the quantity of available biomass that can be reasonably

extracted and the maximum quantity of energy that can be produced. These two pieces of information serve as input to hypothesize a reasonable size of the power plant, which should be fuelled with local biomass. The position within the study area is then set based on the optimization of the district heating network. Once the site and size of the plant is determined, a CBA is carried out to assess the economic feasibility of the project, considering financial, social and environmental variables in the computation of the net present value. CBA is computed for four different scenarios, each of which assumes a potential investor and different objectives. Scenarios will be presented in chapter six. Given the high variability of CBA inputs, the stability of net present value is tested by means of a stochastic sensitivity analysis.
This Doctoral project was born in the framework of recharge.green (Svadlenak-Gomez et al., 2013), a three-year European project funded by the Alpine space program. The project brought together 16 partners from all over the Alps, with the aim of identifying planning strategies and tools for balancing RE production and ecosystem services provision. Eurac Research, from Bolzano (Italy), was one of the partners and funded the PhD scholarship, while the University of Trento joined the project as a subcontractor for some of the activities. The project involved analyses on four different energy sources: solar photovoltaic, wind power, hydro power and forest biomass for energy. The main focus of investigation was identifying trade-offs between energy production and ecosystem services. Study areas were identified by some of the partners, which contributed to provide local data for computations. Specifically, the following study area were identified: Gesso and Vermenagna valleys in Piedmont region (Italy), Mis and Maé valleys in Veneto (Italy), Leiblachtal valley in Tirol (Austria), Triglav National Park (Slovenia) and the Parc Natural Regional du Vercors in the Rhône-Alpes region (France). Additional details about the project, scientific reports and publications may be found at `http://www.recharge-green.eu/`. Recharge.green project endend in Juny 2015, however it was an important starting point to get confidence with the topic of REs production and collected data (in particular for GIS analyses). At the same time, meetings and discussions with other partners were useful to identify open questions and gap to fill with the present work.
This thesis is organized in chapters. Each chapter introduces at first the theoretical background of the topic and then describes the empirical applications to the study area. Chapter two introduces the module to identify energy potential and location of the power plant. Chapter three presents the calculus

of financial costs and benefits included in the CBA, which were estimated by means of a review of available reports of case studies. Chapter four presents the theory of non-market valuation, necessary to include non-market effects of the plant; in this phase a contingent valuation carried out in the study area is also presented. Chapter five is focused on natural capital. The concept of Total Economic Value and some techniques for its estimation are presented and, subsequently, applied to the case study. Finally, the conclusion section summarizes the results, describes the strengths and weaknesses of the thesis and provides some suggestion for future improvements.

Chapter 2

Sizing a district heating power plant

2.1 Introduction

An efficient planning of new power plants requires a detailed organization of many aspects. There are several important issues that need to be addressed, in particular for what concerns the size, in terms of installed power, and the location within a certain area (Marinova et al., 2008).
The main reason to install district heating power plants (DHP) is the possibility to accomplish heating needs of inhabitants in a safer manner, compared to the traditional boiler inside the building (Madlener, 2007). Moreover, the possibility to use REs, such as geothermal energy or bioenergy, allows reducing GHG emissions. Another important advantage of DHPs is the possibility to better control exhaust gases compared to single boilers, because they are concentrated in a unique power plant (Rentizelas et al., 2009). However, there are also drawbacks that should be considered, mainly related to the economic convenience of the investment. In addition to usually long payback periods (caused by the large amount of investment costs), another critical factor is related to the level of thermal energy demand. In fact, evidences seem to indicate that a DHP is convenient only in heavily populated areas, because it requires a high number of users (Kumar et al., 2003). There are also non-strictly economic negative aspects of district heating, connected with energy efficiency. In fact, it has been shown that energy dispersion in the secondary network (inside the building of final users) is higher than traditional system (Rezaie and Rosen, 2012; Aringhieri and Malucelli, 2003), because DHPs are always in function while in the second case thermal energy is produced locally only when it is necessary. Specifically concerning solid biomass, another important issue is the provision of fuel for the plant. Sometimes, the DHP is not calibrated to run efficiently with local resources and biomass has to be imported from distant areas, bringing negative economic and environmental consequences. In economic terms, importing biomass increases costs for fuel provision. For what concerns the environment, transports represent one of the main drivers of air pollution worldwide. From the cited reason, it is clear that DHPs should be carefully planned, in order to tackle the described issues and minimizing the negative aspects.
Despite the possibility to retrieve many contribution dealing with the estimation of energy potential (Sacchelli et al., 2013b,a; Zambelli et al., 2012; Frombo et al., 2009; Fiorese and Guariso, 2010), the scientific literature about power plant location is quite poor. An interesting contribution in this field

is provided by Vallios et al. (2009), which propose to consider population density as important factor affecting siting. Leduc et al. (2010) propose an optimization model to explore a good position for the power plant, however they focus on the choice among municipalities, rather than identifying the proper position of the plant within a certain urban area. Some contributions are conversely focused on designing the DHP network (Yildirim et al., 2010) or improving planning of its capacity (Tol and Svendsen, 2012). To the best of our knowledge, there are no studies combining energy potential and reasonable power plant size and location.
Starting from these premises, the present work introduces a novel methodology to efficiently plan a DHP for a certain area. The first step concerns the estimation of the energy potential, from which it is possible to assess a reasonable capacity of the plant, in terms of installed power, based on the local availability of woodchip. In this way, it is possible to produce energy from local resources, without being in need of importing fuel. Secondly, using data about current energy consumption, buildings with higher energy demand are identified and linked through the heating network. Lastly, the procedure allows identifying a reasonable location for the power plant, based on available warehouses in the industrial zone of the town.
The procedure is all carried out using GRASS GIS, which is a free and open source GIS software, in order to facilitate the diffusion for future uses.

2.2 Methodology

This contribution describes a methodology to help decision-makers in the challenge of efficiently planning a new DHP in a given area. In particular, three main objectives are taken into consideration:

- The local energy potential in terms of forest biomass;
- The local energy demand;
- The installed power of the DHP;
- The location of the DHP inside the desired area.

Estimating the local energy potential is fundamental, because it indicates how much energy can be produced locally. Similarly, it is important to assess how big the DHP should be, in order not to over-estimate the size and increase the level of investment costs. Finally, a DHP should be placed close to where energy is consumed, therefore identifying a "good" location is also relevant. Costs sustained to construct the heating grid network are very high, thus positioning the plant close to the supplied buildings allows reducing the length of the network.

2.2.1 Energy potential

The estimation of forest biomass energy potential considers residuals obtained from wood craft, which can be burned as woodchip. Wood residuals include tops and branches, needles and bark. It is important to notice that, at present, one of the main source of biomass for energy is represented by sawmills residuals. This study does not consider such biomass, assuming that this resource is already exploited in other ways and therefore not sufficient for a new DHP. This simplification is necessary because data on sawmill residuals is not available, although it is acknowledged that it is not likely to hold in all real applications. Bioenergy mass appraisal was conducted modifying an existing software, called Biomassfor (Zambelli et al., 2012; Sacchelli et al., 2013b). The first version of Biomassfor was created by the University of Trento, then it was further developed, with the collaboration of Eurac research, during the Alpine Space project recharge.green (Svadlenak-Gomez et al., 2013). At present, Biomassfor was embedded in a larger set of tools for REs analysis, called **r.green**, within which the name has been switched to **r.green.biomassfor**. r.green energy potential from different sources of REs, namely solar photovoltaic, wind power and hydropower in addition to forest biomass. The new modular structure is presented in figure 2.1, which is aligned for each source of energy. A short description of the main features of r.green.biomassfor is provided in the next section, together with the data that are necessary to use it, while an in-depth explanation of the tool may be found in Garegnani et al. (2015) and the other above-mentioned papers. The spatially-explicit file processing is raster-based, this meaning that input shapefiles are converted into rasters before being included in the computations.

2.2.1.1 r.green.biomassfor

r.green.biomassfor (from now on only Biomassfor) is an Add-on for GRASS GIS, allowing the estimation of forest bioenergy potential, by means of several sub-models (Sacchelli et al., 2013b). Each sub-model calculates a different potential, following a scheme similar to Angelis-Dimakis et al. (2011). There are four modules: Theoretical, Planning, technical and Financial, each calculating the energy potential of a given area by including constrains to the full exploitation of existing wood. Table 2.1 lists the mandatory and optional data necessary to run Biomasfor, as well as a short description and the GIS file type. The output of each module is a raster map, in which each pixel is associated with a certain quantity of producible energy in MWh. In addition, the tool allows computing the quantity of forest biomass in tonnes, which is a useful information for estimating the biomass need of the DHP.

Theoretical Bioenergy The first module calculates the theoretical potential, corresponding to the amount of energy that can be produced from the harvesting of the entire annual increment. There are different assumptions based on forest management and treatment. In coppice-managed forests, the quantity of bioenergy is derived assuming that the entire tree is used for energy. In high stand forests, available bioenergy varies on the basis of the treatment. In the presence of thinning interventions, bioenergy is again calculated considering the whole tree. Conversely, bioenergy derived from final fellings is expressed as a percentage of the cormometric volume (Spinelli and Maganotti, 2007).

Planning Bioenergy Theoretical bioenergy cannot be fully harvested, because it is assumed that there are constrains related to the existing technology. Some parts of the forest cannot be reached with machineries, so the total harvestable energy is lower. Biomassfor considers two harvesting techniques: cable crane and ground-based extraction system. The main constrains included in Biomassfor are related to terrain roughness, distance from the wood collection site and slopes. It is possible to include other optional layers to improve the analysis, for example a file containing lakes and rivers that can alter harvesting decisions in forest.
In addition, the withdrawal of natural resources from forests creates an environmental impact to be taken into account. Biomassfor includes the pos-

Table 2.1: Necessary Data for Biomassfor (source: Sacchelli et al. 2013)

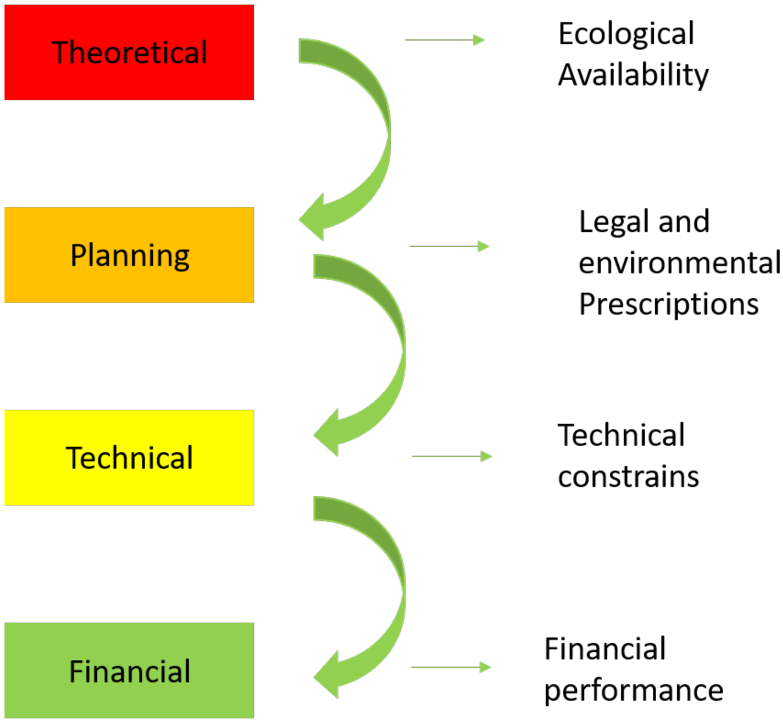
File	Mandatory	Description	Type
DTM	x	Digital Terrain model	ASCII GRID
Roads	x	Main road network	Shapefile
Forest Roads	x	forest road network	Shapefile
Total yield	x	Total yield per year	Shapefile
Yield per type	x	yeald per forest type per year	Shapefile
Management	x	1 = high forest 2 = coppice	Shapefile
Treatment		1 = final felling 2 = thinning	Shapefile
DHP	x	Place were woodchip is collected	Shapefile
Landing sites		Localization of landing sites	Shapefile
Compartments		boundary of compartments	Shapefile
Roughness		classification of terrain roughness	Shapefile
Lakes		Lake features	Shapefile
Rivers		River features	Shapefile
Tree diameters		Average diameters	Shapefile
Tree volumes		Average single tree volume	Shapefile
Boundary		Boundary of the interested area	Shapefile
Energy Demand		Annual bioenergy demand	Shapefile
Soil productivity		Categories of soil fertility	Shapefile
Soil texture		Categories of soil texture	Shapefile
Soil depth		Categories of soil depth	Shapefile
soil compaction risk		Soil compaction risk categories	Shapefile
Fire risk index		fire risk index	Shapefile
Protected Areas		Boundaries of local protected areas	Shapefile
Touristic Value		Suitability of the area for recreation	Shapefile

sibility to explore positive and negative effects of biomass use on the forest environment, by means of additional optional layers. In this thesis the effect on forest ecosystem is estimated in economic terms and will be described in chapter 5, so this module is not described in detail.

Financial Bioenergy This module provides insight on the economic convenience of forest activities. the basic idea is that a forest contractor is willing to reach a certain forest management unit only if harvesting net revenues are expected to be higher than the costs. Revenues considers earnings derived from the sell of both timber and woodchip of each management unit:

$$R_i = \sum_{a=1}^{n} (Y_i \times P_{a,i} \times p_a) \tag{2.1}$$

Figure 2.1: Modules of r.green (Source: Adapted from (Garegnani et al., 2015))



Where n is the total number of tree species in pixel i, $P_{a,i}$ and p_a is the percentage and the market price of $a-th$ tree species, respectively. Harvesting costs are estimated considering hourly costs for machineries, workers and productivity. For each harvesting process, costs are derived in the following manner:

$$C_{P,v,i} = \frac{k_{h,v,i}}{p_{v,i}} * Y_i \tag{2.2}$$

where $k_{h,v,i}$ is the hourly cost for the $v-th$ activity in the $i-th$ forest pixel; $p_{v,i}$ is the hourly productivity for the $v-th$ process in $i-th$ pixel; Y_i represents the yield in each pixel. Once benefits and costs are estimated, the decision rule for a forest contractor is to harvest a certain pixel if the difference between benefits and costs is positive.

2.2.2 Capacity, Location and network of the district heating power plant

When information about energy potential is available, it is possible to hypothesize the size and the location of the power plant.

Capacity. The capacity of the power plant is tailored on the basis of the local available forest biomass. The underlying idea is that the plant should be as big as possible in order to supply a large number of users, benefitting from economy of scale. At the same time, the plant should not be too big, because it might generate inefficiencies. DHP bigger than necessary have higher investment costs, which enlarge payback periods and jeopardize the economic convenience. Moreover, if the local biomass is not enough to fuel the DHP, woodchip has to be imported, thus increasing costs and pollution connected with transport. The total producible energy from biomass E_B is given by:

$$E_b = Q_b \times c_b \times H_{dhp} \times \eta_{DHP} \tag{2.3}$$

Where Q_b is the quantity of biomass, c_b the energetic content of wood, H_{dhp} the annual number of functioning hours and η_{DHP} the DHP efficiency. Information about producible energy is retrieved from r.green and enters this module as input for assessing the size of the DHP. Subsequently, the installed power of the DHP can be derived from 2.3 in this way:

$$P_{dhp} = \frac{E_b}{H_{dhp}} \times (1 + o_{dhp}) \tag{2.4}$$

Where o_{dhp} represents an oversize factor for the plant. The oversize factor accounts for possible future increase in the demand, which may happen because of an increase in the current level of thermal energy demand or connections of additional users. For this reason, the plant is usually planned to be slightly bigger than necessary, even thought he thermal productivity would be less efficient.

Location and Network. In order to hypothesize a proper location for the plant, it is important to understand what is the portion of village, town or city that might be connected to the plant. Buildings are linked to the

DHP by means of a heating grid network, which allows heat produced by the plant to circulate and reach the buildings. Such network is very expensive and represents barely 50% of the total investment cost of the DHP (Curti et al., 2000). For this reason, it has been shown that DHP is, at present, convenient only in densely populated neighbourhoods, because they can be supplied with shorter networks compared to low-density and scattered areas. However, a DHP in a densely populated area may also create problems, connected with traffic and logistics; for this reason, assuming the industrial area as a reasonable location may reduce such drawbacks. Considerations about density of energy demand can be included by means of data on energy consumption per building.

The procedure to identify priority areas, to be supplied with the DHP, starts from the identification of the building with the highest energy consumption. This building is the first to be included in the network, because of its high demand. From this building, the network is created by connecting other buildings; among all candidates, buildings are added by an algorithm that aims at maximizing the following condition:

$$L_n = max \quad \frac{D_{cons}}{L_n}, \quad s.t.: \; Max \quad L_n \quad \cup \quad max \quad E_b \tag{2.5}$$

Where L_n is the $n-th$ building linked to the network, D_{cons} is the consumption density of the building and L_n the length of the network segment necessary to link the building to the rest of the network. The constraints refer to a maximum length of the network and the maximum producible energy. The idea is that the length of the network connecting buildings should not be too long, because it is very expensive and very long networks might affect the economic performance of the DHP. At the same time, the sum of expected energy consumption of connected buildings must not exceed the potential energy obtainable from local forests. Within these limits, the GRASS module calculates all the potential ties among buildings. For each tie, energy consumption and distance between buildings are calculated. Then, among all possible ties, the module includes only connections with the highest ratios. In this way, it is possible to identify interesting buildings, because they have a relevant quantity of expected consumption compared to the necessary additional length of network to be created.

At present, a limitation of this approach is that buildings are linked from edge to edge, thus the total length of the network is given by the sum of these

Table 2.2: Parameters used to assess the energy potential and DHP functioning

Parameter	Description	Value
Efficiency	Efficiency in producing energy	0.8
Oversize	Oversize of the plant	0.3
Hours	Yearly hours of functioning	8000
Network	Maximum network length	20 km
Energy content	Wood energy content	4 kwh / kg

segments. This is a simplification, because the network actually crosses the building, so the total length provided by this approach is underestimated. This negative aspect influences significantly the analysis, in particular for what concerns the estimation of costs for network creation. As it will be shown in the next chapter, at present costs for grid creation are embedded in the investment costs. In this way, the resulting financial analysis is not biased by the network length. However, a future improvement of this procedure might be a better specification of the network, so that these costs may be separated from other investments and the results' quality improved.

2.3 Results

Geographical data for our analyses were all provided by the Natural Park of Alpi Marittime. In particular, we were able to retrieve all the mandatory data and some optional data, namely terrain roughness, lake and rivers, boundaries of the protected areas, boundaries of the study area and forest treatment. Data include all mandatory layes and, among optionals, forest treatment, boundary of the study area, lakes, rivers and boundaries of the protected area (the Natural Park of Alpi Marittime). Concerning parameters of DHP functioning and energy potential assessment, table 2.2 summarized the values included in the analyses. The estimation of bioenergy potential requires additional parameters to be included, however Biomasfor provides default values, which were replicated by r.green, that were used for this application.

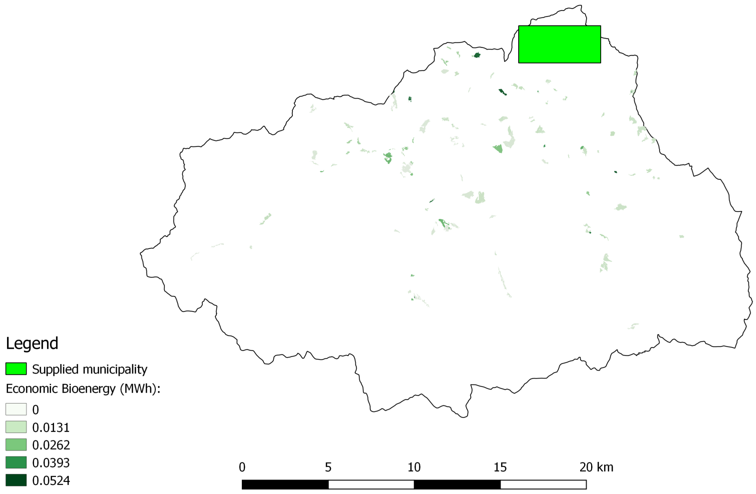
Table 2.3: Total available energy estimated with r.green modules

Module	Biomass (tons)	Energy (MWh)	%
Theoretical	10125.5	40502	100
Legal	7748	30992	76.5
Technical	6311.5	25246	62.3
Economic	3215.5	12862	31.7

Energy Potential The total energy potential of the two valleys, estimated with different modules of r.green, is shown in table 2.3. It can be seen that the theoretical potential is larger than 40,000 MWh per year, which is very close to the total thermal energy demand (around 49,000 MWh). Such quantity declines down to roughly 31,000 in the legal module, which considers prescribed yield insted of annual increment as quantity to be harvested. technical constrains limit the extraction in some areas, thus the potential, considering only accessible pixels declines to 25,000 MWh. Finally, the economic potential is even lower and represents only the 31.7 % of the theoretical availability.

Further analyses are conducted considering that, among the several modules, the economic bioenergy is the quantity more likely to be extracted. This choice was lead by the assumption that forest contractors are only willing to harvest wood in forest parcels where the expected income exceeds the cost of cutting. Thus, it is assumed that the potential derived with the economic module is the closest to reality. The spatial extent of biomass availability is shown in figure 2.2, in which dark green pixels are associated to a bigger availability of energy potential. Harvestable bioenergy is concentrated in the municipalities of Entracque, Robilante and Vernante. In particular, most interesting portions of forests falls outside the Maritime Alps parks, because the protection regime constrains forest harvesting activities inside the park. Assuming a moisture content of wood of 40%, which is the current content in commercial woodchip (Sacchelli et al., 2013b), leads to roughly 3200 tons of biomass annually harvestable. The energetic content of biomass is assumed to be, on average, 4 kwh per kg of woodchip. This might be considered a good approximation of energy content for trees of the entire forested area, because usable energy is mainly affected by moisture content, while differences among tree species are less important. The estimated producible energy, from the local biomass, is assessed to be 12862 MWh, representing 25.8% of the total thermal energy demand of the two valleys. The potential is un-

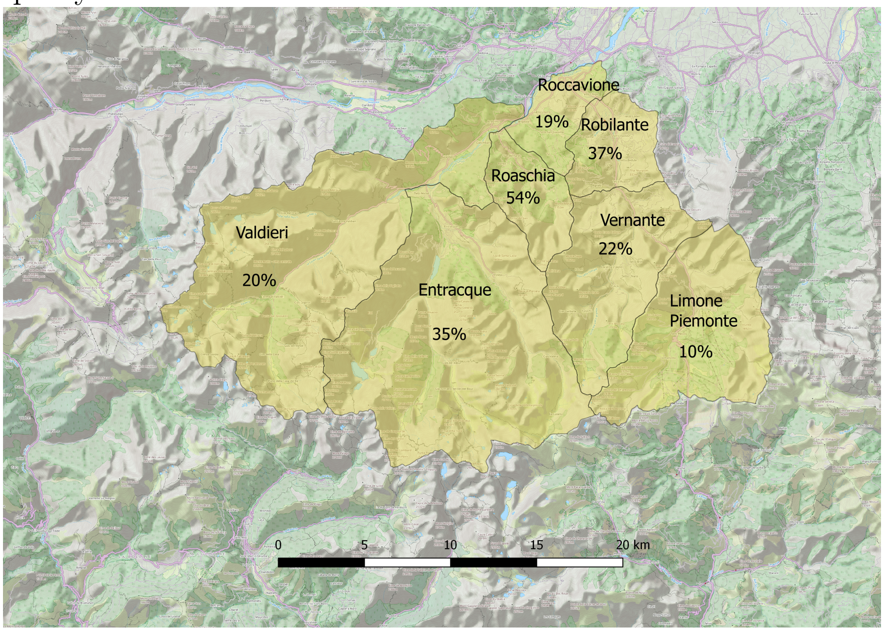
Figure 2.2: Availability of forest bioenergy in Gesso and Vermenagna valleys



evenly distributed across municipalities. In particular, Roaschia has a very small population and, despite the small extention of forests falling inside its boundaries, it may cover 54% of its energy needs from local woodchip. On the opposite side, Limone Piemonte is the municipality with the lowest capability to fulfil the local thermal demand with bioenergy (around 10%). The hypothetical coverage of energy demand in the other munipalities roughly ranges between 20% and 40% of the local heating demand, as shown in 2.3.

The District Heating Plant The most interesting area to supply wih a new DHP fuelled with bioenergy is represented by the green rectangle in figure 2.2. In particular, Roccavione was assessed to be the municipality with the most interesting building structure to settle the power plant. According to the results of potential estimation, and considering an oversize factor of 30%, a reasonable installed power of the plant would be 1.6 MW. Figure 2.4 shows th most interesting area to be supplied, green-colored, in terms of expected heating energy demand and length of network. The light blue building is the position of the plant, representing the closest warehouse of the industrial area. These results were obtained considering as input variables a maximum length for the network of 20 km and a maximum amount of thermal energy demand of 12,000 MWh per year, which is slightly lower than

Figure 2.3: Coverage of heating demand with local biomass, subdivided by municipality

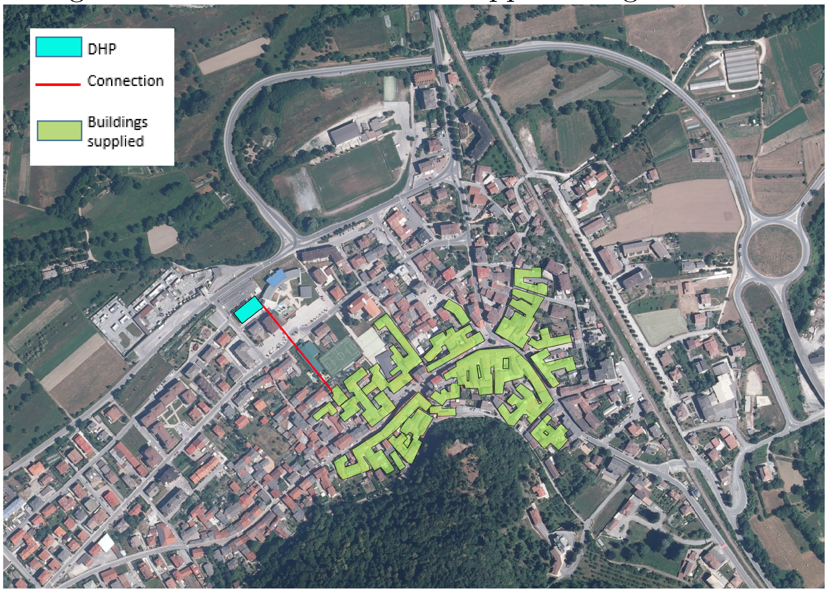


the amount of energy producible with the local biomass. The choice of using an amount of thermal energy demand lower than the total producible energy allows a cautionary estimate of potential users and connected buildings. In fact, the actual producible energy might be lower because of unexpected circumstances, such as average moisture content higher than 40%, damages to wood and other unexpected external events.

2.4 Discussion

The application of the proposed methodology provided interesting insights for what concerns future development of bioenergy in the study area. In terms of energy potential, the procedure was able to assess the quantity of producible energy from local forests. This is an interesting information for forest managers, because they can obtain reasonable figures to understand how worth are local forests in energy terms. In addition, estimating energy potential with this procedure implies assessing also the quantity of harvestable timber, because biofuel is a percentage of timber prescribed yield. Thus decision-makers might have not only information about the importance

Figure 2.4: DHP location and supplied neighbourhood



of forests for energy but also for timber (Sacchelli et al., 2013a). Finally, investigating the spatial extent of forest activities by means of GIS techniques, allows an understanding of what are the most interesting forest management units while planning interventions in forests (Bernetti, 2009). In particular, it is possible to assess what are the portions of forests easily accessible for their morphological conformation and the most convenient from the economic point of view.

Turning the attention to the DHP, the proposed model identified an optimal location of the plant in the industrial area and a neighbourhood to be supplied. In this way, decision makers are equipped with an informing tool in the planning phase, so that priorities might be easily identified and eventually addressed. Of course, a deeper knowledge of the local situation allows refining results. For example, in this study it is not considered whether other DHP are already in place or if buildings connected to the network already have other sources for their heating needs. With such information, already supplied buildings may be excluded in advance from the analysis. Of course, such considerations are only feasible with a very deep knowledge of the local situation, which local decision-makers might have.

The quantity of harvestable bioenergy, assessed to be 3200 tons per year, seems to be rather low if compared to the extension of the area (Spinelli and

Maganotti, 2007). However, it has to be highlighted that an important limitation to the full exploitation of forests is represented by the presence of a vast portion of protected area. Forests falling inside a protection regime are supposed to be exploited with a lower intensity (Hayes, 2006; Balmford et al., 2002; Dixon and Sherman, 1991). In addition to this particular feature of the study area, it has to be highlighted that estimating the potential requires a very high level of data quality. In particular, forest data should include a detailed description of annual increment, prescribed yield and tree volumes. Such data are not easily available and, in the Gesso and Vermenagna valleys, they were accessible only in the part of forest subject to inventory, which does not correspond to the entire extension of local forests. In particular, in private-owned forests data are of a lower quality, and in some cases unavailable, because there is no obligation to deliver results of forest management activities to public administrations. This situation is very common in Italy, as well as in some other European countries. However, approximation of data might be a very common feature for many forests, thus decision-makers have to deal with uncertainty and lack of data in real planning of bio-energy development. For these reasons, the provided procedure is interesting for an ex-ante exploration of the potential of local forests for energy purposes.

2.5 Conclusion

This chapter introduced the methodology for estimating energy potential, location and size of a power plant, fuelled with woodchip obtained from local forests. Based on the provided results, it was shown that a power plant of 1.6 MW of installed power might be adequate for an efficient use of local biomass. It was also highlighted that such estimation might be considered a lower bound estimation, because forest data were not available in some private-owned forests, which may represent an additional pool of woodchip. This tool is useful while planning the development of forest bioenergy, because it returns data that can be used in the exploratory phase of energy planning.

The positive aspects of this approach are the possibility of processing a large amount of data simultaneously, allowing the possibility to include considerations about ecological availability of biomass, technical and legal constrains to extraction, economic aspects of forest activities. In addition, being developed in a free and open source environment facilitates the use and diffusion

of this tool.
As already stressed, the main drawback is connected to data availability. Another limitation that is worth to mention is connected with the calculation of network length, necessary to connected buildings to the DHP. At present, the computation is made by linking buildings from edge to edge, while it is not considered that the network has to phisically cross the building. Thus, network length is underestimated. Given that it has been shown that investment costs to create the network are high (up to 50% of the total investment costs), a precise estimation might be of interest for economic assessments. As it will be shown in the next chapter, this limitation do not bias the present economic analyses, because costs for network creation are embedded in the probabilistic cost function. However, a more realistic identification of the network might be of interest for decision-makers and may represent an issue for a further development of this methodology.

Chapter 3

Financial Analysis

3.1 Introduction

Uncertainty about the economic performance of energy exploitation is a common feature characterizing many REs sources (Menanteau et al., 2003). For this reason, one of the most challenging part, when analysing the possibility to develop district heating from forest biomass, is to provide a reliable estimation of the economic convenience of such a project. The energy sector in general, and district heating plants (DHP) in particular, is highly capital intensive (Kelly and Pollitt, 2010). DHPs are characterized by long payback times and high investment costs (Başoğul and Keçebaş, 2011). Conversely, operating and management costs are on average low. This characteristic implies that the largest share of monetary costs will be sustained at the beginning of the investment period. Investment cost represents an important entry barrier for those who explores the possibility to invest in this field. The choice of constructing a new DHP is therefore case-specific and should be decided after effective and in-depth exploratory studies.

In the literature about energy costs and incomes, a large share of papers deals with the hydropower sector. For example, a first attempt to derive an empirical formula for hydro power plants was carried out by Gordon and Penman in 1979 (Gordon and Penman, 1979), which was later ameliorated by Gordon (Gordon, 1981) and Gordon and Noel (Gordon and Noel, 1986). More recently, Aggidis et al. (2010) studied the costs of small scale hydro power in the UK. The interest towards hydropower financial performance is given mainly by the high variability of expected cost on the basis of geographical and morphological characteristics of the location, which may alter significantly the figures foreseen in ex-ante studies. Whether conditions also play a role, because it affects water availability. Very popular are also papers using Multi-Criteria Analysis to evaluate the convenience of producing energy from different alternative sources. In these contributions, production costs are usually one of the criteria that are compared (Grilli et al., 2016b). The literature is poorer if considering the financial performance of district heating, in particular using forest bioenergy as fuel. Some studies deal with the role of thermal energy in minimizing production costs (Badescu, 2007). Concerning electricity, some studies focus on the relationship between optimal capacity of the plant and the fluctuation of prices (Gabaix et al., 2003). Other authors focus on comparing alternative processing options, or on performances of power plants fuelled with different sources of biomass (Fahlén

and Ahlgren, 2009). To the best of my knowledge, there are rarely previously published papers that attempted to derive a general framework to evaluate the entire financial performance of a DHP fuelled with residuals of forest activities, in particular in the European area.
In the present chapter, an analysis of financial costs and benefits of producing thermal heating through forest biomass is carried out. The main objective is to provide a general framework to evaluate expected financial flows when planning the construction of a new DHP. For this purpose, a sample of Italian existing power plant has been collected and their economic performance investigated. Based on the gathered information, a linear probability model was created in order to predict investment costs, based on the installed power of the DHP and the possibility to make cogeneration of electricity. Concerning operating and management costs, other functions were created to account for the expected woodchip, the number of workers and other costs necessary to run the DHP. On the other hand, income were estimated based on the expected income from the sell of thermal and (if present) electric energy. Such an analysis will be useful to obtain a general overview of the sector, its attractiveness and possible cost barriers that outsiders would face when planning to penetrate the market. Results will also be helpful to foresee the expected performance of a new DHP, which may aid possible decision-makers (both private or public) to explore the financial potential of an investment in this field.

3.2 Methodology

Data collection was conducted considering existing DHP in Italy. Only Italian case studies were considered in order to account for the Italian levels of costs for infrastructures, machineries, fuel, salaries and other relevant expenditures. This feature allows Italian cost appraisal with a higher level of precision but, at the same time, it would be difficult to extend the result in other countries. Different countries might have different salary levels and prices, therefore costs and benefits might be different. Despite this negative aspect, the present work would be helpful to create a basic contribution in this field that might be enriched in the future.
The sample included in the analysis was gathered through a web search in google and google scholar databases, the list of reports and DHPs are included in appendix of the present chapter. Data on such DHPs are mainly contained

in reports or business plans, therefore it was considered not necessary to extend the search in other scientific databases. The following keywords were used in combination: Forest bioenergy, DHP, investment cost, balance sheet, business plan. Collected documents were mainly composed of reports and feasibility studies. Globally, it was able to collect thirty-four relevant DHPs of installed power between 400 KW and 20 MW, so that it is possible to predict costs for a wide range of hypothetical capacity of the DHP to be built. The analysis include:

- Investment costs;
- Operating and Management costs;
- Expected income.

Methodology for the estimation of financial figures differ for each of the above-mentioned group of flows. Different approaches were necessary, because it was not possible to retrieve all the necessary data for all the DHPs in the database. For example, while information about investment costs was easy to obtain, operating costs are difficult to quantify and some of the reports did not show such data. Thus, predictive functions are not the same and will be described separately in the following sections.

3.2.1 Investment costs

Investment costs are related to the expenditures sustained in the development phase of the DHP, necessary to create the physical structure and the equipment for the operational use. This group includes the following expenditures:

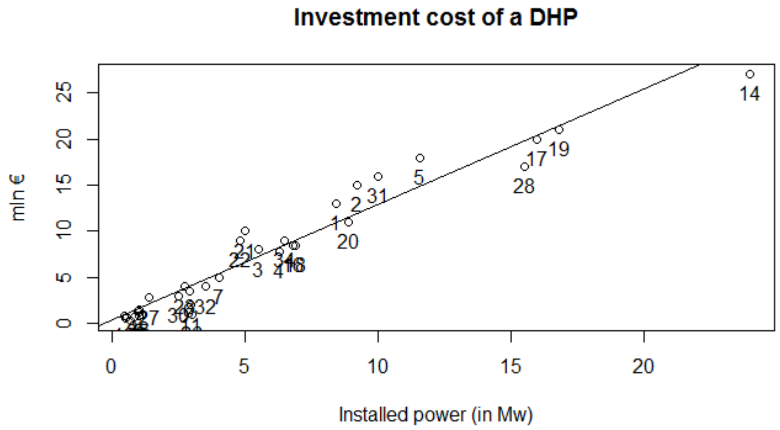
- Project;
- Boiler;
- Heating network;
- Machineries;
- Warehouse.

In the latest years, it is quite common for DHPs to include the possibility to cogenerate electricity, in order to provide an even more efficient use of fuel. This idea is particularly interesting for Italy, because renewable electricity is subsidized, thus producers may rely on additional source of income. The subsidy scheme will be described in detail in the section concerning income estimation. Of course, including the possibility to produce electricity modifies the investment costs of the DHP, because additional machineries have to be included in the estimation. In this study, we include the possibility to produce electricity in cogeneration with heating through the Organic Rankine cycle (ORC) system, which is the most common technology in small and medium plants. Investment costs is a continuous variable, thus linear regression seems to be adequate for creating a predictive model. All the analyses were carried out using R (R Core Team, 2013). It was found that the main drivers affecting investment costs are related to the capacity of the DHP, in terms of installed power, and the possibility to generate electricity in cogeneration or not. Thus, selected dependent variables were the installed power (continuous, in MW) and a dummy variable equal to 1 if the plant is created for cogeneration and 0 otherwise. Consequently, the predictive model takes the form:

$$C_I = \beta_1 MW + \beta_2 Cogen + \beta_3 + \epsilon \tag{3.1}$$

Where the dependent variable C_I is the level of investment costs, associated with a given installed power MW and the possibility to generate electricity, captured by $Cogen$, while ϵ is the random disturbance. In order to control for multi-collinearity, the variance inflation factor (VIF) was calculated, even if, in principle, there is no reason for installed power and cogeneration to be correlated or linearly dependent. The VIF calculation did not highlight the presence of multi-collineary between the covariates, returning a value very close to one. It was decided not to add other covariates, in order not to require too many data for future applications; in addition the goodness of fit, in terms of explained variance, was high enough to reasonably hypothesize a good explanatory power of the model. After a first regression, it was noticed that transformations of the dependent variable (logarithmic or exponential) were not necessary, given that the relationship was satisfactory. However, a particular influential observation that requires investigation was detected (Belsley et al., 2005). From figure 3.1, it can be seen that there are some observations mildly distant from the regression line (for example 31, 5 and 28). For these observations, a Chauvenet criterion test rejected

Figure 3.1: graphical representation of the fitted line across observations



the possibility to be considered outliers. However the most troublesome observation is the one labelled 14 (top-right corner of the figure), i.e. a very big DHP of 24 MW of installed power. As it can be seen, this observation is abundantly below the fitted line. This may suggest that, after a certain threshold of installed power, investment costs increase at lower rates. This is reasonable and might be explained by economy of scales, occurring when the capacity of the DHP are very high, most likely after 20 MW of installed power. In order to reduce the effect of such an influential observation two possible solutions are (a) increase sample size (if possible) or (b) delete the observation. It was very hard to find additional DHPs including all the necessary information, thus it was attempted to delete the observation and run the analysis again. The main drawback of deleting this observation is that the new model would not include data on power plants bigger than 18 MW, thus lowering prediction power for very big DHPs. However, it is unlikely that huge plants may be created in a sustainable way with local bioenergy, because forests would hardly provide enough woodchip for such purposes. The new model was very similar to the first one, in terms of magnitude of the coefficients and statistical significance, while the goodness of fit slightly improved and the Breusch-Pagan test rejected heteroscedasticity at 95% confidence level (p-value equal to 0.06). It was also checked whether the model respect the assumption of normally distributed residuals, by means of the Kolmogorov-Smirnov non-parametric test, which is necessary for the t-tests to be valid. The test, returning a p-value of 0.20, failed to reject the assumption of normality. Thus it was decided to use the model without the influential observation, lowering the set of DHPs to thirty-three.

3.2.2 Operating and Management Costs

The investigation of operating and management costs was not as straight forward as for investment costs, because data were harder to obtain. many reports did not mention operating costs, while other expressed the level of operating costs as a percentage of the investment costs. For this reason, it was decided to divide operating costs into three groups and provide an estimation function for each. The identified groups were (a) workforce, (b) fuel (woodchip) and (c) other operating and management costs. The description of the estimation methods is presented in the next paragraphs.

Workforce As other typology of operating expenditures, cost for workers is not a relevant part of the project. DHPs have many automatized functions, in particular when their capacity is small. The calculation of workforce expenditure is derived by the follong equation:

$$C_w = N_w \times w \tag{3.2}$$

Where C_w is the gross expenditures for the workforce, N_w the expected number of workers full-time employed and w the gross yearly wage for each worker. In order to assess a reasonable number of workers, a step function was created based on the capacity of the DHP, in which each range of installed power is associated with a certain number of workers. More formally, given a certain installed power MW, the expected number of workers is given by:

$$N_w = \begin{cases} 3, & \text{if } MW \leq 2 \\ 5, & \text{if } 2 < MW \leq 4 \\ 8, & \text{if } 4 < MW \leq 8 \\ 15, & \text{if } 8 < MW \leq 12 \\ 20, & \text{if } 12 < MW \leq 20 \\ 30, & \text{otherwise} \end{cases} \tag{3.3}$$

Workers are assumed to be full-time employed 40 hours per week, according to the Italian labour laws.

Cost for fuel Cost for fuel is related to the quantity of woodchip annually needed to run the DHP. The formula to calculate this expenditure is the following:

$$C_f = Q_f \times p_f \tag{3.4}$$

Where C_f represents the total cost sustained for woodchip, Q_f the quantity (in tons) and p_f the unit price (per ton) of woodchip with a certain moisture content. For the purpose of our analysis, the quantity of woodchip is derived from r.green tool described in the previous chapter. The price per ton of woodchip was provided by local forest consultants and Maritime Alps park managers, assessed to be 55 € /ton.

(other Operating and Management costs) There are other expenses that has to be sustained for the functioning of a DHP. In particular, relevant expenses are related to:

- Insurances;
- Has disposal;
- Ordinary Maintenance;
- Extra-ordinary Maintenance;
- Energy and Electricity.

Each of these expenses is negligible if compared to other costs and difficult to retrieve, thus they are included in a unique calculation. In some application, these expenditures are estimated as a percentage of the investment costs. In particular, it was found that preliminary studies and business plans consider a level between 5% and 10% of the investment cost as a reliable value for such expenditures. This range is considered also in this study, with a default value of 5%. Thermal energy is assumed to be supplied by the DHP itself (and also electricity if the plant includes cogeneration), thus costs for energy are not included.

3.2.3 Income assessment

Estimating financial incomes from the DHP is quite straightforward, compared to the estimation of costs. Monetary income of a DHP are connected with the energy produced and sold. Energy produced will be only thermal for standard DHP, while in the case of cogeneration income will also be provided by the produced electricity. Formally, income from energy selling is computed in the following way:

$$\Pi_{dhp} = Q_{th} \times p_{th} + Q_{el} \times S_{el} \tag{3.5}$$

In which Π_{dhp} is the total expected income from the DHP, Q_{th} represents the estimated total thermal energy produced, p_{th} is the price of thermal energy, Q_{el} is the quantity of electricity produced and S_{el} is the subside for electricity. Energy and electricity produced is assumed to be the net quantity after considering a 9% of self-consumption. The price for thermal energy was obtained from a report of the Piedmont region, containing average values for 2016. Concerning unit income from electricity generation, the subsides scheme is regulated by the Italian institute for energy services ("Gestore dei Servizi Energetici", GSE). GSE provides incentives for RE produced from different sources and, concerning solid biomass, there are two level of subsides. Power plants bigger than 1 MW of installed power receive 70 € per MWh as basic price plus 110 € as subsidy, through the "green certificate" scheme. Thus, globally, power plants may receive 180 € per MWh. Conversely, power plant smaller than 1 MW of installed power may benefit of a higher tariff called "tariffa omnicomprensiva" (omni-comprehensive tariff). This tariff is 280 € per MWh nd does not distinguish between energy price and subsidy The omni-comprehensive tariff is guaranteed for 15 years and does not foresees increment even to recover inflation.

3.3 Results

Results are reported in separate sections. In the first section, results of the predictive model for the investment costs are presented. other costs and benefits flows are included in the second section, where the application of the procedure to the case study is introduced.

Table 3.1: Linear Regression for the investment costs

Variable	Coefficient	St. Err.	p value	Sign.
MW	1.32670	0.06522	.000	***
Cogen	-0.34274	-0.463	0.647	
Intercept	0.12221	0.41503	0.770	
Obs		33		
R^2		0.941		

3.3.1 Investment cost function

Results of the linear regression for the function are shown in table 3.1. In general, the R^2 statistic suggests that the model has a good explanatory power for the data, being able to explain roughly 94 % of their variability. It can be seen that the variable MW is positive and statistically significant. This was expected and suggests that bigger power plants are more costly. Conversely, the coefficient for cogeneration of electricity is negative, although is not significantly different from zero. The negative sign may sound odd, however it may be explained by the procedure through which investment costs are calculated. In fact, the installed power of the plants is given by the sum of thermal and electric parts. Thus, for example, a DHP only for thermal purposes of 1 MW is considered to be equal to a cogeneration plant in which 0.8 MW of power is for thermal energy and 0.2 MW of power for electricity. This simplification was necessary because investment costs were not described in detail and it was difficult to separate figures for thermal investment from figures of electricity generation. The negative coefficient for cogeneration may indicate that the cost for increasing the total installed power is lower if done with cogeneration but, in practice, this difference does not seem to matter. Finally, the intercept is very small and non-significant.

3.3.2 Application of the methodology to the case study

The described methodology to identify financial flows of a DHP was applied to the plant identified in the previous chapter, i.e. of a 1.6 MW of installed power. It is assumed that the DHP is created mainly for heating purposes but includes a small cogeneration system through ORC, which allows recovering 15% of efficiency in energy conversion. Table 3.2 shows the variables

Table 3.2: Parameters included in the financial analysis

Variable	Parameter
Efficiency of the plant	80%
Efficiency of the network	90%
DHP Oversize Factor	30%
Hours of Functioning	8,000
Self - consumption	9%
Thermal energy price	58 €/MWh
Quantity of woodchips	3,000 tons
Cost of woodchip	55 €/ton
Number of workers	3
Gross cost of workers	40,000 €/worker
Other O and M costs	5% of investment

that were included in the computations.
In particular, the thermal energy price was retrieved from the regional statistics in Piedmont, as already stated, as well as the price for woodchip. Concerning costs for workers, it was decided to use an average of 40,000 € per year as gross salary. This figure maybe overestimates the cost for a single worker, however it is supposed that, out of three necessary workers, one might be a manager whose earnings are higher than others. For this reason, 40,000 € can be considered a weighted average of different levels of salary. The level of other operating and management cost was estimated to be 5%, which seems to be reasonable for including insurance and maintenance into the calculation.

Investment costs Investment costs were assessed to be 1.9 mnl €. This figure seems to be reasonable and comparable to values that can be found in real applications. The precision is mainly given by the high fit of the statistical model previously described, which is able to include a large portion of explained variance.

Operating and Management costs Operating and management costs are estimated to be roughly 380,000 € per year, globally. Out of this, 120,000 € are related to costs for workers, which is similar to the cost sustained to acquire woodchip, assessed to be 165,000 €. Lastly, other operating and management costs are estimated to account for 95,000 €.

Income The quantity of thermal energy that can be sold is reduced because of efficiency losses, in the plant and in the network. Thus, from the annual 12862 MWh obtainable from local biomass, only 8427 MWh are supposed to be sold to generate income. This corresponds to roughly 390,000 € of earnings from thermal energy. In addition, earnings are derived from the sell of electricity, produced in cogeneration through the ORC system. This additional income is roughly 275,000 €. Thus globally, expected income are estimated to be 665,000 €.

3.4 Discussions

It can be seen that, as already anticipated, producing thermal energy from biomass is capital intensive, with levels of investment costs quite high and difficult to recover in a short period of time. Investment costs were assessed to be higher than 1.9 mln of €, which is reasonable considering expenditures for warehouses, boiler and other machineries (Franzin, 2016). On the other hand, operating costs are lower and around 380,000 € per year. From the estimation of expected income, it can be seen that, considering only thermal energy, there is a very uncertain economic convenience in building a DHP fuelled with woodchip. In fact, estimated income is very close to annual costs for operations, thus cost sustained for the initial investment will be hardly recoverable in a reasonable period of time. For this reason, potential investors are expected to choose not to invest in such a deal and look for profits in other sector.

Conversely, when it is assumed that the plant is able to use part of energy for electricity, the economic convenience of the plant is much higher. This happens because of subsidies, which allows investors to obtain prices for the energy they sell higher than the equilibrium market price (Kalkuhl et al., 2013). For this reason, including cogeneration in a DHP seems to be an effective strategy to make the sector profitable and increasing the share of energy produced from renewable sources. However, this feature holds at

present because of the GSE subsidies, which might be different or even absent in the future. Without subsidies, considering figures included in the present analysis, electricity producers would not obtain 180 € per MWh but only 70 €, thus decreasing the general income level at 497,000 €. It is clear that in this case the economic performance is jeopardized, because expected income are very close to management cost; lower earnings render the investment less profitable and increases the payback time.
The described methodology proved to be useful for estimating expected costs and benefits in a stochastic framework. In the planning phase, such an approach can be useful to created different viable scenarios of investment and choosing the most appropriate one. It has to be highlighted that real applications might have different needs and data to be included. For example, investment costs are estimated considering that the entire heating network should be built, but in reality this might be already available. Thus, expected costs will be lower. Conversely, the identification of the suitable area for the DHP considers, at present, only available existing warehouse, while in some cases there is the need to build it, thus increasing the level of investment costs. For the cited reason, the variables and elements included should be carefully screened by decision-makers in real application.

3.5 Conclusions

This chapter introduces the methodology to estimate the financial performance of a DHP, by means of automatic procedures to calculate investment costs, operating costs and expected income. Results suggested that the economic balance is positive and the investment is desirable only when the DHP is projected to produce both thermal energy and electricity in cogeneration. Results may be useful for future planning policies. Highlighting the expected cost of DHPs of different capacities it is useful to understand the level of initial investment and the payback time, so that a potential investor may explore in advance the magnitude of a financial effort.
The main positive aspects of this approach is that it requires relatively a small amount of data and hypothesis about the functioning of the DHP. Negative aspects are connected with the necessity to evaluate, case-by-case, whether the included list of costs are exhaustive or redundant. This procedure is based on Italian figures, which might be unrealistic if the methodology is applied with the same numbers presented here. However, formulas may be

modified with a limited effort according to specific needs and situations, thus assuring model validity.

Appendices

Appendix: List of existing Italian DHPs

Source	Province	Comune	Cogen	heat power (MW)	Tot power (MW)
Biomasfor	Trentino	S Martino	no	8	8.43
Biomasfor	Trentino	Cavalese	no	8	9.2
Biomasfor	Trentino	Fonao	Yes	5.5	5.5
Biomasfor	Trentino	Predazzo	no	2.3	6.3
Biomasfor	Trentino	S Michele	no	3.6	11.6
Biomasfor	Trentino	Coredo	no	2.4	2.9
Biomasfor	Trentino	Peio	no	4	4
Biomasfor	Trentino	Malosco	no	1.1	1.1
Biomasfor	Trentino	Pellizzano	no	1	1
Biomasfor	Trentino	Ledro	no	0.5	0.5
Biomasfor	Trentino	S Orsola	no	1.5	2.95
Biomasfor	Trentino	Grumes	no	0.43	0.43
Biomasfor	Trentino	Tres	no	0.54	0.54
Biomasfor	Trentino	Primiero	Yes	16.5	17.5
Biomasfor	Trentino	Cloz	no	0.8	0.8
Renerfor	Val d´Aosta	Pollein	no	4.1	6.82
Renerfor	Val d´Aosta	Morgex	no	9.5	16
Renerfor	Val d´Aosta	Pre S Didier	no	4.1	6.9
Renerfor	Val d´Aosta	La Thuile	Yes	9	16.8
Lizzola SPA	Lombardia	Valbondione	Yes	4.1	8.91
ALPENERGYWOOD	Lombardia	Sondalo	no	5	5
ENAMA	Toscana	Calenzano	Yes	4	4.8
ENAMA	Lombardia	Abbiategrasso	Yes	2.5	2.7
ENAMA	Friuli VG	Budoia	no	0.7	0.7
ENAMA	Toscana	Rufina	no	0.97	0.97
ENAMA	Veneto	Oderzo	no	3	3
FIPER	Friuli VG	Forni	no	1.4	1.4
FIPER	Lombardia	Sedrina	Yes	12.4	15.5
FIPER	Lombardia	Marchirolo	no	1	1
FIPER	Piemonte	Ormea	no	2.5	2.5
FIPER	Piemonte	Torino	no	10	10
FIPER	Piemonte	Torino	no	3.5	3.5
FIPER	Piemonte	Alessandria	no	1	1
FIPER	Piemonte	Cuneo	Yes	5.5	6.5

Chapter 4

Evaluating social Benefits

4.1 Introduction

The literature on non-market valuation acknowledges that people have economic value for goods and services, even in the absence of a market, in which equilibrium prices are determined (Champ et al., 2012). Identifying the value of non-market goods and services is an important and, at the same time, challenging issues in the decision-making process. Typical examples are public goods and services, which are usually provided by public administrations to citizens. Public goods are characterized by two fundamental features: non-rivality and non-excludability (Kaul and Mendoza, 2003). A good is non-rival when its consumption from an individual does not affect the possibility for others consumption. For example, street lighting is provided by public administrations and it is non-rival (all the people may benefit from public lighting simultaneously without restrictions) and non-excludable (it is not possible to exclude someone from the light), it is therefore a public good. A typical problem, when developing public policies, is to find a decision rule to understand whether a hypothetical project may be considered welfare-increasing or not for people. This situation happens because public goods are always costly, indeed they have to be provided by public money, but, most of them, do not generate monetary incomes. In many cases, public administrations do not provide public investments for economic advantages but for the benefit of the people (Hanley et al., 2009). Pensions, health systems and public education are examples of public-funded services, for which costs are certain but benefit are uncertain. In such a situation it is not clear, among several alternatives, what is the best solution in terms of welfare for the target citizens. Valuing non-market goods and find effective strategies to reliably price them is important to understand expected benefits of public projects. Valuing benefits of public-provided goods allows comparisons between alternative projects or policies, so that the one producing the highest level of benefit might be identified and, eventually, chosen.

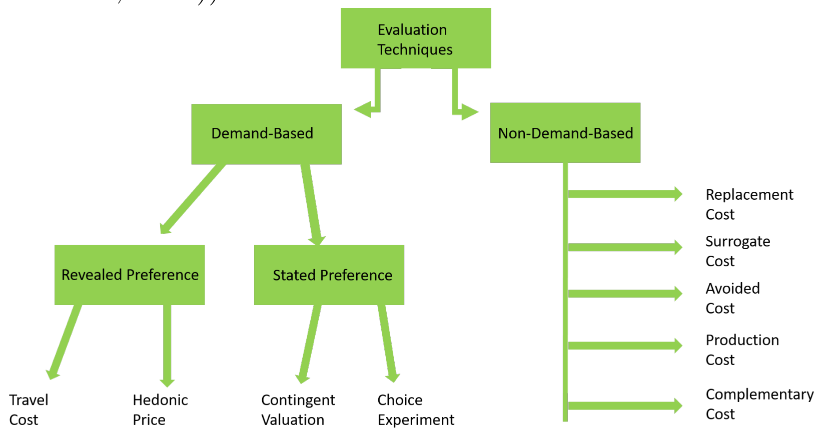
The construction of a new DHP fuelled with biomass, may be financed by a public administration with (at least) two objectives: supply buildings with thermal energy and reducing GHG emissions. In addition, using local biomass may have positive cascade effects on the local economy. Such a DHP might be considered a public good, whose effects are not only related to energy provision but also to the reduction of fossil fuels use. What matters in this context is not only the expected financial return but also the perceived

individuals' benefit for GHG abatements.
With this in mind, the aim of the present chapter is twofold. The first objective is to provide an meta-analysis of the literature on non-market applications in the REs sector. This will illustrate the levels of WTP people shows in different countries, so that the reader may acquire a clear overview of the topic and understand the functioning of the techniques. The second objective is to show a field survey carried out in the Gesso and Vermenagna valleys, which will be used as a measure of the perceived social benefit of the DHP, when the choice of investing is taken by the public sector. Given that the literature stresses the importance of testing the convergence of results with already existing studies, papers included in the meta-analysis will also be used to test convergence validity of the case study.

4.1.1 Brief overview of the most common evaluation techniques

There are several approaches to value non-market goods. In particular, Bateman and Turner (Bateman and Turner, 1993) distinguish two main groups of methodologies, as shown in figure 4.1: non-demand based and demand based methods. Non-demand based methods are usually applied for the evaluation of environmental (and sometimes health-related) goods and services. These techniques look at the costs that would be sustained to replace or substitute an environmental good or service and will be described in more detail in the next chapter. Demand-based techniques are all focused on the estimation of a demand curve for the public good or service. The traditional microeconomic theory acknowledges that people consume because they can obtain utility from goods. People are assumed to trade-off several bundles of goods and choose the one proving the highest level of utility, based on their preferences (Bowles, 2009). In this context, an individual will choose the bundle of goods a over b if it is the choice maximizing his/her utility, subject to his/her budget constrain (Besanko and Braeutigam, 2011). The demand curve for a good describes the relationship between the quantity that an individual is willing to buy at certain price levels, it is therefore an expression of individuals preference. This relationship is inverse, indicating that people would buy additional quantities of a good if the unit price decreases. The inverse relationship between price and quantity indicates that, with a given budget constrain, lower prices allow consuming more, thus low prices increase

Figure 4.1: Economic Evaluation Techniques (Source: Adapted from (Bateman and Turner, 1993))



welfare for the individual. Conversely, higher prices decrease the quantity that is possible to consume, decreasing welfare as well. Thus, the objective of demand-based techniques is to investigate individuals preferences, by approximating a demand curve for the public good or service. There are two strategies for this purpose: using revealed preferences or stated preferences.

4.1.1.1 Revealed preferences

Revealed preferences techniques have the objective of deriving the demand curve for a good by looking at close and similar markets. In particular, there are two techniques: travel cost method (TCM) and hedonic price method (HPM). These methodologies have the main advantage to capture use values with a good level of approximation, because they bear from the observation of actual behaviour of individuals. However, the main drawback is that they are not able to estimate non-use values, which are not possible to assess by observing real choices but only in hypothetical settings.

Travel Cost Method. The TCM method was first proposed by Hotelling in 1947 (Hotelling, 1947) and then refined by Knetsch and Clawson (1966). The method is mainly implemented to value recreational activities in open areas. The main intuition is that costs sustained by visitors may approximate the value of their recreational experience. In this context, the quantity of recreation is valued as the number of trips tourists undertake in a given timespan, while the associated unit cost is represented by the travel cost sustained to reach the destination. People are assumed to be travel cost-sensitive, meaning that people living closer to the destination will undertake more visits compared to distant people, because the unit cost for a trip is lower than for the others. The demand function is integrated with socio-economic characteristics and sometimes with environmental and site-specific variables, thus allowing the identification of marginal effects caused by individuals and site characteristics. Count data models are the most common approaches to analyse TCM single demand function, in particular Poisson and Negative Binomial models (Hellerstein, 1991). Once the model is estimated, the typical welfare measure that is calculated to asses the value of on trip is consumer surplus (CS) (Besanko and Braeutigam, 2011).

Hedonic Pricing. HPM bases the theoretical foundation in Lancasters characteristics theory, subsequently developed by Rosen and sometimes referred to as the Lancaster-Rosen approach (Lancaster, 1966; Rosen, 1974). HPM uses data of a surrogate market and identifies the good to be valued as a characteristic, or attribute, that partly describe the marketed good. The most common market used is housing, in fact the price of a house is given by a number of house characteristics (including number of bedrooms, size, exposition, proximity to facilities and shops etc) but also neighbourhood characteristics, for example air pollution and noise levels.The marginal effect can be seen as the implicit price of that characteristics (sometimes called also differential rent), i.e. the value people implicitly give to that characteristic, revealed from their preferences. A typical assumption made in HPM applications is that market buyers have weakly separable utility functions, meaning that the marginal rate of substitution between two goods is independent from the quantity they consume. This assumption allows estimating a demand curve for the non-market good ignoring prices of other goods and services. The literature do not provide a reference model to carry out a hedonic regression, usually a Cox-Box transformation is performed before the analysis to understand the best functional form (Hanley et al., 2009).

4.1.1.2 Stated preferences

Stated preference techniques are implemented when a surrogate market for the non-market good is difficult to identify (Boxall et al., 1996). The procedure in this case consists of creating a hypothetical market scenario and observing how people behave in that situation. For example, the scenario may elicit an increase in the environmental quality; a high environmental quality creates benefits for people, thus it is expected that people are willing to pay for an increased environmental quality. In the context of stated preferences, compensating variation (CV) and equivalent variation (EV) are often used welfare measures, expressing the effects of the scenario on welfare (Champ et al., 2012). A CV is the maximum amount of money one is willing to sacrifice for increasing welfare, while EV is the minimum amount the same individual would accept as compensation, if a new project decreases his/her welfare. Depending on the scenarios, CV and EV will translate in willingness to pay (WTP) or willing to accept a compensation(WTA). In particular, in a welfare-increasing scenario CV is WTP and EV is WTA; conversely EV is WTP and CV is WTA in a welfare-decreasing scenario. The WTP approach is an extremely flexible tool, because it allows estimating use and non-use values in a wide range of situations. Stated preference surveys are usually implemented by means of questionnaires, administrated to a sample of the target population. Nevertheless, stated preferences are sometimes criticized and still many are sceptical about their usage (Kanninen, 1995). In particular, it is argued that eliciting WTP has several biases to be taken into account. For example, the hypothetical nature of the question might cause a yes-answer situation, because respondents do not adequately consider their budget constrains (Cummings et al., 1986) and consider the payment only hypothetical (Moser et al., 2013). Conversely, people may also state they are not willing to pay as a protest against a possible tax (García-Llorente et al., 2011). The scenario might also be too much vague, thus increasing the difficult for interviewed people to figure out the situation for what they are asked to pay. From another point of view, it has been shown that individual preferences are not an adequate measure of the importance of a good or service. This is particularly important for environmental goods and biodiversity. For instance, the scientific literature suggests that people are more prone to pay for conserving large mammals with anthropomorphic features rather than fish, reptiles, insects and other repelling or dangerous species (Martin-Lopez et al., 2008). However, some of that might be extremely important for the health of the ecosystem and their extinction might threaten ecosystem resilience. Conservation is fundamental but most likely not captured by individuals preferences. Despite the cited critics, this kind of preference assessment is widely applied. In addition, the NOAA panel report assured the validity of contingent valuation (Arrow et al., 1993a), thus from the point of view of economics stated preferences are justified. using stated preferences methods is the only solution to approach public goods evaluation in a welfarist manner. Stated preference methods make use of questionnaires (Gios and Notaro, 2001), usually including starting and warm-up questions introducing the topic, attitudinal questions, scenario description and WTP elicitation, questions to collect personal (socio-demographic) characteristics. There are two main approaches to evaluate stated preferences: the Contingent Valuation Method (CVM) and the choice experiment (CE).

Contingent Valuation. The CVM method is the first-born stated preference technique and it is embedded in the framework of Random Utility Models (RUM). Already proposed by Ciriacy-Wantrup (1947), the first application of CVM was implemented in 1963, when Davis applied the technique to value hunters recreation in Maine (Davis, 1963). After this pioneering study, the methods was extensively used and developed in the seventies and, since then, it became the most applied method for valuing non-market goods, in particular in the environmental sphere. In 1989 a famous episode brought attention of the economists worldwide on CVM. In fact, the oil tanker Exxon Valdez shipwrecked, spilling around 11 millions of oil gallons in the sea, close to the coast in Alaska, causing huge environmental damages. It was decided to quantify environmental damages by means of a CV survey (Carson et al., 1992), assuming USA inhabitants as the target population. As a reaction, economists and CVM practitioners started a long-lasting debate about reliability of CVM. This debate brought the US government to establish a panel of eight Nobel prize winners (the so called NOAA panel) to discuss about suitability of CVM to be used in legal trials for quantifying environmental damages (Arrow et al., 1993a). The panel assured the suitability of CVM and provided a series of good practice and guidelines to undertake a CVM study in the most effective and reliable way. For example, the report advices the use of WTP over WTA, because the latter is more likely to overestimate the value. The NOAA panel report boosted the use of CVM worldwide and it is still the most applied technique, mainly because of its simplicity (Fuente and Colina, 2010). CVM is carried out by creating a hypothetical contingent scenario, which may foresee an increase or decrease in the individual welfare, and ask respondents their WTP/WTA for that scenario. Data are subsequently analysed by means of regression techniques, depending on the

WTP question format. Typically, closed-ended CVM consists in proposing a certain cost for the scenario and asking respondents if they would pay that amount or not. In this case, the response variable would be the discrete choice between accepting to pay and not acceptance to pay, therefore statistical analyses are based on binary outcome models, i.e. probit and logit. The closed-ended format has the main advantage to reproduce situation very common to respondents, i.e. whether to buy or not a certain good with a certain price. As an important drawback, this format is able to provide only limited information from each respondent, because people accepting to pay might accept even higher prices and, on the other hand, people not willing to pay a certain amount might accept lower figures. In this situation, the sample size has to be very large in order to obtain meaningful results. Another question format, called open-ended, is conversely created by asking respondents the maximum amount of money they are willing to pay for the proposed scenario. In this case the response variable is the level of WTP, which is continuous and estimated in a hedonic framework, by means of ordinary least square or limited dependent variable models (tobit). In this case, collected information is greater, because people are invited to state the maximum amount of WTP without any restrictions, however without any indication of reasonable amount of money they might state unrealistic figures. Another common approach is to include a payment card, in which several amount are proposed and respondents are invited to choose the one they are likely to accept as payment for the scenario. In this case, statistical analyses are conducted with the same models as for open-ended formats or, to a minor extent, with interval regression models.

Choice Experiment. Differently from the other described techniques, born for environmental evaluation, CEs were first applied in the marketing sphere and later on extended to transportation economics, health and environmental economics and other fields. Choice models originated from Lancastrians attribute theory, RUMs (Manski, 1977) and McFaddens conditional logit model (McFadden, 1974). Similarly to the HPM, CEs foresee the decomposition of the good to be valued in its fundamental attributes. Each attribute is associated to a certain number of levels that may assume. One of the attribute is the cost associated with the alternative, in order to make monetary trade-offs with non-cost attributes. The combination of attributes and levels allows the creation of several different alternatives, presented to respondents iteratively. Respondents have to face several choice situations (in general between 6 and 12) they are asked to select the best alternative among the ones that are presented (Riera et al., 2012). Usually, each choice task includes 3 or 4 alternatives, out of which one is an opt-out alternative with a null cost (Henser et al., 2005). Given these characteristics, CEs are sometimes thought as a further and more sophisticated specification of a close-ended contingent valuation.

4.2 WTP for green energy: a meta-analysis

REs cannot be considered a non-market good, because energy is supplied to final users in an energy market, in which price is determined independently from the energy source. However, REs are more costly but they assure a lower level of GHG emissions and a better air quality. For this reason, people may choose to pay a price premium for a supply of energy produced with renewable sources, WTP may represent a good indicator for this higher price. In this section an overview of the research done so far in the RE sector is provided, by means of a meta-analysis of the literature.

4.2.1 Data collection

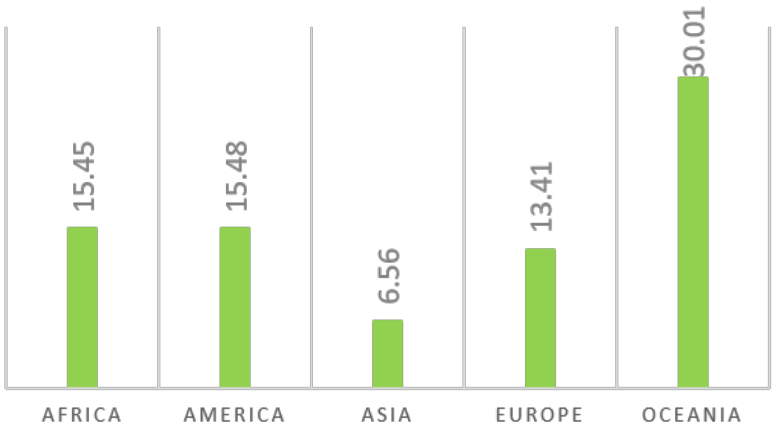
Data on individual WTP were collected through an extensive research in the Scopus and Google scholar databases. The following keywords were used in combination: Renewable energy, willingness to pay, wind, solar, hydro power, biomass, bioenergy, electricity, geothermal, power. Unpublished work (working papers and reports) available on-line was also included. The evaluation techniques that are considered in this study are CV and CE. The initial body of literature identified in the web search contained other relevant references, which were also included in the study. Only studies containing individual WTP (in nominal value) were selected, in order to obtain comparable figures across studies. Some papers were discarded because they were not useful for the purpose of this study. In particular, some studies were excluded because the surveyed sample was not representative of the reference population. For example, the paper by Gossling et al. (2005) was not included because it sampled only students. Students are not the only electricity consumers, thus including this paper may provoke selection bias. Similarly, it was discarded the work by Kostakis and Sardianou (2012), because they surveyed only tourists. In other cases, information about individual WTP was missing or inconvertible into monthly WTP. For example Wiser (2007) investigated methodological aspects connected with payment vehicle used in CV, without providing explicit figures concerning individual WTP. Given that it was impossible to calculate WTP with such information, this work was excluded. Similarly, Liu et al. (2013) showed WTP as a percentage of the bill, which was not convertible into individual monthly WTP. Some other papers had the focus on technologies (e.g. Longo et al., 2008; Scarpa and Willis, 2010) rather than price premiums for electricity and were discarded as well. The paper by Roe et al. (2001) was also excluded because, despite declaring the investigation of WTP, survey methodology was not described and it was unclear whether the procedure followed a CV/CE application or not. At the end of the paper selection 34 studies, undertaken in 16 different countries and containing 151 observations, were included for the following analyses. The list of papers is reported in Appendix. Our dataset contained individual WTP per month. If the primary study contained annual WTP, monthly WTP was derived by dividing the average amount by twelve. In order to facilitate comparisons of the figures across countries and years, figures were converted to USD and corrected to the 2010 prices by the purchasing power parity exchange rates, available from the OECD website [1].

4.2.2 Data Description

The overall mean WTP was found to be of 13.29 USD per month (median 9.80 USD), which is very similar to the one found by Sundt and Rehdanz (2015) with less observations. The smallest value was found in the analysis carried out by Navrud and Bråten (2007) and it is of only 0.09 USD. This study applied CE as elicitation method and such a small value may be the result of trade-offs made by respondents among different alternatives (values of WTP for other energy sources derived from this paper are in fact higher). The highest WTP was 53.67 USD, registered in the USA by Sims (2013). Concerning the distribution of data by continent, it is possible to see that America and Europe provide the higher number of observations, sixty-five and sixty-three, respectively. Asia contributes with sixteen observations, while Africa and Oceania have very few studies and subsequently a small number of observations, respectively five and three. In particular, it

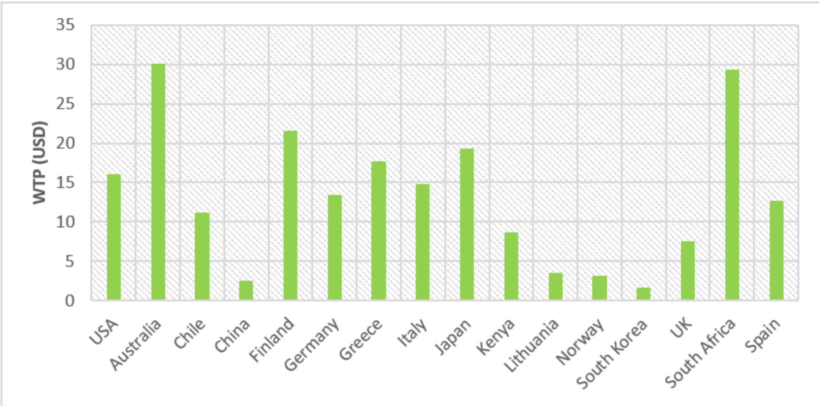
[1] https://www.oecd.org/std/prices-ppp/purchasingpowerparitiespppsdata.htm

Figure 4.2: WTP by continent



was possible to retrieve just one study from the Oceania continent mad by Ivanova (2013), who survey residents from Queensland (Australia). Figure 4.2 summarizes the distribution of the average WTP in each continent. Asia shows the average WTP with 6.56 USD/month, while Oceania the highest with around 30 USD/month. The figure for Oceania comes from the average of three observations of just one paper, thus it cannot be considered highly representative of the entire continent. Similar considerations hold for Africa, in which five observations are still not enough to be considered representative. The geographical distribution of the studies indicates that more research may be desirable in Africa, Oceania and Asia, in order to provide meaningful comparisons. Out of the thirty-four studies, only five come from developing countries, namely Chile, China (two), Kenya and South Africa and one from a country in transition (Lithuania). Concerning country-level differences, Australia shows the highest WTP for renewables with 30.01 USD per month (the same as for Oceania as a whole, given that this is the only study in the continent), followed by South Africa (21.39 USD per month). The lowest levels of WTP may be found in Asia; in particular, residents in South Korea declared an average WTP of 1.48 USD per month, while in China 2.45 USD per month. The detail of the WTP by each country included in the study is summarized in figure 4.3. The WTP distribution was also explored across energy sources. The present dataset contained a majority of observations aiming at exploring price premiums for electricity derived from energy mix or non-specified energy source (67 observations). Other observations included WTP for one specific kind of electricity source. In particular,

Figure 4.3: WTP by country



thirty-six observations concerned the use of biomass, twenty-three for solar energy (including both photovoltaic and solar thermal), twenty-one for wind energy. Hydropower and geothermal energy were proved to be the least studied, with only three and one observations, respectively. Probably, hydropower has not been extensively investigated because in many part of the world it is already well-established and the energy potential for further exploitation is relatively low. This hypothesis is confirmed by technical studies on hydropower potential (see, among others, Larentis et al., 2010; Paish, 2002), as well as by the fact that collected data on country-level RE production show a strong dominance of hydropower share over other energy sources in all countries. Concerning geothermal energy, the reason of so small interest may be due to few possibilities to develop it in large areas. Usually, geothermal energy is installed in individual houses for self-consumption, while bigger power plants require using deep-located energy, which is site-specific and require *ad hoc* assessments. The difficulty in retrieving geothermal energy may lead to difficulties in creating credible scenarios for respondents, so that often it is studied with evaluation techniques different from stated preferences, such as multi-criteria analysis (see, among others, Stein, 2013). The dominance of solar and wind energy could be related to the fact that, in some countries, they have been subsidized by governments, thus attracting interests of researchers and professionals. For what concerns WTP, on average people are willing to contribute to energy mix solutions with about 13.10 USD. The use of biomass for energy has a lower stated WTP, of 11.02 USD. WTP for wind and solar were assessed to be very similar, of about 14.14.66 USD and 14.40 USD, respectively. Eventually, WTP for hydropower and geothermal energy was of 9.57 USD and 36.90 USD. Once again, the number of observation for these two sources are too limited for a proper assessment of their WTP level.

4.2.3 Meta-regression model

The body of collected literature was included in a meta-regression model to explore factors affecting the level of WTP. There are many approaches for modelling meta-regressions. The usual implementation is by means of weighted least square (WLS), panel or multi-level models. In particular, panel models are quite common in meta-analyses concerning evaluation of ecosystem services (e.g., Zandersen and Tol, 2009; De Salvo and Signorello, 2015) because they are capable to consider the individual effect of each study (Greene, 2003). Other authors, on the other hand, assume that each study counts equally in the dataset and estimate the model through ordinary least square. Empirical examples of this approach are found in Barrio and Loureiro (2010) and Loomis and White (1996). In the present study, panel models were hardly applicable. Most of the covariates have the same value within a study and would be dropped because of collinearity (Cameron and Trivedi, 2005), when running a panel model. In order to account for the fact that the observations of a study are related, in this work we made use of a WLS regression, using sampling weights. Sampling weight were assigned so that studies with fewer observations have greater weight, so that they can have the same importance of studies with a larger number of observations. This approach has already been implemented by Sundt and Rehdanz (2015) for a similar study. Regressions are implemented in Stata 12, which produces robust standard errors when running a WLS, thus correcting automatically the model for minor problems connected with heteroscedasticity and non-linearity (Cameron and Trivedi, 2009). The dependent variable is the monthly WTP for an increase of the share of RE supply. After the initial computation, it was noted that taking the natural logarithm of the individual WTP allowed a better fit of the model and a general increase of the quality of the results. Thus a semi-log linear regression was implemented.

The explanatory variables included in the models are reported in table 4.1, providing a short description and summarizing the main descriptive statistics. In particular, it was decided to understand the effect of emissions (CO2) and electricity consumption (CONS) on the stated WTP. It is plausible to foresee an effect of the current level of emissions on WTP, because peo-

Table 4.1: Variables included in the meta-regression model

Variable	Description	Mean	Min	Max
CO2	Annual CO2 emissions per capita	11.86	0.22	19.61
CONS	Annual electricity consumption (Mw)	9.63	0.14	25.09
SHARE_RE	Share of RE in the country	17.76	1.41	91.93
SH_HYDRO	Share of hydropower in the country	12.55	1.11	90.52
NUCLEAR	1 = country has nuclear reactors 0 = no nuclear reactors	0.66	0	1
CV	1 = used CV 0 = used CE	0.7	0	1
PERSONAL	1 = Face to face administration 0 = otherwise	0.52	0	1
C_STUDY	1 = study area is local or regional 0 = study area is a country	0.57	0	1
SOLAR	1 = increase in solar energy specified 0 = not specified	0.15	0	1
WIND	1 = increase in wind energy specified 0 = not specified	0.14	0	1
KNOW	1 = knowledge of RE in the model 0 = not included	0.26	0	1
AGE	1 = age included in the model 0 = not included	0.6	0	1
EDUC	1 = education included in the model 0 = not included	0.53	0	1
ATTITUDE	1 = attitudes included in the model 0 = not included	0.57	0	1
INCOME	1 = income included in the model 0 = not included	0.72	0	1

ple living in polluted areas may wish to pay for their abatement. Other state-level variables included the share of renewable energy ($SHARE_{RE}$), the share of hydropower (SH_{HYDRO}) and a dummy variable equal to one if the state produces nuclear energy and zero otherwise ($NUCLEAR$). Concerning survey-specific variables, the covariate labelled CV is a dummy variable equal to if the study used a contingent valuation approach and zero otherwise; C_STUDY is another dummy equal to one if the survey administrated at country level and zero if it was a smaller case study. $PERSONAL$ and WEB are both dummy variables, equal to one if the study was administrated face to face and via web, respectively, and zero otherwise. $SOLAR$ and $WIND$ are dummies, equal to one if the observation foresaw an increase of solar (wind) energy and zero otherwise. The other variables in table 4.1 are all dummies, to control for the variables included in the primary study. For example, AGE identifies the observations in which respondents age is included in the econometric model. It was checked the presence of multicollinearity, i.e. linearly related independent variable, in the model by calculating the Variance Inflation Factor (VIF) (Greene, 2003). According to some references, variables with a VIF higher than 20 should be dropped (Belsley et al., 2005), even if others considered only covariates with VIF lower than 10 (Ezebilo, 2012). The VIF calculation showed no particular problems of multicollinearity, also confirmed by the good overall significance of the models.

4.2.4 Meta-regression Results and Discussions

Results of the meta-regression are presented in table 4.2. It can be noticed that the level of CO2 emissions per capita has a positive and significant effect on WTP. This means that studies carried out in more polluted areas have the chance to provide higher WTP estimates. Such result is reasonable, because people living in polluted areas are probably aware of the pollution problems and may wish to improve the air quality. Conversely, the current level of energy consumption is negatively related to WTP for RE. This result may be originated by the fact that higher levels of energy consumption are reflected in higher energy bill, thus making people reluctant to be willing to pay more. Interestingly, the coefficient for nuclear energy is negative and statistically significant. This means that people living in countries that are nuclear energy producers are less prone to pay for RE. This result may appear surprising, because it could be expected that people living close to nuclear plants may be concerned about security and environmental problems. For example, in France it has been shown that people living close to nuclear reactors are more willing to pay for renewables (Mahieu et al., 2015). Actually, other studies (see, for example, Welsch and Biermann, 2014) highlights how the negative attitude towards nuclear energy has been detected only in the recent years, in particular after the Fukushima disaster. In general, environmental concerns are more intense after a catastrophe (Binder and Blankenberg, 2016).

Table 4.2: Meta-Analysis: WLS results

Variable	Coefficients	Std. Err.	t	Signif.
CO_2	0.297	5.380E-2	5.53	****
CONS	-0.299	5.980E-2	-5	****
NUCLEAR	-0.970	0.293	-3.3	***
SHARE_RE	-2.57E-2	1.857E-2	-1.39	
SH_hydro	4.810E-2	2.087E-2	2.299	**
CV	-0.390	0.204	-1.91	*
PERSONAL	-0.561	0.197	-2.84	***
C_STUDY	-0.89	0.268	-3.31	***
KNOW	-1.22	0.272	-4.51	**
AGE	1.81	0.423	4.29	**
EDUC	-1.980	0.409	-4.84	****
SOLAR	0.399	0.178	2.23	****
WIND	0.542	0.238	2.27	****
ATTITUDE	0.825	0.253	3.26	***
INCOME	-0.627	0.211	-2.97	***
constant	3.32	0.489	6.78	*****
N		151		
R^2		0.570		
AIC		371.6		
BIC		419.8		

Previously, people were almost indifferent or even in favour of nuclear reactors. This evidence comply with the positive WTP for nuclear energy found by Borchers et al. (2007), who surveyed citizens from the United States. It could be interesting to add more empirical evidences to this findings, with future real applications understanding relationships between RE and nuclear energy. The current share of RE ($SHARE\_RE$) has a negative coefficient but not significant, suggesting no effects on WTP.

CV has a negative and statistically significant coefficient, meaning that CV studies provide lower WTP compare to CEs, on average. Similarly, the coefficient for PERSONAL is negative, suggesting that face-to-face interviews are expected to provide cautionary estimates, thus confirming the prescriptions of the NOAA panel (Arrow et al., 1993b). Interestingly, the negative and large coefficient for the variable C_STUDY indicates that in case studies

WTP is considerably lower than in country-level survey. Probably, this result is because in case studies people may figure out that new power plants are likely to be constructed in their region. This may create the so-called NIMBY (not in my backyard) phenomenon (Van der Horst, 2007; Kahn, 2000), making people reluctant to pay. SOLAR and WIND are variables indicating whether the survey asked to pay for an increase of solar or wind energy, respectively. The coefficient for these variables are positive and statistically significant in all the models. This indicates that if energy source is clearly stated in the survey, the probability to have higher WTP increases. Specifying the energy source contribute to a more realistic scenario. In particular in CV applications people are presented with just one hypothetical situation and including energy sources should be preferred to obtain reliable estimates. In CE, attributes are presented in combinations and respondents, when the source of energy is not specified, may focus on the other attributes and still provide consistent choices. The other included variables, namely KNOW, AGE, EDUC, ATTITUDE and INCOME are all dummies controlling for whether such variables were included in the primary study or not. They are all significant, indicating that their explanatory power is high and should always be included in future applications, in order not to run the risk of having biased coefficient. In particular, this holds for CV studies, because covariates explaining WTP always contain personal information. Nevertheless, CE analyses seldom include interactions between attributes and personal characteristics in the utility functions, thus indicating that there is space for their inclusion also in CE studies. In addition, the latest applications of hybrid choice models (Hoyos et al., 2015; Ben-Akiva et al., 2002) show that including personal and attitudinal information in CE is important for modelling preference heterogeneity.

For the purpose of the present research, such meta-analysis provided an overview of the research done worldwide, allowing the reader to understand the topic that are discussed and the level of WTP people stated in many countries. The identified average results may serve as terms of comparison for the convergence validity of empirical studies, in order to test the reliability of WTP figures.

4.3 WTP for REs in Gesso and Vermenagna valleys

In order to understand the level of WTP for REs in Gesso and Vermenagna valleys, a CVM study was carried out.

4.3.1 Conceptual framework

CVM is implemented by creating a hypothetical scenario and a possible policy measure to achieve that scenario (Bandara and Tisdell, 2004; Hanemann, 1994; Welsh and Poe, 1998). By eliciting respondents WTP for the policy, it is possible to foresee respondents acceptability of the policy measure provided (Gios and Notaro, 2001). From an economic perspective, the stated amount that people are willing to pay represent the compensative variation between the pre and post intervention (Hanley et al., 2009). Roughly speaking, the increased utility provided by the hypothesized 100% supply of RE fully compensate the dis-utility of payment for the project and make the individual indifferent among the two alternatives (Ezebilo, 2011). The WTP for the proposed policy is defined by the following indirect utility function:

$$v(p, y^0, e^0) = v(p, y^1 - WTP, e^1) \tag{4.1}$$

Where $v(.)$ is the indirect utility function, p is the price of all the consumed goods, y is the personal income, e is the RE share with (superscript 1) and without (superscript 0) the policy (e1 ¿ e0). (Champ et al., 2012). Data were collected by means of semi-structured questionnaires, administered face-to-face to a sample of inhabitants, that were randomly selected in the Gesso and Vermenagna valleys . A pre-test on 20 respondents was implemented and highlighted the necessity of some small changes, mainly wordings and minor other adjustments. The questions didn't change in the substance after the pre-test, so the answers collected in this step were included in the final computation. The questionnaire, which is available in the appendix of the present chapter, contained 27 questions organized in 4 thematic sections. The first section contained warm-up questions, to get respondents familiar with topic and help them focusing on their experience with RE and power plants. The second section was aimed at gathering information about the perceived impacts that four RE sources have on ecosystem services: ground-mounted solar photovoltaic, wind power, hydro power and forest biomass for energy. Such sources were chosen because they are the focus of investigation of the cited recharge.green project. The third section contained scenario description and WTP question, described in detail in the next sub-section. The forth section was aimed at collection the socio-demographic information of the respondents.

4.3.1.1 WTP question

In a face to face field survey, we asked people if they were willing to pay something more (and how much) in the heat energy bill for a 100% of thermal supply provided by REs. This scenario is coherent with the general purposes of the thesis, because if a user would obtain thermal energy exclusively from woodchip, if connected to the DHP. We included cheap talk in order to provide respondents with as much information as possible about how to reach such RE supply (Lusk, 2003; Mahieu et al., 2012; Morrison and Brown, 2009); in addition, cheap talks were useful to encourage respondents stating the real WTP level and obtaining reliable answers. The question format was a payment card, with a ladder of values (Horton et al., 2003; Meyerhoff and Liebe, 2006), in which respondents had to thick the amount they were willing to pay. This method of eliciting WTP is also known as payment card (Gios and Notaro, 2001). The justification of payment was the necessity for municipalities to have new funds for increasing RE. Subsequently, the selected amounts were subdivided by the stated energy bill they are currently paying. This was made in order to derive a percentage of increase of the energy bill.

4.3.2 Data Analysis

In CVM studies, ordinary least square (OLS) and Tobit (Tobin, 1958) regressions are the most implemented models to explore WTP with open-ended or payment card formats (Ezebilo et al., 2015). Both have advantages and drawbacks. In particular, OLS estimation is the best unbiased estimator when a clear linear relationship in the data can be identified (Puntanen and Styan, 1989). In addition, it requires a smaller sample size compared to maximum likelihood models. However, in the presence of a censored data, as it may happen while modelling WTP, coefficients may be biased. On the other side, tobit addresses the issue of censoring in a better way, but it requires higher sample sizes because of the maximum likelihood estimator. In addition, to-

bit requires some assumptions similar to OLS, such as normally-distributed error terms. Unfortunately, our dataset includes a small sample size problem and censoring at the same time, thus it is unclear which econometric model should be preferred. For this reason, both OLS and tobit are presented, even though results do not vary significantly in terms of marginal effects.
Tobit, as already stated, is capable to better address the CVM data with many zeros, which are typical in such studies (Yoo et al., 2001). Tobit is an econometric model in which the dependent variable is censored, i.e. there is an upper or lower limit. In the case of WTP the model is censored at zero. WTP for the individual i can be expressed, assuming a continuous and quasi-concave utility function, as a function of individuals characteristics:

$$WTP_i = \beta \cdot X_i + \epsilon_i \tag{4.2}$$

Where ϵ_i is a vector of personal characteristics, beta the parameters to be estimated and i the error component. The Tobit model can be defined as:

$$y_i^* = \beta \cdot X_i + \epsilon_i \tag{4.3}$$

Where y^* is the latent (unobservable) variable for WTP_i, x_i a vector of individual characteristics and ϵ_i $N(0,2)$. The observed counterpart for y^*, called y_i, is:

$$y_i = \begin{cases} y_i = y^*, & \text{if } y_i > 0 \\ y_i = 0, & \text{otherwise} \end{cases} \tag{4.4}$$

The Tobit model is estimated through the maximum likelihood estimator. The dependent variables used for the estimation of the model, together with some descriptive statistics and expected signs, are listed in table 4.3. The variable labelled *know* represents the personal knowledge on RE. In order to elicit such knowledge, we asked respondents to state whether they did or not one or more activities connected with RE in the past two years. The activities were: participation to public meetings, education connected with RE, readings on magazines or newspapers, participation to meetings of environmental associations, work in the field of RE, watching tv documentaries or newscasts, discussion with relatives or friends on RE. Each activity had a score based on the importance of the activity for information, the individual score was given by the sum of the scores obtained in each activity. The expected sign of such variable is positive, because it is assumed that the more a person is interested in RE and the more he is willing to increase the

Table 4.3: Variables included in regression models

Variable	Description	Mean	Max	Min	Expected sign
Know	Personal Knowledge of RE (continuous)	8.65	22	0	+
Hydro_fut	possibility of further development of hydropower	2.28	4	0	+/-
Bio_fut	possibility of further development of bioenergy	2.94	4	0	+/-
sex	0 = female 1= male	0.26	1	0	+
age	0 = <30 1 = 31 - 40 2 = 41 - 50 3 = 51 - 60 4 = >60	3.1	4	0	-
household	Number of people in the household	2.82	7	1	-
Env_ass	0 = not member of an environmental associations 1 = member of an environmental association	0.16	1	0	+
income	Classes of income	2.06	6	1	+

share of renewable production. *Hydro_fut* and *bio_fut* represent the personal perception about the possibility to further develop hydro power and forest biomass for energy, respectively. We decided to focus on these two sources of RE because they are the ones most likely to be developed in the area. Other sources, such as wind power or solar photovoltaic, are subject to many constrains due to the protection regimes and the landscape. As already stated in the introduction, the expected sign for these two variables is ambiguous, because it is not certain a priori if the environmental or economic considerations prevail. The other variables included in the model were related to the personal characteristics of the respondents, such as sex, age, number of people in the household, membership of an environmental association and personal income. During the statistical analysis, we controlled for the subsistence of the basic assumption of tobit model, in particular we investigated whether the residuals were normally distributed and homoscedastic (Greene, 2003). The normality of the residuals was investigated graphically by the kernel density distribution. Due to the presence of some heteroscedasticity, sandwich estimator was used to derive robust standard errors (Angrist and Pischke, 2008). The adoption of robust standard errors contributed to a better fit and a higher significance of the estimated parameters. It was also checked the presence of multicollinearity (i.e. linearly dependent variables), The VIF for the included independent variables did not exceed 4.71, meaning that multicollinearity is not a serious problem for the model.

4.3.3 Results and Discussion

Out of the 83 collected questionnaires, only 74 were compiled enough to be useful for the analysis. Three respondents were discarded because they found the questionnaire too long and withdrawn before completion. Despite the number of respondents is not so big, the valleys are very low-density populated and it is difficult to achieve higher number of respondents. The interviewer reported that people were difficult to attract and it was impossible to increase the sample size. We then had to eliminate six protesters who declared 0 WTP because they didn't want other power plants in their territories. These respondents were assumed to be lead by a sort of nimby syndrome (Bell et al., 2013; Van der Horst, 2007) during their decision-making process, so they were excluded from the sample. The final number of observations was 68. Respondents declared an average WTP of 5.2 € per month (13% more, on average, in their energy bill) for receiving an energy provision from renewable sources.

Results of the econometric models are shown in table 4.4, in which both OLS and tobit are presented. As it can be seen, the two models are quite consistent in terms of signs of the coefficients and significance levels, while the magnitude of marginal effects is slightly different. It was decided to suppress the constant term to avoid the possibility to obtain WTP higher than zero in correspondence of zero income. This might cause higher coefficients in absolute values for the other covariates, but at the same time is expected to provide a more realistic link with the income variable. Among the personal characteristics that influenced this result, it can be seen that the personal knowledge and interest towards RE positively affects WTP. This is reasonable because people who actively acquire information in the RE field should be more sensitive towards the topic and, in general, towards environmental consciousness. The expected possibility to further develop hydro power plants in the valleys is positively correlated to the WTP as well. The expected possibility to develop forest biomass for energy purposes has also a positive coefficient, but it is not statistically significant at 95% confidence level. On the other hand, the older people are and the less likely would be willing to pay for RE; in fact, age is negatively correlated to WTP.

Table 4.4: Results for OLS and Tobit models

	OLS		Tobit	
Variable	Coefficient	t-statistic	Coefficient	t-statistic
Know	6.34E-3	1.68*	1.09E-2	2.19**
	(3.77E-3)		(5.00E-3)	
Hydro_fut	3.4619E-2	2.28**	4.20E-2	1.88*
	(1.516E-2)		(2.20E-2)	
Bio_fut	1.457E-2	0.76	2.10E-2	0.75
	(1.930E-2)		(2.7E-2)	
sex	2.5971E-2	0.53	1.7001E-2	0.27
	(4.94E-2)		(6.40E-2)	
age	-1.69E-2	-1.6*	-4.39E-2	-2.53***
	(1.0615E-2)		(1.700E-2)	
household	-2.841E-2	-1.95*	-4.7E-2	-2.37**
	(1.456E-2)		(0.02)	
Env_ass	-2.608E-2	-0.51	-3.599E-2	-0.52
	(5.084E-2)		(6.800E-2)	
income	4.144E-2	2.04**	4.599E-2	1.72*
	(2.035E-2)		(2.590E-2)	
N	68		68	
-Log-Likelihood	-		10.37	
F test	7.49		3.64	
R^2	0.51		-	
Pseudo R^2	-		0.40	
Prob > F	.000		1.60E-3	

Similarly, larger households are less likely to contribute to REs. This maybe because as the number of people in the household increase, the energy bill increases as well, thus making people less positive towards additional expenses. Sex of the respondents seems to be not important for describing WTP, since the coefficient is not statistically different from 0. This result suggest equality of preferences for RE between sexes. Finally, income is positively correlated to WTP, as expected. The positive relationship between income and WTP is highlighted in the literature, because the more people earn and the more are willing to pay for enhancing the environmental quality.

WTP was calculated in both model as a percentage of the current stated energy bill. In particular, the OLS model suggests that people are willing to contribute to REs, on average, with a 13.7% increase in the energy bill, which corresponds to around 6.8 € per month. Differently, the tobit model provided a more cautionary estimate of the WTP, reaching only the 7.6% of the monthly bill (3.8 €). These figures may be easily compared to the values identified in the meta-analysis.

Comparing these results to other papers in the literature, it is possible to see that they are largely comparable to results included in the meta-analysis, even if Italian average seems to be higher. A lower WTP may be explained by income levels and age structure of respondents. Gesso and Vermenagna valleys are non-industrial areas and tourism is only concentrated in the municipality of Limone Piemonte. Thus, income is lower than Italian average. In addition, they are characterized by a population older than the average, with high rates of retirement.

In general, the positive WTP is an index of a positive public acceptance of RE (Zografakis et al., 2010). Such positive attitude could be explained by the fact that nowadays there are several limits to the exploitation of natural resources in the study area, because of the conservation regime affecting approximately one third of the territory. People may have the intuition that using natural resources for energy is one of the few opportunities they have, to increase incomes and attenuate the tendency to emigrate from the valleys. Estimating the total welfare effect of this study is quite difficult, mainly because assessing the total population is an hard task. In fact, according to official registers, local population is around 10.000 inhabitants but, in practice, the number of people living in the area is considerably smaller. Many people moved to close big cities for studying and working, even if their official residence is still in the valleys. We may hypothesize that roughly half of the official population permanently lives in the valleys, with a good level of approximation. For the purpose of this thesis, it was decided to consider the inhabitants of the two valleys as relevant population for estimating global welfare effects, because they include the forested area from which the DHP is assumed to be fuelled. This corresponds to roughly 4000 households, globally [2].

4.4 Conclusions

The present chapter introduced the concepts of social benefits of public and non-market goods and services, showing the main economic techniques for their evaluation. In addition, a meta-analysis of the literature and a field study were presented. The field study investigated public acceptance of RE development in Gesso and Vermenagna valleys, located in the Alps. Results highlighted that local inhabitants have a positive WTP for RE, even if lower than Italian average. A further development of power plants may be seen as an opportunity, rather than a menace to the environment. Probably, the fact that nowadays the population is decreasing and local opportunities for jobs are scarce are key factors for understanding the local acceptance of RE. The exploitation of resources for RE may represent a good strategy for the local development. Like other Alpine contexts, it is difficult for local inhabitants to rely on photovoltaic or wind power, because of legal constrains and potential availability. Hydro power is currently exploited through big power plants, so a good strategy for limiting the negative visual impacts could be to focus on small and micro power plants. Concerning the use of forest biomass for energy, the possibilities for further exploitation are manifold. In fact, most of the public forest is quite old and managed with coppice treatment. Coppice is not good for high quality timber but, on the other hand, the yield for bioenergy is considerable. The conservation regime of the Alpi Marittime Natural Park may represent a limit to such development, because of possible negative effect on local biodiversity and soil fertility. For the cited reason, a careful planning of the activities is fundamental for a sustainable development of the valleys.

[2] The number of households was estimated dividing the population by 2.5, which is the average household size for Piedmont region.

Appendices

List of papers included in the meta-analysis:

Study	Method	Year of the Survey	Survey Administration	N. observations
(Borchers et al., 2007)	CE	2006	personal	19
(Aldy et al., 2012)	CV	2011	Wed-based	3
(Aravena et al., 2014)	CV	2008	personal	4
(Bollino, 2009)	CV	2007	Web-based	9
(Bigerna and Polinori, 2011)	CV	2006	Web-based	9
(Cicia et al., 2012)	CV	2009	telephone	7
(Gracia et al., 2012)	CV	2010	Personal	3
(Hanemann et al., 2010)	CV	2009	Personal	1
(Kaenzig et al., 2013)	CE	2009	personal	3
(Mueller, 2013)	CV	2013	mail	4
(Kim et al., 2013)	CV	2008	Personal	4
(Nomura and Akai, 2004)	CV	2000	mail	3
(Zografakis et al., 2010)	CV	2007	Personal	1
(Zhang and Wu, 2012)	CV	2010	Web-based	1
(Komarek et al., 2011)	CE	2009	Personal	9
(Kosenius and Ollikainen, 2013)	CE	2008	Web-based	6
(Soliño et al., 2009a)	CV	2006	Personal	4
(Susaeta et al., 2011)	CE	2008	Web-based	1
(Yoo and Kwak, 2009)	CV	2008	Personal	2
(Grilli et al., 2015)	CV	2015	Personal	1
(Abdullah and Jeanty, 2011)	CV	2007	Personal	4
(Cameron et al., 2002)	CV	1998	Web-based	9

(Hite et al., 2008)	CV	2005	personal	2
(Streimikienė and Mikalauskiene, 2014)	CV	2013	personal	1
(Soliño et al., 2009b)	CV	2006	personal	2
(Navrud and Bråten, 2007)	CE	2005	personal	4
(Kontogianni et al., 2013)	CV	2007	personal	6
(Hanley and Nevin, 1999)	CV	1998	personal	3
(Vecchiato and Tempesta, 2015)	CE	2013	Web-based	3
(Mozumder et al., 2011)	CV	2008	Web-based	9
(Ivanova, 2012)	CV	2004	mail	3
(Oliver et al., 2011)	CV	2008	telephone	1
(Guo et al., 2014)	CV	2010	personal	6
(Sims, 2013)	CV	2003	telephone	3

QUESTIONNAIRE TO CITIZENS

"Social perception on Renewable Energies"

Ami of the present questionnaire is understanding citizens´opinion about renewable energy development in Gesso and Vermenagna valleys.

The questionnaire was created by the European Academy (EURAC) of Bolzano, the Agricultural Research Council and Economics and the University of Trento, in collaboration with the Maritime Alps Natural Park. This survey is created for scientific purposes only, collected data will be computed and published only in aggregated form, according to the law D. Lgs. 196/2003. Thank you for your precious contribution.

Date ___________________ Municipality of residence _______________________________

1. Do you know what are renewable energies?

   Yes ◻ No ◻

2. Are you in favour of renewable energy?

   Yes ◻ No ◻ I don´t Know ◻

3. In your opinion, how much information and communication may influence public opinion on renewable energy?

Very much	Much	not much	not at all	I don´t know
◻	◻	◻	◻	◻

4. In the last two years, did you do one of the following activities on renewable energies?

	Sì	No
Public meetings	◻	◻
Educational studies	◻	◻
Read of magazines of newspapers	◻	◻
Read Journal articles	◻	◻
Meeting of environmental associations	◻	◻
Television or radio newscasts	◻	◻
Job in the field of renewable energy	◻	◻
Discussion with family or friends	◻	◻

5. At present, how much is **ground photovoltaic** developed in the valley? *Show picture 1*

Very Much	Fairly Much	Not Much	Not at all	I don´t know
☐	☐	☐	☐	☐

If answered not much, not at all or I don´t know, go to question n. 8.

6. At present, how much is **wind power** developed in the valley? *Show picture 2*

Very Much	Fairly Much	Not Much	Not at all	I don´t know
☐	☐	☐	☐	☐

If answered not much, not at all or I don´t know, go to question n. 10.

7. At present, how much is the use of forest biomass developed in the valley? *Show picture 3*

Very Much	Fairly Much	Not Much	Not at all	I don´t know
☐	☐	☐	☐	☐

If answered not much, not at all or I don´t know, go to question n. 12.

8. At present, how much is hydropower developed in the valley? *Show picture*

Very Much	Fairly Much	Not Much	Not at all	I don´t know
☐	☐	☐	☐	☐

If answered not much, not at all or I don´t know, go to question n. 15.

9. Do you think it is still possible to develop renewable energy in the two valleys?

	Very Much	Fairly Much	Not Much	Not at all	I don´t know
Solar	☐	☐	☐	☐	☐
Wind	☐	☐	☐	☐	☐
Forest Biomass	☐	☐	☐	☐	☐
Hydropower	☐	☐	☐	☐	☐

10. How muchi s your current energy bill ? _________________________ €

11. Would you be willing to pay something more in your energy bill for an energy supply originated exclusively from renewable sources? We invite you to answer to this question imaging that you have to pay now. If you choose to pay you will have less money for other purchases.

Yes	No
☐	☐ (go to question 20)

12. If yes, what is the **maximum amount** you would be willing to pay?

0,50 €	☐	7,00 €	☐	15,00 €	☐
1,00 €	☐	8,00 €	☐	16,00 €	☐
2,00 €	☐	9,00 €	☐	17,00 €	☐
2,50 €	☐	10,00 €	☐	18,00 €	☐
3,00 €	☐	11,00 €	☐	19,00 €	☐
4,00 €	☐	12,00 €	☐	20,00 €	☐
5,00 €	☐	13,00 €	☐	Other ________€	☐
6,00 €	☐	14,00 €	☐		☐

13. **If yes,** Could you indicate why you are willing to pay?

	Very Much	Fairly Much	At all
In the long run Energy expenses will be lower.	☐	☐	☐
Municipalities will manage energy supply with positive earnings	☐	☐	☐
Renewables reduce pollution	☐	☐	☐
I believe in health benefits from renewables	☐	☐	☐
Renewables contribute to save the planet.	☐	☐	☐
Renewables are important in the place where I live	☐	☐	☐
Other (specify)___________________________________	☐	☐	☐

(go to question 21)

14. **If no,** Could you indicate why you are not willing to pay?

The bill is already high	☐
I don´t think there are benefits in developing renewable energy	☐
I don´t want to pay more for the same service	☐
I don´t think the scenario is realistic	☐
I don´t want power plants in my territory	☐
I am independent from the energetic point of view	☐
Other (specify)___________________________________	☐

15. Gender:

□ F □ M

16. Age:

□ Less than 30 years old □ 31-40 years old □ 41-50 years old □ 51-60 years old □ More than 60 years old

17. Titolo di studio:

□ Licenza elementare □ Licenza media □ Diploma di scuola superiore

□ Laurea □ Post-laurea

18. Employment status:

□ Full-employed □ Unemployed □ Retired □ Student

19. Number of people in your household ______________________

20. Are you a member of some association?

	Yes	No
Cultural associations	□	□
Environmental associations	□	□
Sport associations	□	□

21. Average monthly income?

Less than 1000 €	□
Between 1000 € and 1500 €	□
Between 1501€ and 2000 €	□
Between 2001 € and 2500 €	□
Between 2501 € and 3000 €	□
More than 3000 €	□

Chapter 5

Economic value of ecosystem services and impacts of harvesting biomass

5.1 Introduction

An important issue to be addressed, while planning the development of REs, is the potential impact on the environment. Natural ecosystems provide a multitude of benefits to human society (assessment MEA, 2005) such as natural resources (food, water, wood for construction and for bio-energy, fodder and medicinal plants), pollination, clean water provision, protection against natural risks (landslides, flooding, rockfalls and avalanches), carbon sequestration and storage, tourism and recreation (Fisher et al., 2009; Notaro and Paletto, 2012; Vihervaara et al., 2010). Such benefits are called ecosystem services (ES), which is a terminology introduced by (Ehrlich et al., 1983), replacing the previous concept of ecosystem function. The use of natural resources (not only for energy but also for other purposes) affects the environment, positively or negatively. Potential effects of human activities on natural ecosystems should be clearly identified, so that negative impacts can be (where possible) minimized.

5.1.1 Ecosystem Services

ES are defined as conditions and processes through which natural ecosystems sustain and fulfil human life (Daily, 1997) and the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 2016). They are fundamental for the prosecution of life on earth and should be therefore preserved. The focus of this definition is the relationship between humans and nature, which is less explicit in the term "ecosystem function". Although the ES concept is not new, it started gaining importance in the recent years, in particular after the decision of European Union to include them in the European political agenda (environmental, agricultural and biodiversity policies) (Maes et al., 2012). Accounting the comprehensive set of benefits derived from nature is an interesting strategy to better address policy and management decisions, as proposed by Westman (1977). In order to facilitate ES identification and quantification, several classifications were proposed across the years. In particular, a first categorization was proposed by the Millennium Ecosystem Assessment (assessment MEA, 2005):

- Provisioning services;;
- Regulating services;

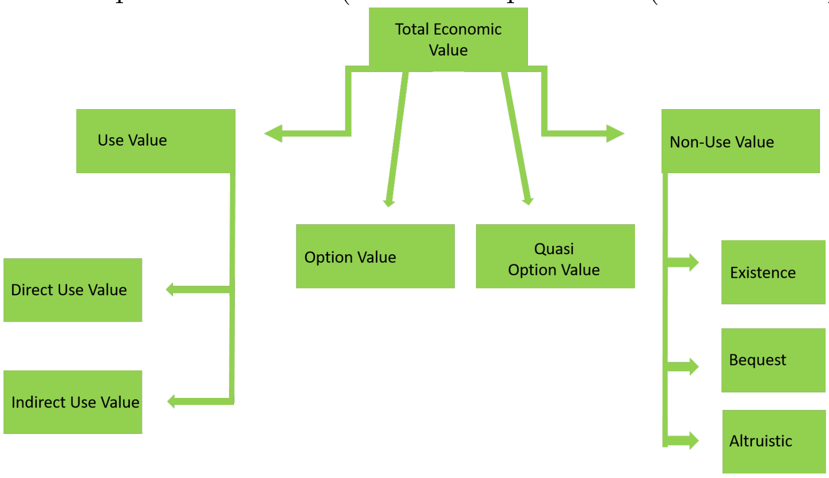
- Cultural services;
- Supporting services.

Provisioning services are all the material goods that can be extracted from the environment (for example, timber, fish, berries and mushrooms etc...). Regulating services are instead related to the role of ecosystem in the regulation of ecological processes (i.e. water and climate regulation). Cultural services include non-material benefits provided by ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Finally, supporting services are necessary for the production of all other ecosystem services. These include services such as biodiversity, nutrient recycling, primary production and soil formation.

From the very beginning, this four-category classification raised some doubt, in particular because the difference between regulating and supporting services was not completely clear. For this reason, following classification dropped out the category of supporting services, in particular in the classifications proposed by CICES (Haines-Young and Potschin, 2013) and TEEB (Mace et al., 2012). The new reclassification of ES, which excluded the supporting services, has been designed to prevent double counting (Hein et al., 2006). Double counting are particularly worrisome in economic application, because it may lead to a considerable overestimation of the worth of nature.

Referring to Eade and Moran (1996), in the decisions related to the natural resources management two key-aspects must be taken into account with special regards on different ES categories: the economic value of benefits provided by ES and the spatial distribution of these benefits. Still today, the economic value of ecosystem goods and services are often little considered in decision making due to lack of awareness of their value for human well-being (Grt-Regamey et al., 2008). Nevertheless, problems exist to define their exact value, for instance to compare exploitation and conservation costs of natural resources on the long term. In order to overcome this limit, several methods have been developed and applied for the assessment of the economic values of ES (Mitchell and Carson, 1989; Rosenberger and Loomis, 2001; Garrod and Willis, 1999). These methods i.e. contingent valuation, choice experiment allow the assignment of a monetary value to ES without a market.

Figure 5.1: Components of TEV (source: adapted from (Pearce et al., 2006))



5.1.2 Total Economic Value

The ES concept is strictly connected with the Total Economic Value (TEV) of natural resources. TEV is a concept developed within the discipline of cost-benefit analysis (CBA), relating to the benefits people obtain from having a certain quantity (or quality) of natural resources, compared to not having it. In this framework, identifying ESs is an important step for the assessment of the TEV for a given area. As it can be seen from figure 5.1, TEV is the net sum of four main components. Use values are related to the benefits obtained by humans from the use of certain environmental goods. Use values can be split into direct and indirect use values. The first category includes benefits people obtain because of consumption of natural resources. Timber is a typical use value of forests. Indirect use values are connected with non-removable products in nature. For example, the value of a forest for hydro-geological protection is a non-use value, because people benefits from the capability of forest to stabilize the soil without removing resources from it. Option values are related to the opportunity cost of using the natural resource instead of conserving for future uses. There is a slight distinction between option value and quasi-option value. The first is a value traditionally linked to the interest rate, meaning that intertemporal decision between consumption and conservation may be affected by expectation of the present and future value of the resource. Quasi option value refers to the opportunity cost of conserving the resource, because in the future scientific discoveries may suggest alternative uses (still unknown) that increase the

vealue of the resource. Finally, non-use values are related to the value of the environment *per se*, without considering benefits for people. This category include existence, altruism and bequest values. For example, conserving a particular species in its natural environment may be important for many individual even if they do not see it (Loomis et al., 2000).
Valuing ES is extremely beneficial, for improving the standard national accounting and estimate TEV. The System of National Accounts (SNA), introduced in the early 50s, is nowadays thought to be too weak for describing the real status of the national assets (Kendrick, 2012). In particular, the focus of criticism is related to the environmental resources, which are undervalued by SNA but they have a great importance in the framework of sustainability. In the recent decades, it was pointed out that integrating SNA with environmental considerations may be useful for highlighting interactions between the economic system and the environment (Scarpa, 1993), understanding at the same time how natural capital is depleted by economic activities. The evaluation of non-market benefits of forest ES goes in this direction, providing additional information to better understand the worth of natural capital, which is not only given by the marketable goods but also by passive use and non-use values (Adamowicz et al., 1998). The green accounting approach foresees that any change in the stock of natural resources should be carefully considered, because it affects the future generation of both market and non-market benefits.

5.1.3 Valuing and mapping ES for energy policies

ES are not homogeneous across landscapes but rather heterogeneous in space (Fisher et al., 2009). In other words, ES are linked to the spatial dimension of the defined zone in which those services are provided (Busch et al., 2012). The quantification and mapping of ES is considered a fundamental requirement for planning at the landscape scale (i.e. land use changes, renewable energies development, silvicultural treatments) (Hauck et al., 2013). The approaches and indicators used for a spatial mapping of ES has been documented in detail by literature reviews (Egoh et al., 2012; Martnez-Harms and Balvanera, 2012; Maes et al., 2013). The spatial extent of ES are very important when planning the use of forest biomass for energy. In fact, the withdrawal of resources from the environment causes an impact on forest

ecosystem that should be considered, in order not to jeopardize its sustainable use.
Starting from these considerations, the main objective of the chapter is to develop a method to evaluate ES, provide accurate and detailed information about their spatial distribution and assess how this value varies when resources are extracted for energy purposes. The spatial distribution of the flow of benefits supplied by ES provides important information to support the decision makers (i.e. planners and managers) in the definition and implementation of the landscape planning strategies in the different portions of the territory. Besides, the economic evaluation of ES can be provide useful information to understand the worth of natural capital, following the green accounting approach. In a first stage of the work, main ecosystem goods and services supplied by forests were evaluated from the economic point of view using appropriate economic valuation methods. In the second stage, the values of ES were made spatially explicit using a Geographical Information System approach (using GRASS and Quantum-GIS environments) and taking into account the ecological characteristics of each ecosystem service. Finally, by means of overlapping techniques, it is possible to estimate the variation of ES values in the areas where biomass is harvested. In this way, it is possible to quantify the effects of biomass use on the value of natural capital, such information can be used to apply CBA more exhaustively.

5.2 Methodology

There are three main stages of analysis, which will be described separately: economic valuation of ES, ES mapping and ES economic impact assessment. Economic techniques used belongs to the group of non-demand based methods. Each ES was evaluated considering the annual flow and not the stock available in forest. This means, for example, that timber production is evaluated considering, as quantity of timber, the annual increment of forest, not the entire growing stock. This allows estimating the annual value, rather than the global worth of forest, which is a more suitable measure for estimating the difference in forest value before and after the extraction of resources.

5.2.1 Valuing ESs

Non-demand based economic evaluation techniques include economic valuations in which individual preferences are not considered, neither from revealed nor from stated data. In general, such techniques are applied by estimating the value of production (for tangible goods) or the costs sustained to replace the natural resource, in case of damages of disappearance. In this contribution four ESs are considered: timber and fuelwood, carbon sequestration, natural hazard protection and recreation. Such ESs were chosen because they are very important, easily valuable and cover the three categories of ES suggested by TEEB and CICES. Specifically, timber and fuelwood provision are included in the sphere of provisioning services, carbon sequestration and hazard protection are regulating services and, lastly, recreation is the most studied cultural service. This list is of course not exhaustive, in fact biomass use may impact also on other ESs, but it was very difficult to evaluate other services with non-demand based methods without double counting. According to Turner et al. (1992), such techniques are useful because they provide interesting information in project appraisal, even though it is argued that they tend to overestimate the costs of projects.

Timber and Fuelwood production The sum of timber and fuelwood production is considered as the value of the main forest product. These values were estimated though a market approach, aiming at estimating the value of production, with the following formula:

$$GPV_w = \sum_{i=1}^{N} Q_{ti} \times p_{ti} + \sum_{i=1}^{M} Q_{fi} \times p_{fi} \tag{5.1}$$

Where GPV_w is the gross production vale of wood products, Q_{ti} is the quantity of timber, which is possible harvesting according to the prescribed yield, of the tree species i; p_{ti} is the unit price of timber for tree species i and N represents the number of tree species in forest. Similarly, Q_{fi} is the quantity of fuelwood, of the tree species i that can be extracted; p_{fi} is the unit price of fuelwood for tree species i and M represents the number of tree species in forest. Quantities of timber and fuelwood were provided by local forest managers, whereas prices were derived from the local wood market statistics.

Carbon sequestration Carbon sequestration was evaluated with an approach similar to value of production, using volunteer carbon market prices as unit price. The procedure used to estimate the quantity of carbon stored follows the For-Est approach (Federici et al. 2008), based on the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land use, land-use Change and Forestry (IPCC, 2003). IPCC guidelines are focused on accounting the stock of carbon available in the five main pools (above-ground and below-ground biomass, deadwood biomass, litter and soil). In order to have an estimation of the annual forests capacity to transform atmospheric carbon into biomass, we considered only above-ground and below-ground biomass. The choice of excluding the other pools was driven by their intrinsic characteristics, the carbon stock of litter, soil and deadwood is characterized by multi-year dynamics and changes in the annual increment of carbon stock are negligible. In addition, understorey vegetation was not considered as well, due to the lack of the necessary data. The quantity of above-ground biomass (AGB) was estimated with the following formula:

$$AGB = \sum_{i=1}^{N} I_i \times WDB_i \times BEF_i \tag{5.2}$$

Where I is the annual increment (expressed in m^3/ha) of each tree species i, WBD is the wood basal density and BEF the biomass expansion factor coefficient. Similarly, below-ground biomass (BGB) was estimated with the following formula:

$$BGB = \sum_{i=1}^{N} I_i \times WDB_i \times R_i \tag{5.3}$$

Where R is the roots/shoot ratio, which converts AGB in roots biomass. The coefficients BEF, WBD and R vary with tree species and were taken from the literature (Vitullo et al., 2008). Once the total woody biomass was estimated, carbon was assessed to be a percentage of the total. In the literature, carbon content is assumed to be about 50% of total biomass (Sollins et al., 1987; Coomes et al., 2002). Finally, the quantity of carbon was multiplied by the average carbon price, taken from the voluntary European market, in order to derive the value of carbon sequestration V_{cs}:

$$V_{cs} = [(AGB + BGB) \times 0.50] \times p_c \tag{5.4}$$

in which p_c is the carbon price in the voluntary energy market, assessed to be 4.59 €/ton stored (Peters-Stanley and Yin, 2016).

Table 5.1: Engineering works used for the replacement cost method

Protection Typology	Surface (ha)	Engineering work	Unit cost (€/m2)	Lifetime
Soil erosion (indirect protection)	4.088	Hydroseed	3.82	15
Riverbank protection (indirect protection)	50.6	Geotextiles	14.65	20
Landslades (direct protection)	256.69	Simple palisade	92.56	25
Avalanches (indirect protection)	810.26	Nets to hold back the snow	265.3	25

Hazard protection Evaluation of hazard protection includes both direct and indirect protection (Dorren et al., 2004). Direct protection refers to the capability of forests to protect human lives and activities, for example from avalanches and landslides. Indirect protection, conversely, is the property of stabilizing soils from erosions and regulation of water streams. Protection against these natural hazards was economically evaluated though the replacement cost method, consisting in calculating the cost of anthropic capital necessary to replace the forest in the areas where timber and woodchip are extracted. Another common non-demand based technique used to value hazard protection is the avoided cost method, consisting in assessing the value of damages occurred in the absence of the environmental good (in this case, forest). However, this method usually return very high figures, because it takes into account potential death of people, damages to buildings and other infrastructure. Given that it was intended to provide cautionary estimates of forest TEV, the option of choosing the avoid cost was discarded. The resulting formula for the annual value is a sum of the actual value of the N engineering works to create:

$$V_p = \sum_{i=1}^{N} \frac{uC_i \times r \times (1+r)}{(1+r)^{t_i - 1}} \tag{5.5}$$

Where V_p is the annual value of protection, uC_i represent the unit cost of engineering work i, r is the environmental discount rate (assumed to be 2%, according to Freeman (2003)) and t_i the lifetime. In particular, as visible in table 5.1, it was assumed to replace the indirect protective function with hydroseed and geotextiles (the latter for riverbank protection). For what concerns the direct protective function, a simple palisade was hypothesized for landslide protection and nets to hold back the snow for avalanches. Unit prices were retrieved from the official price list for public work of the piedmont region [1].

Outdoor Recreation Recreation is one of the most studied non-market service that people derive from nature. The commonly used techniques for evaluating the recreational functions of an area are travel cost (TC) and contingent valuation (CV), both requiring a field survey to collect data (Hotelling, 1947; Notaro and Paletto, 2011; Notaro et al., 2008). Due to lack of necessary resources it was not possible to carry out a field survey in the study area, thus at the beginning it was explored the possibility to retrieve data from public databases to apply a zonal TC. Such data were not available for the entire study site, thus it was decided to use the Benefit Transfer technique (BT). BT consists on examining the results of surveys undertaken in specific contexts (study sites) and transferring them to similar unstudied situations of interest for policy making (policy site) (Leon-Gonzalez and Scarpa, 2008). BT has some limitations that are worth to mention. In particular, it is considered a second best solution, because it is based on previous studies rather than *ad hoc* surveys. Transferring the value of other studies might provide bias estimations if policy and study sites are different. Moreover, practitioners tend to agree that contingent valuation estimations, being based on a specific hypothetical scenario (”contingent” to a specific site), are not good to be transferred. Rather, travel cost methods might be more robust measure to transfer (Zandersen and Tol, 2009). Despite this negative aspects, BT is probably the most used technique in cost-benefit analysis, because it is cheap in terms of both money and time. BT can be carried out by transferring the value function, a point estimate or average values from a meta-analysis of studies (Wilson and Hoehn, 2006). The latter solution is seldom thought to be the most reliable, because it considers a wide range of different site characteristics. For the present study, we used the method of average value transfer recreational services using a measure of central tendency of all subsets of relevant studies as the transfer measure for the policy site issue (Bartczak et al., 2008; Rosenberger and Loomis, 2001). After an accurate literature review, we collected 28 papers

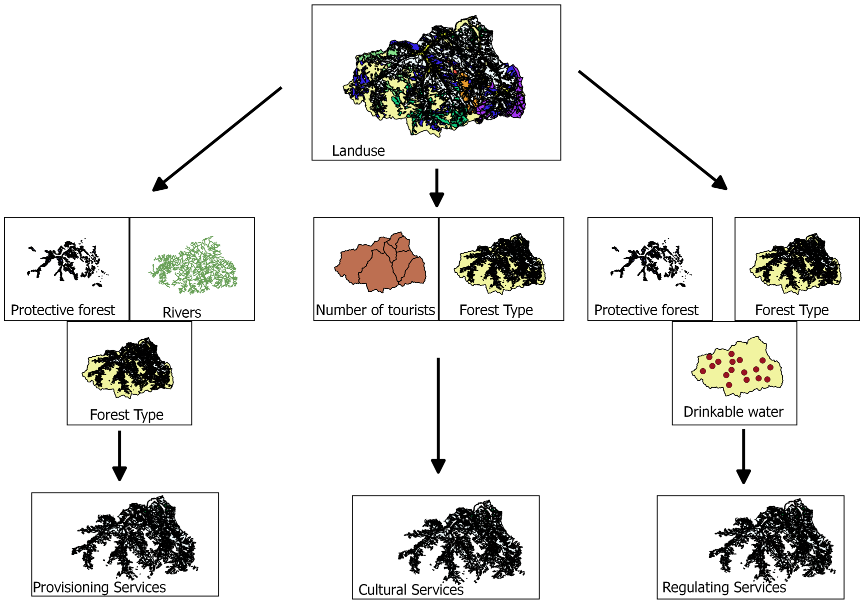
[1] http://www.regione.piemonte.it/oopp/prezzario/

dealing with recreational values in European mountain forests. We decided to focus only on European mountain forests because of the necessity to have data as much comparable as possible between the study sites and the policy site, as prescribed by Rosenberger and Loomis (2001). In addition, we considered only studies assessing the recreational values of hiking, free camping, sightseeing, walking and picnicking. Other outdoor activities - such as hunting recreation, mushrooms and berries picking and fishing - were excluded in order to avoid double counting problems with the other ES evaluated. A detailed description of the BT approach is available in Grilli et al. (2014). The meta-analysis allowed the identification of a mean welfare measure for the benefits of European mountain forests, as well as different values for different tree species composition, in particular for mixed, pure coniferous and pure broadleaf forests.

5.2.2 ES mapping

Spatial analyses were carried out following prescriptions of the literature, in particular Paletto et al. (2015b), which provided mapping methods for the economic values of ESs. The economic values of the benefits provided by ES were made spatially explicit taking into account the ecological characteristics of each ecosystem service and using a GIS approach (Quantum-GIS). Thereby we aim at reproducing causal relationships between primary and secondary environmental variables and specific ES (Maes et al., 2012; Troy and Wilson, 2006; Naidoo and Ricketts, 2006). The methodological framework used for mapping ES is shown in figure 5.2. A set of thematic layers representing key variables was used. Layers were overlapped to analyse the spatial distribution of ES benefits. The used key variables were: (1) land uses; (2) forest types, distinguishing among pure conifer forests, pure broadleaved forests and mixed forests; (4) forest tracks and paths network; (5) hydrographic network (rivers and streams); (6) type of forest protection (direct or indirect protection); (7) Boundaries of municipalities. Such layers are very common in ES mapping and are considered frequently in spatial analysis (Kareiva, 2011; Martínez-Harms and Balvanera, 2012; Egoh et al., 2008). The map of land uses was used to distinguish the areas to be evaluated, i.e. forests. According with the categorization of ES shown before, thematic layers were combined by using an overlay procedure. The resulting map is characterized by a number of polygons which express the values of ES supply. Regard-

Figure 5.2: Graphical representation of ES mapping (Adapted from: (Rodriguez Garcia et al., 2016))



ing the provisioning services, the spatial distribution of timber and fuelwood was accounted considering the different forest types. Concerning regulating services, the carbon storage was mapped considering the difference among forest types. The value of indirect protection against natural hazards was assigned to the buffer of the rivers and streams (indirect protection), while the value of the landslides protection was attributed only to the direct protective forests. According to Hawes and Smith (2005) a buffer of the river width 30 m was used (15 m for side).

Finally for what concerns cultural services, the value of outdoor recreation was assigned taking into account land use, forest type, forest tracks and paths network, and number of tourists. In other words, the value attributed to each individual forest polygon is the average value of outdoor recreation considering the tourism attractiveness of the polygon (forest type and altitude). Moreover, the forest areas with a high recreational value were identified using a topographical map by 19 local stakeholders. Local stakeholders were identified considering their expertise and knowledge of local context (Grilli et al., 2015a). Consequently, the outdoor recreational values derived by meta-analysis have been applied only in the areas with high recreational values following the statements made by stakeholders.

5.2.3 Assessing the Economic Impact

Assessing the economic impact of biomass use on ESs is not straightforward, and the procedure was implemented after consultations with experts in the sector (Grilli et al., 2015a, 2016d), with the aim of better understanding the relationship between the extraction of resources from forests and the effect on ES provision. According to a recent review of the literature on RE impact on ESs (Hastik et al., 2015b), provisioning services and regulating services are affected by biomass extraction in a negative way. In these cases, it was assumed a linear negative impact in each forest management unit in which biomass is collected. More formally:

$$V_{t1} = V_{t0} - V_{t0} \times (Q_1 - Q_0) \tag{5.6}$$

Where V_{t1} and V_{t0} are the value after and before biomass collection, Q_1 and Q_0 the amount of wood in forest after and before extraction.

On the other hand, assessing the effect of bioenergy harvesting on recreation is less clear. The same reference reports only minor and temporary impacts, only during harvesting activities. Other authors, conversely, suggest a positive impact from the tourist point of view. This happens because gathering biomass involves collecting waste and residuals from tourist paths and reducing the presence of litter and deadwood. These activities create a sense of well-preserved environment, which is usually preferred by visitors (Gundersen and Frivold, 2008; Tahvanainen et al., 2001). It is difficult to provide an objective and precise quantification of this effect. For this reason, in order to have a measure of the positive externality provided by biomass harvesting on tourism, it was undertaken a survey to some local expert in the fields of nature conservation and energy planning, in which they were asked to state the effect of biomass on a 5 point-Likert scale. The mean value of the effect indicator was then converted into a percentage, expressing the share of economic loss or benefit following the use of forest biomass for energy. The formula for the conversion was the following:

$$100 : I = m : x \tag{5.7}$$

Where I is the width of the interval (ranging from -2 to +2), m_j is the mean score, obtained from the answers of experts, and x the percentage of impact. A full description of the survey is available in Grilli et al. (2015a, 2016d).

This procedure was automatized in GRASS GIS by a specific module within the **r.green**, called *r.impact*. The complete functioning of the module is described in Grilli et al. (2017).

5.3 Application to the case study

The described procedure was applied to the valleys of Gesso and Vermenagna in Italy. Results regarding the economic value of ESs, their mapping and expected economic impact will be shown in separate sections.

5.3.1 ES Values

Results of the valuation of ES are summarized in table 5.2, which include average, maximum and minimu values. It can be noticed that, among provi-

Table 5.2: ES economic assessment results

ES	Mean Value	Max	Min
(€ / ha)			
Timber	131	250	10
Fuelwood	14	21	5
Soil erosion Protection	568		
Landslides Protection	707	-	-
Avalanches Protection	3765	-	-
Carbon Sequestration	48	61	10
Recreation	26.1	95.4	24.5

sioning services, timber production provides the highest annual benefit, with an average value of 131 €/ha per year. Highest values are recorded for silver fir forests. On the other hand, lowest values were found for oak and shrubs. While it is reasonable thinking that shrubs show a small timber value, because the quality is very low, the low figure for oak forests can be explained by a very small amount of prescribed yield. Fuelwood is the only other provisioning ES considered in the study; in this case, values are much smaller, with an average value of 14 € / ha. Concerning protection, only average values were estimated for three different environmental hazards (soil erosion, landslides and avalanches). In this case, the indirect protection against soil erosion is low-valuable, as well as protection against landslides, compared to the protection against avalanches. Such result is influenced exclusively by the engineering work necessary to replace forest functions. Carbon sequestration has an average value of 48 € / ha, with a maximum of 61 and a minimum of 10. This result is highly influenced by the carbon price, which is at present very low, and most likely do not reflect the actual value of carbon for air and ecosystem quality. Finally, recreation was estimated to be, averaged across tree species, 9.72 € per visit. This figure rise up to around 17 € per visit in mixed forests, while it is lower for conifers (7.7 € per visit) and broad-leaf forests (4.8 € per visit). Considering extension of forest and number of tourists, these figures were converted in values per hectares, to be comparable with the evaluation of other ESs. The mean value per hectare is around 26 €, the lowest being 24.5 and the highest 95 €.

5.3.2 ES mapping

The economic value of ESs, previously described, were mapped using GRASS GIS for vector computation, while QGis was used for drawing maps, which are included in appendix of the present chapter. Figure 3 shows the spatial extent of provisioning services in the study area, calculated as the sum of material goods that can eb extracted (timber and fuel wood). The portions of forest with zero value is the non-productive forest, i.e. without prescribed yield of timber. Conversely, the value of productive forest ranges between 15.70 € / ha to almost 300 € / ha. Differences are mainly related to tree species composition, in fact greener polygons are associated with more costly timber. In particular, European larch and silver fir were found to be the most valuable tree species for timber(with a price of 110 and 90 € / ton, respectively), but they are only located in small part of the forest. Most of productive forest is cover with breadleaves, i.e. beech and chestnut, with a lower value per ton (40 € / ton). Least valuable areas contain either only fuelwood or shrubs. Picture 4 includes the spatially-explicit dimension of regulating services, containing carbon sequestration and hazard protection. It can be immediately noticed that they are much more valuable than provisioning services in absolute terms. this result is heavily affected by hazard protection, in particular for what concerns the direct protection against landslides and avalanches. This result is a direct consequence of the high cost for surrogate works but, at the same time, it is a reasonable. In fact, the absence of such protective function, damages to humans and infrastructure may be relevant. Least valuable forest, in terms of regulating services, is the non-protective part, which is value only in terms of carbon sequestration potential. Figure ranges between 10 € / ha Lastly, recreational values are visible in figure 5. In this case, values largely depend on tree species composition and number of tourist in the different municipalities. Values range between 7 € / ha and 622 € / ha. Limone Piemonte is the municipality with the highest recreational value. This is the municipality with the highest number of tourist annually, thus the result is reasonable.

5.3.3 Impact of Biomass harvesting

As already cited in the methodological section, provisioning services and regulating services were assessed to be negatively affected by the use of forest biomass for energy. While the negative impact for regulating services is quite obvious, a negative effect of biomass harvesting on provisioning services is less clear. In fact, the use of biomass residues represents an added value to traditional forest products. However, for the present analysis we rely on the findings of Hastik et al. (2015b), which reported a general negative impact of biomass harvesting on provisioning services, after a collection of several papers in this subject. Conversely, a small positive impact of tourism was estimated after an expert survey. Specifically, the positive impact of bioenergy harvesting on recreational activities was estimated to be 8%. It is assumed that the economic values of ESs change only in those area where prescribed yield is higher than zero.
The global effect of extracting resources from forest was assessed to be negative, i.e. a cost. In particular, the annual decrease of the value of natural capital was estimated to be 200K €.

5.4 Discussion

Forest management decisions, in an inter-temporal framework, may be seen as the opportunity cost of using the resource today instead of in the future. When prescribed yield is lower than annual increment, the stock of forest capital is not affected and will be available in the future. However, the withdrawal of biomass prevents future increases in such stock, at least part of it. Thus, harvesting certain amounts of biomass has an impact on natural capital growth that should be considered; decisions to be taken are different when the decision maker aims at preserving forest TEV or increasing its value. Not all ESs are negatively affected by biomass harvesting. For example, an intelligent planning of timber withdrawal may contribute to a better environment for other trees' growth and, at the same time, increase landscape amenity for recreational activities. Nevertheless, negative impacts on TEV have to be taken into account and, given that it is very difficult to foresee precisely the global effects, it was decided to rely on the findings of Hastik et al. (2015b), which documented negative externalities for provisioning and regulating services. This choice is also in line with the precautionary principle.

It can be argued that non-demand based economic techniques do not reflect a "real" estimation of the economic value of the ES, because they do not take into account individual preferences. The market approach used for valuing provisioning services is not affected by such critique, because market prices reflect individuals' WTP for that good. However, for what concerns replacement cost and, partly, the market price approach for carbon sequestration, questions about validity of the estimations may arise. However, it can be reasonably assumed that, if forests were destroyed, avalanches and landslides may become a serious problem and people may demand this service. Thus, it is reasonable to assume that people would be willing to contribute for, at least, the cheapest solution assuring protection, i.e. the engineering works included in this work. Carbon sequestration was estimated using voluntary market prices, it is therefore a market approach. Nevertheless, the economic actors demanding carbon credits are companies and not individuals. Probably, the shadow price for carbon sequestration of individual is higher and a stated preference approach might be useful to confirm this hypothesis.

In this chapter, it was shown that protection against natural hazards has an extremely valuable function in forests. Such result is confirmed by several other studies, carried out using different techniques (Notaro et al., 2008; Olschewski et al., 2012; Notaro and Paletto, 2012). Together with hazard protection, provisioning services showed high monetary values. This is also reasonable, because timber and other products are important goods people derive from forests and are considered extremely valuable (Rist et al., 2012; Seidl et al., 2007). The value of recreation was assessed to be between roughly

5 € / visit and 17 € /visit, which is in line with other studies; in particular, the high recreational value of mixed forests seems to be a very well known phenomenon (Grilli et al., 2014; Fizaine and Court, 2015). In general, the rank of ESs monetary values seems to be similar to other TEV studies (Grilli et al., 2015b). The value of carbon sequestration is particular low, however it was highlighted that the result is affected by the low carbon price. As already stated before, a future improvement may be represented by a stated preference exercise to value carbon sequestration, in order to compare individual preferences with non-demand based results.
Average values of ESs were included in a GIS environment to create spatially distributed estimates of ESs, based on geomorphological characteristics of the forest. Forests do not provide evenly distributed ES but, rather, different forested areas provide different ESs, both in terms of type of ES and quantity. In this way, it was possible to identify forested areas producing more than one ES. In Gesso and Vermenagna valleys, highest values for provisioning services were found in silver fir and larch forests, in particular in the municipalities of Roccavione and Roaschia. Conversely, regulating services were more valuable in some scattered areas within the two valleys, in particular in those places were protection against avalanches and landslides are is higher. Finally, recreation is important in tourist places, in particular in the municipality of Limone Piemonte. The spatial extent of ES assessment allows understanding which category of ES are likely to be affected in different areas of the forest, giving at the same time information to decision makers for more effective decisions.

5.5 Conclusions

This chapter introduced the concept of natural capital and TEV, providing at the same time a methodology for valuation, mapping and assessing economic impacts of biomass on forest values. The procedure was applied to the Gesso and Vermenagna valleys; results indicate that the general impact of biomass harvesting on natural capital is negative, thus producing negative externalities. The global effect can be considered a cost of around 200 thousands € / year.
The main advantage to use such an approach to forest management is the possibility to include alternative uses of forest resources in decision making.

In fact, the effect of biomass harvesting on use and non-use values of forest is taken into account, providing an estimation of the general effect of activities on forest capital. At the same time, the spatial extent of the analysis allows understanding which portions of forest are likely to be heavily affected and provide specific policies case by case.
Limitations of this study are related to two main aspects: economic evaluation techniques and quantification of the externalities. In particular, it was highlighted that the literature on non-market valuation tends to consider approaches based on demand-based methods superior to non-demand based techniques. Traditionally, the value of goods is supposed to reflect individual preferences, thus it is not possible to estimate an economic value without capturing preferences. However, preference estimation for each component of TEV is very difficult and time consuming, while non-demand based techniques provide ready to use figures for decision-makers. The quantification of externalities are also a critical part of the study, because environmental effects are always characterized by high degrees of uncertainty. However, a precise estimation of negative externalities is important for a better specification of forest strategies. For this reason, the present study might be important as one of the first attempts to include such considerations in decision-making.

Appendices

Figure 3: Map of Provisioning Services

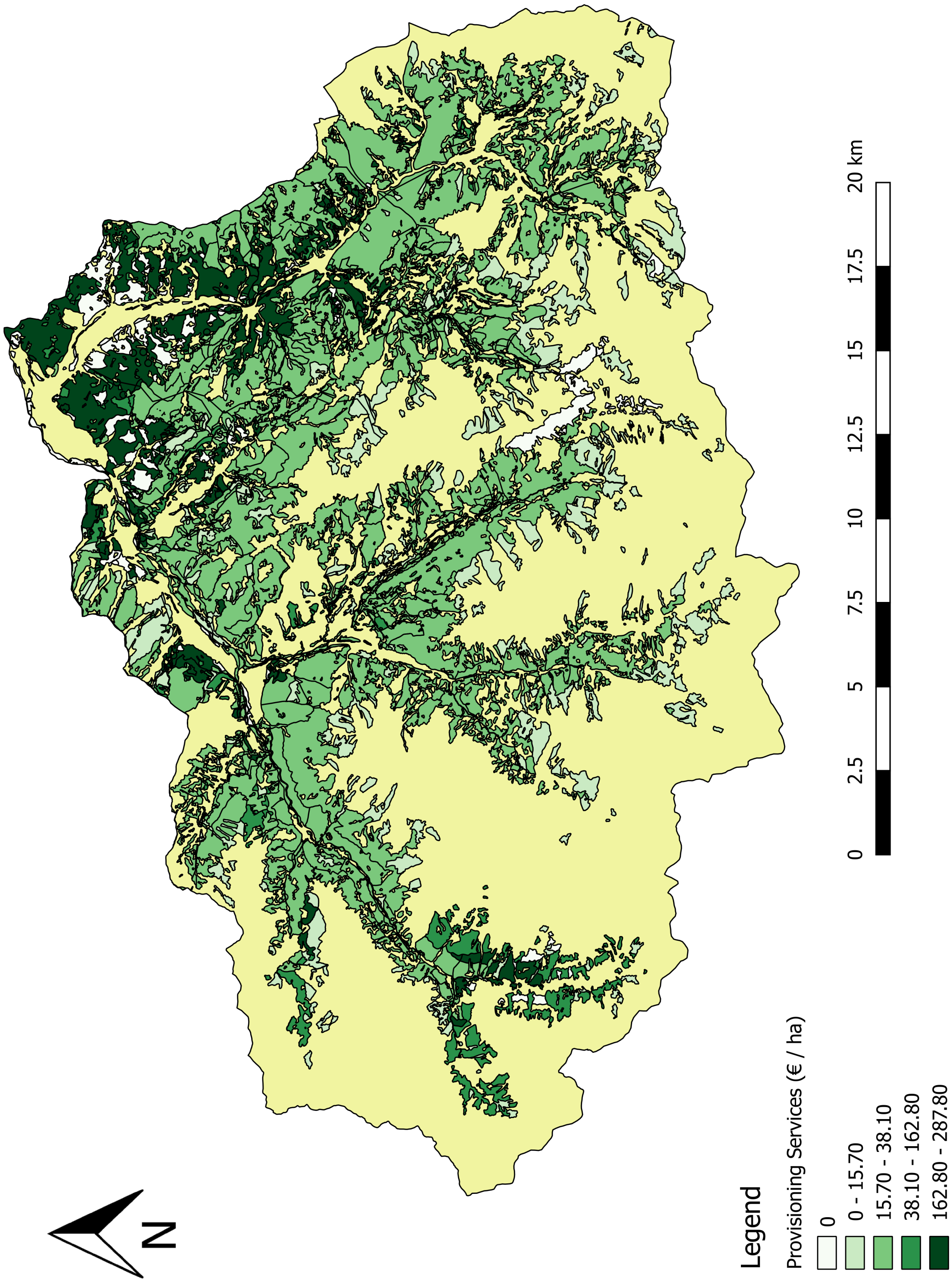


Figure 4: Map of Regulating Services

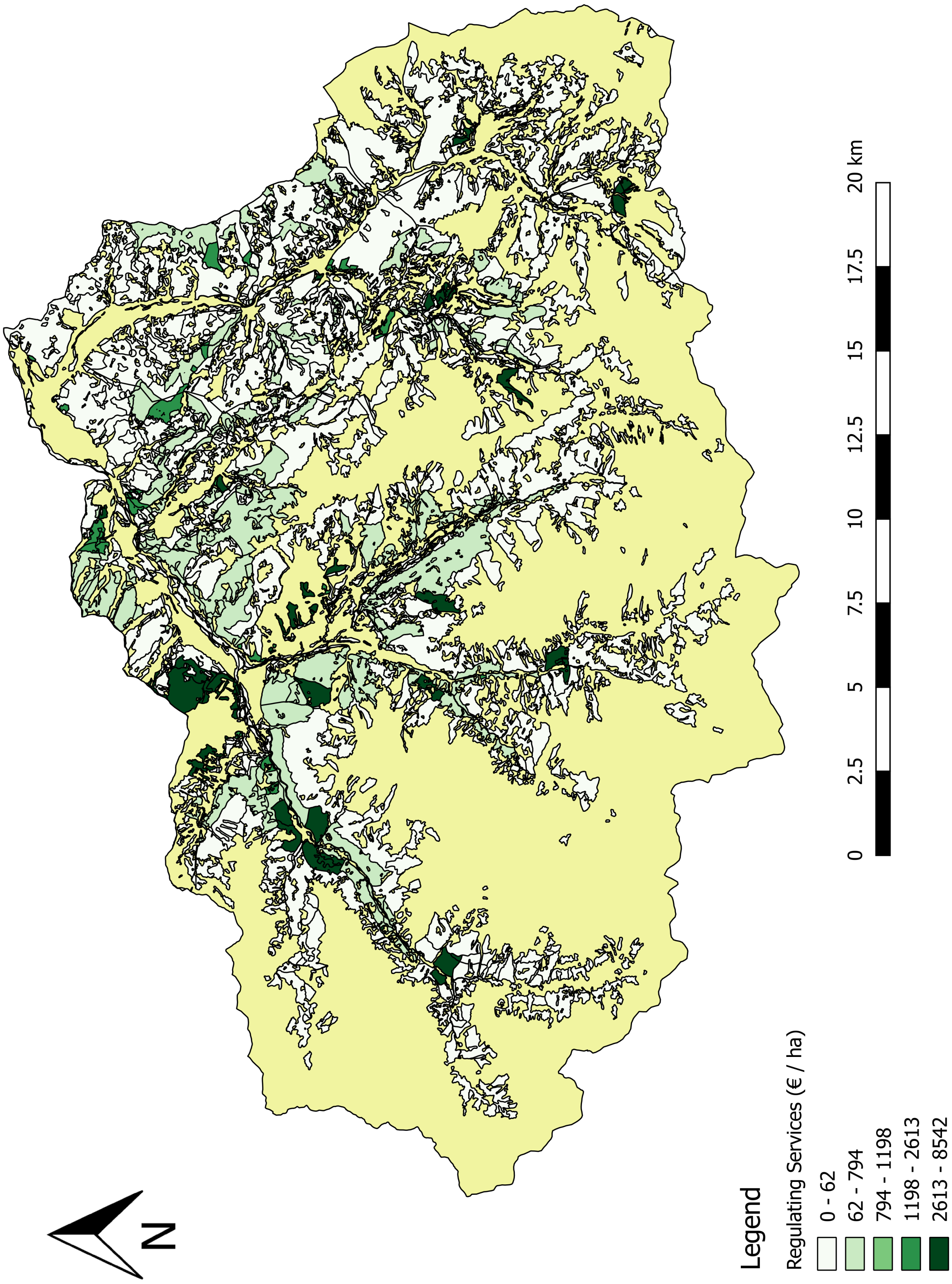
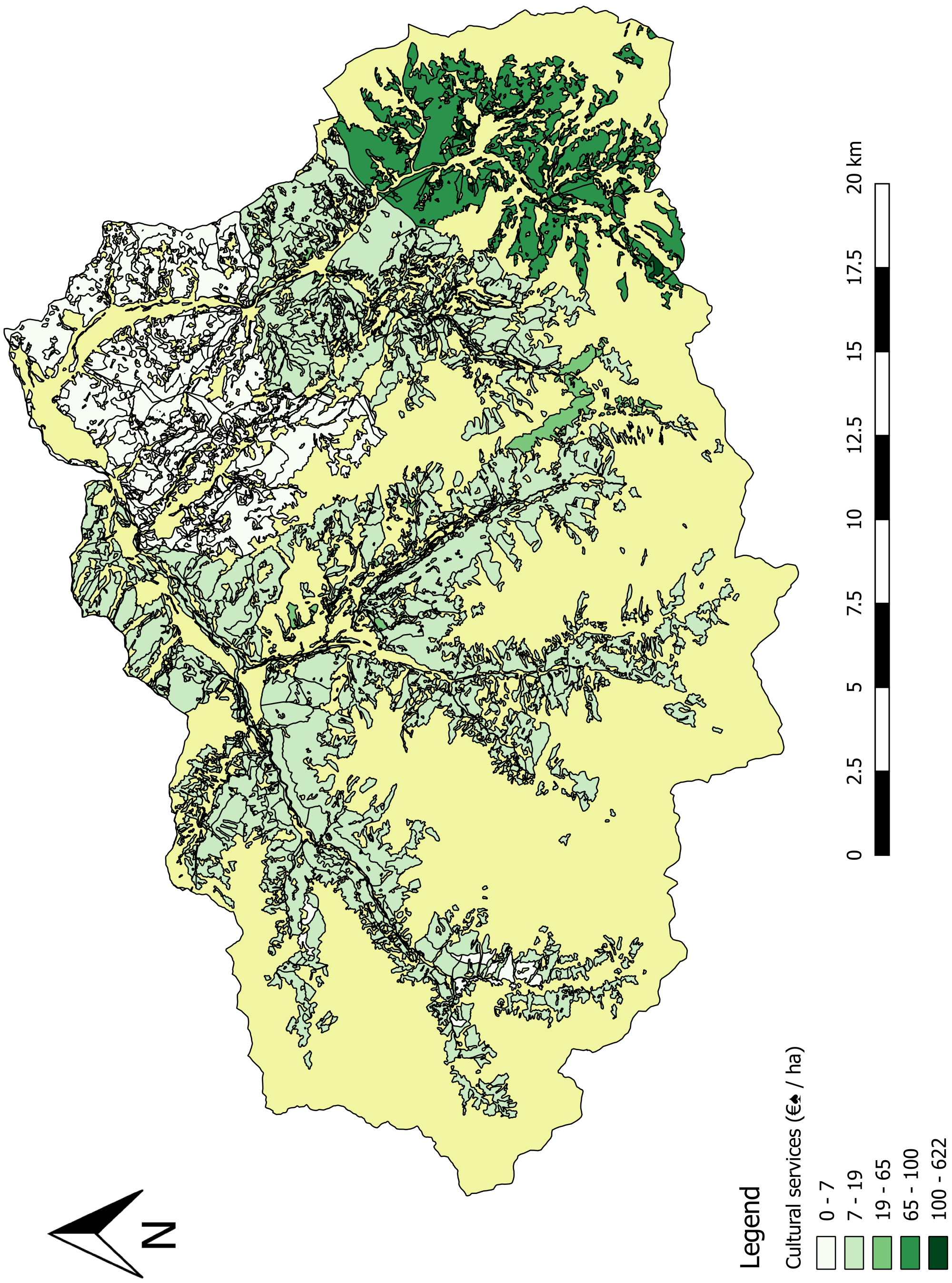


Figure 5: Map of Cultural Services



Chapter 6

Cost-Benefit Analysis

6.1 Introduction

The economic feasibility of programmes, projects and plans is the main objective of project evaluations. Specifically, a typical ex-ante evaluation of a project is carried out in terms of its consequences, i.e. costs and benefits (Pearce et al., 2006). In this context, Cost-Benefit Analysis (CBA) and Cost-Effectiveness Analysis (CEA) are the most common tools in applied economics, which can be used for project appraisal in the environmental field. The main difference among the two techniques is that, while CBA needs all costs and benefits to be expressed in monetary terms, CEA foresees monetary costs and non-monetary benefits (Robinson, 1993). CBA makes use of the Total Economic Value (TEV) concept, thus projects are evaluated considering market and non-market values in the analysis. Given this difference, within the sphere of neoclassical economics CBA is considered a welfarist approach, while CEA only partly welfarist (Garber and Phelps, 1997). When evaluating alternatives by CEA, costs are quantified in monetary terms, while benefits are measured as only one non-monetary outcome. It is not possible to sum different benefits in CEA because the unit of measure is not the same, thus CEA compares the main expected output of the policy against its cost. Results are usually presented by means of an indicator called Incremental Cost-Effectiveness Ratio (ICER) (Beckman and Svensson, 2015). By means of CEA, alternatives are ordered based on the main benefit for the society. CEA is useful when the policy is expected to produce one outcome (or really few); in particular, it is widely applied in health economics, because the monetization of health benefits is seldom criticized (Bobinac et al., 2012). The main indicator used to value benefits is the Quality adjusted life years (QALYs), measuring the expected increment in total life years produced by the policy on target society (Gray et al., 2010).

In the presence of multiple and non-commensurable benefits, the use of a monetary quantification allows summing policy effects, providing a more exhaustive view of the problem. In this context, CBA seems to be a more adequate tool for including the entire set of benefits in the evaluation (Molinos-Senante et al., 2011). In CBA, market and non-market costs and benefits are evaluated in monetary terms, then alternatives are compared by means of the Net Present Value (NPV) (Almansa and Martínez-Paz, 2011). This view is sometimes criticized, because of reluctance to put a value on natural resources (Wegner and Pascual, 2011). Many authors argue that economic values of natural resources are not good indicators in decision making, because some natural entities have an intrinsic value separate from anthropogenic existence; thus choices cannot be made based on human values (Beria et al., 2012). In this vision, decisions should be taken according to experts' judgements, while economists should identify the least costly solution for that decision. This approach is sometimes called Cost Minimization Analysis (CMA), in which alternatives providing the same benefits are compared based on the expected costs. The decision rule is to choose the alternative with the least possible cost (Duenas, 2013). However, this project appraisal methodology is not able to evaluate the welfare change of alternatives on the affected population, which is only possible by relying on conventional neoclassical paradigms. In addition, it has been shown that CBA and CEA provide more robust estimations compared to CMA (Dakin and Wordsworth, 2013). For the cited reasons, CMA seems to be effective in particular cases, namely when the society is rich in resources, extremely risk-averse and the effects of decisions are irreversible. This views complies with the precautionay principle, as described by Costanza (1992). In many decisions the precautionary principle is not this much important and can be relaxed, while CBA becomes more interesting. In fact, CBA is more suitable to estimate the welfare effect of a policy alternative and, at the same time, it usually allows lower welfare losses compared to CEA (Bateman et al., 2003).

When planning the use of forest biomass for energy and, more generally, the extraction of forest resources from the environment, there are few situation in which irreversibility issues really matters (Gunn et al., 2012). In particular, when harvested quantities are lower than the annual regeneration, the risk of irreversibility appears to be very small. For the cited reason, forest bioenergy management strategies seems to be adequate for being evaluated with CBA. In general, there are manifold applications of CBA in the energy sector. An interesting contribution is provided by Tol (2012), which provided a CBA evaluation of the EU energy policy, the so-called EU 20/20/2020 package. Other applications include the evaluation of photovoltaic options (Ramadhan and Naseeb, 2011; Ajao et al., 2011), energy retrofit (Friedman et al., 2014) or evaluation of investments in electricity interconnectors (De Nooij, 2011). Also popular is the evaluation of the waste-energy chain (Jamasb and Nepal, 2010). Specifically concerning biomass, Wiskerke et al. (2010) provided an assessment of different options to supply small householders with bioenergy in Tanzania, by means of CBA. On the other hand, CBA applied

to the assessment of DHP feasibility is less developed.
Starting from these premises, the aim of the present chapter is to evaluate the viability of a District Heating Plant (DHP) fuelled with local biomass by means of CBA. This chapter summarizes and concludes the analysis carried out in the previous chapters, calculating the expected economic performance of the DHP in terms of its NPV.

6.2 Methodology

The discipline of CBA is grounded on the standard economic view, which is usually called "Welfarist", representing the basis for policy evaluation in many applied fields such as envirnomental economics, transportation, labour market and, to some extent, health economics. Welfare economics aims at studying the definition and the measure of social welfare, by designing public policies and making social evaluations. Subsequently, a welfarist approach to policy evaluation aims at identifying the welfare effect of a programme for the society.

6.2.1 The Welfarist Approach

The welfarist thought is grounded on the traditional neoclassical economics, thanks to the contributions of, among others, Hicks, Pareto and Kaldor (Chipman and Moore, 1978). The new welfare economics literature identified some basic assumptions that are necessary for the assessment of social well-being (Engelbrecht, 2009). In particular, a first assumption is that **outcome matters**, meaning that larger quantities of goods are preferred over small quantities. Moreover, **consumer sovereignity** is assumed, meaning that the individual is the best judge of his own welfare; only the individual is able to assess whether a good or service provides additional utility for himself or not. In addition, **utility** is assumed to be ordinal, however it is difficult to translate such utility in a cardinal measure of value. This means that it is possible to rank alternatives according to the utility they provide, but nothing can be said about *how much* utility provides the bundle of goods A over B. Finally, it is also **impossible to compare interpersonal utilities**, because individuals have different tastes, values and backgrounds. For example, the utility an individual A retrieves from drinking a glass of wine might not be same of that experienced by individual B. This is a direct consequence of preference heterogeneity, meaning that preferences for goods are different across individuals, thus the utility people receive from the consumption of goods is different as well (Hanley et al., 2009). These basic concepts are essential to identify a definition of efficiency and, in addition, to establish a decision rule for valuing welfare changes of alternative policy measures.

Pareto Efficiency. According to above-cited assumptions, efficiency is valued according to the Pareto criterion, for which *an allocation is Pareto efficient (also called Pareto optimal) if no alternative allocation can make at least an individual better off without making anyone else worse off* (Werning, 2007). This definition is a very basic notion and do not imply a socially desirable situation. In fact, Pareto efficiency do not take into account income distribution equality across social classes or a general well-being of the society.

The Kaldor-Hicks criterion. From this definition of efficiency, it is very difficult to identify a Pareto-efficient solution, because each decision involves a loss of welfare for some category of stakeholders, directly or indirectly. For this reason, Pareto criterion has been relaxed introducing the concept of *side payments*, by means of which a system of compensation can be established, and 'potential Pareto improvement'. Within this vision, the Kaldor-Hicks criterion (also called Kaldor-Hicks compensation test) states that a policy should be adopted if those who are expected to gain from the policy could fully compensate losers and still be better off (Stringham, 2001). It is important to highlight that compensation is only theoretical, no actual money transfer is need for this criterion to be valid. The intuition is that such an approach is able to maximize the aggregate wealth for the society. Moreover, it is believed that, in a long run, gainers and losers of public policy even out; this means that gainers in a certain policy might be losers in the next programme and *vice versa*, so that in a long period of time welfare effect for each individual would be, on average, the same. Finally, it is also believed that, once the aggregate wealth is maximized with a Kaldor-Hicks criterion, equality in distribution may be achieved as a second best solution, using transfer mechanisms.

6.2.2 CBA theory

The idea of CBA is to apply the economic theory to both private or public investment decision, allowing the comparison among different options (Cartwright, 2000). This is a considerable advantage of CBA, allowing the evaluation of investment decision at both company and public level. The core of CBA includes two main principles: (1) all costs and benefits of the project should be assessed and (2) they should be measured with the same unit of money (Layard and Glaister, 1994). Money are used in CBA as a metrics to evaluate utility changes for individuals. Goods and services in CBA are measured in terms of *shadow prices*, defined as the net welfare effect of a unit increase in that good or services, for the relevant stakeholders. Thus, for example, WTP represents a shadow price for the perceived increase in welfare when the DHP is created. In general, the social welfare function assumes that utility changes are equal for everyone in the target population (Hanley et al., 2009).

Not all costs and benefits of a policy or programme are immediate, they rather occur with a time lag, therefore the comparison have to be carried out considering future inflows and outflows. This is traditionally carried out by a discount rate, which estimate the present values of future effects. The formula to calculate the NPV, which is the main CBA indicator, is the following:

$$NPV = -C_0 + \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \tag{6.1}$$

Where C_0 is the investment cost, which occur in the initial period and therefore not discounted, T is the policy lifetime, B_t and C_t are benefits and costs sustained in period t, respectively, and r the discount rate. A positive NPV (NPV > 0) is considered welfare-increasing, according to the Kaldor-Hicks criterion, a negative NPV (NPV < 0) is conversely welfare-decreasing.

6.2.3 Scenarios

In principle, exploring the feasibility of a DHP might be of interest of several different economic actors, in fact such a project can be undertaken by both private subjects and public institutions. However, different actors have different objectives. Typically, a private entrepreneur is interested in the economic performance, while a public institution may look for a solution maximizing welfare for the target population. Thus, an important aspect, when CBA is applied, is to identify the relevant stakeholders that the project wants to address. Depending on the typology of investor and his objectives, costs and benefits may be different and, subsequently, the economic results may change as well. For this reason, in this contribution four scenarios are proposed, each containing different groups of costs and benefits, in order to show how assumptions on input values modify the economic result of the project. Scenarios that are expected to be explored by private individuals are assumed to be beneficial for the entrepreneur, while scenarios involving social aspects are assumed to benefit for the entire community.

Financial Scenario The financial scenario is the baseline situation, because monetary inputs and outputs are always of interest and do not depend on the type of investor (private or public). However, it can be reasonably assumed that a private subject would look at this scenario, because an entrepreneur is only interested to the financial performance of the DHP. Investing in a certain sector, in this case, is driven exclusively by financial reasons. The decision rule to evaluate the project consists in accepting solutions in which financial benefits are larger than financial costs. Flows of costs and benefits that are included are investment costs, operating and management costs and income, i.e. the work presented in chapter three. In this case, CBA results are very similar to a standard business evaluation, carried out by private companies (Abrams, 2010; Fishman et al., 2002; Pratt, 2009).

Social Scenario The benefits that a DHP provides to society are not only related to the mere supply of energy. In fact, the increase in the share of RE allows reducing greenhouse gases emissions (GHG), which is a social benefit because it contributes to a better air quality and helps fulfilling the EU carbon targets. Although being a source of emission because of combustion, the use of forest bioenergy is considered carbon neutral, because it affects the normal cycle of carbon and, conversely to fossil fuels, do not release carbon stored for millions of years. At the same time, it has been shown that a further development of the forest-timber-energy chain is helpful to increase the efficiency of the forest sector, providing additional income for local communities. For this reason, the decision of building a new DHP may be taken by a local public administration, typically a municipality. In this context, the new DHP may be seen as a public good, which is provided with the aim to not only increase energy independence but also for social reasons. In a utilitarian framework, what should be of interest for the public administration is the welfare change of the project. This is not only given by monetary performances but also by non-market benefits, which are usually approximated in CBA with willingness to pay (WTP) for the project. Thus, this scenario includes, in addition to financial flows, WTP for renewables that was assessed in chapter four.

Financial-Environmental Scenario Together with the two main above-described scenarios, it might be of interest exploring the effects of biomass use on local natural capital. In other words, this means analysing environmental externalities, occurring when natural resources are extracted from the ecosystem for human benefits. Usually, the amount of extracted resources is not higher than annual regeneration, thus the stock of natural capital is not affected. However, cutting the increment does not allow a future increase in the stock of natural capital. For this reason, the choice of using resources at present may be seen as a time preference trade-off. Therefore, analysing the opportunity cost of present use of resources, against conservation for the future, might be of interest for the forest owner. This can be investigated by including in CBA the expected variation in the forest's total economic value (TEV). A potential economic actor, interested in such analysis, might be a forest owner, who wants to create a DHP for an efficient use of biomass residuals. At the same time, he is concerned about the status of his forest assets. In Italy, it is unlikely that a single forest owner would explore this possibility. However, a common practice for small landholders is to create cooperatives, thought which people voluntary unite for common economic interests. In the province of Cuneo, in which the valleys of Gesso and Vermenagna are located, there are successful examples of this practice; among others, the experience of **Gestalp** worth being mentioned [1].

Social and Environmental Scenario The last case that has been hypothesized has been called *Social and Environmental scenario*, because it includes, in addition to financial performances, social and environmental flows of effects. This is the scenario including the largest set of inflows and outflows. Such a scenario might be the case of a public institution owning local

[1]http://www.gestalp.it/

forests. In Italy, roughly 50% of forested area is owned by public administration, in particular provinces and municipalities. The provinces of Trento and Bolzano, among others, are examples in which the public sector owns almost the entire forest lands. For this reason, exploring this case might be interesting for public decision makers.

Time preferences An important issue in CBA is how to deal with time preferences and this is related to the level of discount rate. A discount rate equal to zero assumes present and future to be equally important. However, the usual approach considers present costs and benefits as more important and urgent than those in the future, because of the high level of uncertainty about the future (Feldstein, 1964). For this reason the discount rate used in CBA is always higher than zero. The optimal level of discount rate is debated in the literature, because it requires assumptions about the importance of future generations. Typically, CBA practitioners suggest a discount rate between 3.5% and 8%, but it is not unusual to find contributions using 10% or even 15% (Boardman et al., 2006). In order to point out differences in the NPV occurring with different assumptions on discount rate, the above-described four scenarios will be presented considering three different discount rates: 2% (very close to the social discount rate), 5% and 10%.

6.2.4 Sensitivity Analysis

The set of included variables are estimations, derived by analysing data on real existing DHP and field surveys, that are subject to a certain level of uncertainty. There are many reasons for which a real application might show different figures in the computation of costs and benefits, including unexpected delays, additional costs for permissions, lower quantity or quality of available woodchip, etc. In this context, estimated costs and benefits should not be seen as point estimates but rather distributions, each with a certain range of variation (Briggs et al., 1994). In order to account for possible deviation from central tendencies, a sensitivity analysis (SA) may be performed. A SA can be conducted to test the robustness of results, to show how stable is the model in the presence of stochastic disturbances, which might change the level of expected costs and benefits. In addition, a SA can be carried out to assess what is the value added of collecting additional information about the project, in order to reduce the level of uncertainty. There are two main groups of sensitivity analyses: Deterministic Sensitivity Analsysis (DSA) and Probabilistic Sensitivity Analysis (PSA) (Wallace, 2000). DSA is conducted by changing the values of parameters, there are two main groups of DSA: partial SA and worst-and-best SA. The former foresees a change in the parameters that are assessed to be most important or most variable. The NPV is computed with the new assumptions on costs and benefits and, if positive, the project is likely to be welfare-increasing. This typology of SA is useful when the confidence of the analyst in the data is high enough to suspect only few changes in some variables. Worst-and-best SA, on the other hand, is performed considering in the calculation of NPV the worst situation (i.e. highest level of expected costs and lowest possible level of benefits) and the best situation (i.e. lowest level of costs and highest value for benefits). If the NPV is positive in the worst case, it can be reasonably concluded that the project provides additional benefits for the local population. This procedure is suitable for extremely risk-averse people. However, the largest share of empirical applications would show a positive NPV for the best case and a negative value in the worst case. Thus worst-and-best SA is usually considered to be an exercise providing only a small amount of information and useful only for decision-makers extremely risk averse. In general, the main limitations of DSA are connected with the fact that not all available information is used and the variance of NPV is not considered in the computation.

On the other hand, a PSA considers uncertainties in the model as distributions with a location and a scale parameter (Doubilet et al., 1985). Uncertainty is modelled with Monte Carlo simulations, involving the use of computational algorithms to randomly sampling from the distributions and obtain numerical results. In this way, it is possible to execute a trail with a certain number of draws from each distribution, typically from five to ten thousands, and calculate the NPV for each draw. Project performance is evaluated under many different conditions, returning a reliable estimate of the NPV distribution. In order to perform a PSA, assumptions about distribution of costs and benefits are essential. The scientific literature suggests that costs might be modelled with a gamma distribution, because it constrains data to be positive. In this way, costs will always be positive, indicating expenditures for the decision-maker. Conversely, a cautionary estimation of the NPV might be achieved assuming a normal distribution for benefits (Beckman and Svensson, 2015). The normal distribution is symmet-

Table 6.1: Costs and Benefits

COSTS (1,000 €)		BENEFITS (1,000 €)	
Typology	Value	Tipology	Value
Investment cost	(1,900)	Production value	511.8 /year
Operating costs	(296) / year	WTP	249 / year
Environmental costs	(200) /year		

Table 6.2: Baseline scenarios(Discount rate: 5%)

Scenario	NPV	Annual NPV
Financial	1,655,857	82,792.85
Social	4,758,947	237,947.35
Financial-Environmental	4,322,770	216,138.5
Social-Environmental	1,219,680	60,984

ric around the mean and defined between minus and plus infinity. In this way, benefits may take both positive and negative values, thus accounting for situation in which cash flow is negative. In order to respect literature prescriptions, this contributions make use of gamma distributions for costs and normal distributions for benefits.
In order to apply PSA, average values of costs and benefits were used as location parameters, while standard deviations are included assuming a variability of input data of 20% from central values.

6.3 Application to the case study

The CBA methodology has been applied to the case study of Gesso and Vermenagna valleys, using the input data presented in table 3.2. Such input data, identified in the previous chapters, returned the figures for costs and benefits presented in table 6.1;Scenarios' NPV derived from these data are described in the following subsections.

6.3.1 Net Present Value

The baseline set of scenarios, assuming a discount rate of 5%, is shown in table 6.2. It can be seen that the all four NPVs are positive, thus apparently

Table 6.3: Results considering a 2% discount rate

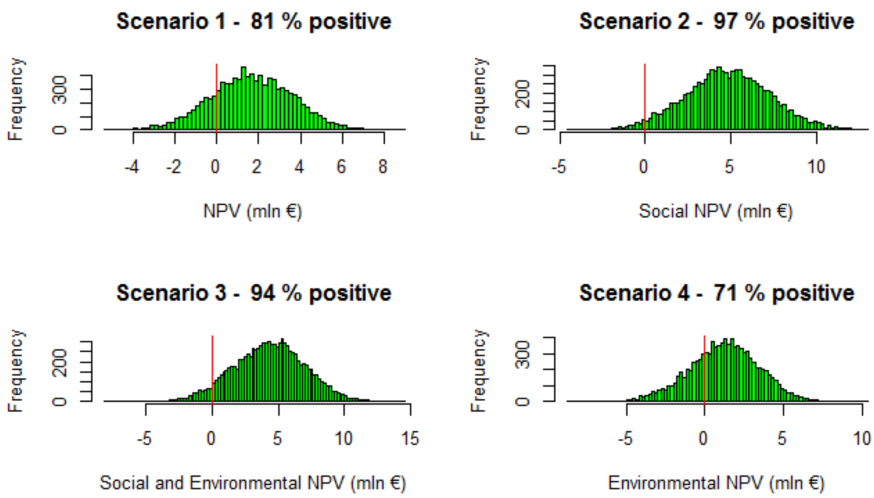
Scenario	NPV	Annual NPV
Financial	2,766,257	138,312.85
Social	6,837,764	341,888.2
Financial Environmental	6,265,464	313,273.2
Social Environmental	2,193,957	109,697.85

Table 6.4: Results considering a 10% discount rate

Scenario	NPV	Annual NPV
Financial	528,491.20	26,424.55
Social	2,648,368.5	132,418.42
Financial-Environmental	2,350,393.80	117,519.68
Social-Environmental	230,516.5	11,525.82

the options seem to be welfare increasing. However, there are considerable differences, suggesting that different underlying assumptions matter. In particular, the financial c enario is positive and about 1.6 mln €, corresponding to an annual NPV of about 82 thousands €. The other scenario corresponding to a private investor is very similar and assessed to be 1.2 thousands globally, leading to an average annual earning of roughly 60 thousands €. On the other hand, scenarios assuming public investors seem to be much more worthy, in fact the global NPV in the social scenario is 4.7 mln €, while the NPV for the social and environmental scenario is 4.3 mln €. Moving to table 6.3, it is possible how NPV of the different scenarios change due to a smaller discount rate. The rank of scenarios, based on their NPV, is the same, nevertheless figures are higher. This means that, assuming a smaller discount rate, the economic convenience of the project increases. The financial scenario rise up to 2.7 mln €, while the social and the financial-environmental scenarios show a NPV well above 6 mln €. The financial-environmental scenario is still the least profitable, with a NPV of 2.1 mln €. Finally, in table 6.4 it is possible to see results of the four scenarios with a 10% discount rate. In this case, performances are worse than those presented before. In particular, the financial scenario produced a NPV of roughly 0.5 mln €, while the financial-environmental scenario only 0.23 mln €. Public scenarios are still higher but, in this case, reach only figures of about 2 mln €.

Figure 6.1: Sensitivity Analysis with 5% discount rate

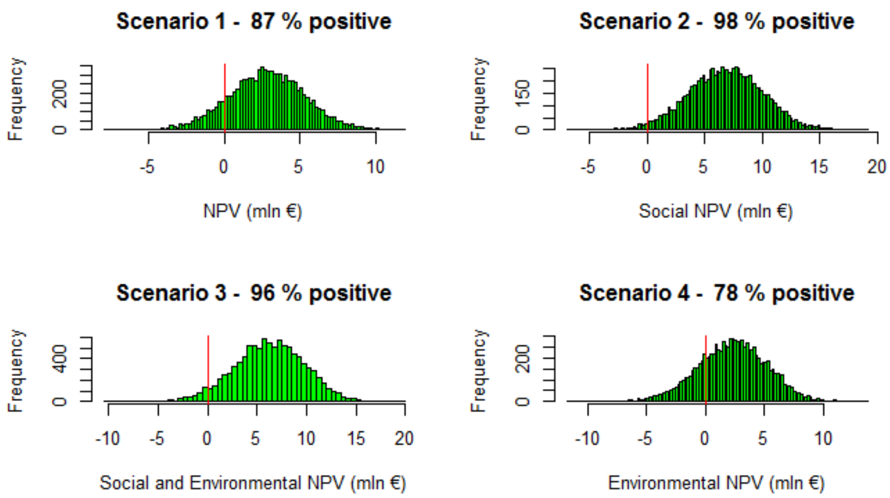


6.3.2 Sensitivity Analysis results

The sensitivity analysis was conducted for all scenarios, by drawing 10,000 draws from cost and benefit distributions. Figure 6.1 reports histogram charts, showing the NPV at each random draw. It is possible to see that in the first scenario (financial), the NPV is positive 81% of the times; The figure rise up to 95% and 97% in the social and social-environmental scenarios, respectively. Finally, the financial-environmental scenario is positive 71% of the times.

Similarly, figure 6.2 shows results when the discount rate is 2%. In this case, scenario performances increase, meaning that the average NPV is larger and the probability of a positive NPV across different draws is higher. In particular, the financial scenario is positive for the 87% of the draws, while the financial-environmental scenario 78% of the times. When social benefits are included, NPV is positive 98% of the times and, in the social-environmental scenario, 96% of the times. Finally, results with a 10% discount rate are shown in figure 6.3. This is the worst situation, because NPVs are lower for each case considered. In particular, the average NPV is well below 1 mln € in both scenarios assumed to be explored by private investors. In addition, the probability to obtain a negative NPV increases, in fact the financial scenario presents positive NPV only in 64% of the times and, considering also environmental externalities (financial-environmental scenario), this probability

Figure 6.2: Sensitivity Analysis with 2% discount rate

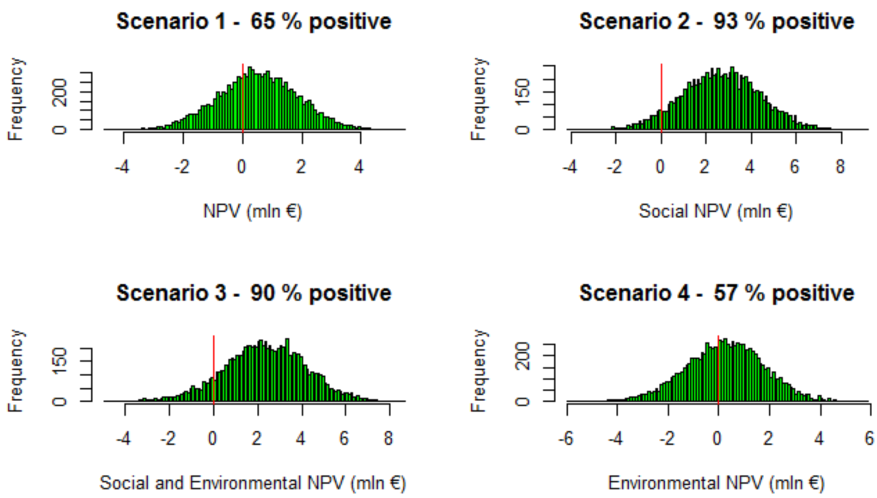


lower at 57% of the times. Conversely, scenarios possibly explored by public institutions are positive more than 90% of the times.

6.4 Discussions

The CBA analysis provided interesting insights about the economic feasibility of a DHP in the Gesso and Vermenagna valleys. First of all, it was shown that the NPV is, on average, positive most of the times, thus result is welfare increasing with a good level of confidence. The social scenario was proved to be the largest with all discount rate used, followed by the social-environmental scenario. Financial and financial-environmental scenarios showed much lower average NPVs, meaning that the project of a new DHP is less profitable for private initiatives. Decisions about the economic convenience of such a project largely depends on assumptions regarding discount rate, in fact performances change considerably when the rate is 2% and when its assumed to be 10%. Typically, capital-intensive projects, with long payback times, are more feasible when the discount rate is low. This is visible from the results, in particular for what concerns the financial scenario. It is important to highlight that this evaluation does not assure that a DHP will be considered profitable by investors. In fact, there are other variables and factors affecting the choice of investing. In particular, the financial sce-

Figure 6.3: Sensitivity Analysis with 10% discount rate



nario would be hardly realized, although showing a positive NPV, because the return on investment is rather low. The annual NPV is not enough to encourage potential entrepreneurs, which would be most likely attracted by other economic sectors. In general, results confirm that DHP fuelled with bioenergy are characterized by long payback time and high investment costs. This situation is even worse, if it is taken into account that incomes include a part of subsidy for electricity cogeneration, without which economic performances would be even lower. In addition, taxation is only considered with regard to indirect and work taxes (embedded in the costs for workers and materials), while other source of taxation, such as income, are not considered. Including this other source of outflow would lower NPV even more. Problems connected with economic performances of DHPs are not only related to the case study, it is rather a common phenomenon. For this reason, a detailed planning of the activities seems to be necessary to avoid losses. While running a sensitivity analysis, the analyst may assess project profitability by calculating the probability to obtain a NPV higher than a desired amount, rather than zero. In fact, a positive NPV assures the increase in welfare, but does not justify a private investment. For example, considering a discount rate of 5% in the financial scenario, the probability to obtain a NPV higher than one mln € is 63%, while the probability of being higher than two mln € is 43%. These data are more informative for a potential investor, because

they predict the possibility to obtain future earnings, and may help deciding the investment based on individual's risk propensity.
The situation is different, if considered from the point of view of public institutions, because what matter for them is the increase in society's welfare. In fact, including individuals' willingness to pay as a contribution for the project, the positive NPV suggests that the DHP is welfare-increasing, according to the Kaldor-Hicks criterion. Therefore local administrations would be interested in such a project. A public institution may obtain several advantages from the development of forest bioenergy. Forest biomass use helps achieving EU's targets; these are mandatory for European member states and the present analysis showed the potential contribution of forests in this context. The use of 3,000 t of forest biomass corresponds to roughly 810 t of diesel and almost 1 mln m^3 of methane. In addition, there are ancillary benefits of increasing the use of local resources that are not taken into account in this CBA. In particular, such a project helps reducing dependence on energy imports, which is very common in Italy and the study area is also affected. Being very close to the French-Italian border, municipalities of the Gesso and Vermenagna valleys regularly purchase nuclear energy from France, to fulfil their energy needs when local production is too low. A gradual switch to local and renewable sources of energy might stop (or at least reduce) this trend. Other possible benefits are related to health benefits that local inhabitants might experience. Despite the release of a certain quantity of CO_2, GHG emissions from biomass are lower than those released by other fuels; this contributes to a cleaner air and possibly to a better health status for local inhabitants. Such benefits were not considered, due to lack of data and the difficulty to translate these effects into monetary figures for CBA. Health improvements, as mentioned in the introduction, are usually quantified with the QALY indicator, which most of analysts refuse to value in monetary terms due to ethical reasons. Nevertheless, the welfare improvement of the DHP, from a public policy perspective, seems to be clear ever without considering health effects.

6.5 Conclusions

The present chapter introduced the methodology for a CBA in the forest bioenergy sector. Computations of the previous chapters were used to provide a synthetic indicator for evaluating the economic convenience of a DHP, i.e. the NPV. Four different scenarios were evaluated, based on different assumptions about the potential investors and forest properties. At the same time, a probabilistic sensitivity analysis was conducted on results, to assess results stability in the presence of unexpected variations of costs and benefits. Results suggest that the project of a DHP is welfare-increasing in a context of public policy evaluation. Conversely, from a private point of view results are more ambiguous, because the NPV is positive but probably not enough to justify an investment. In this situation, the decision to create a DHP largely depends on individual risk propensity. The main positive aspect of CBA is the possibility to use money as common metrics to assess and compare different types of costs and benefits; this is convenient when a program can be valued in terms of welfare change and its consequences are not irreversible. Conversely, in the presence of irreversible effects, relying on individual preferences might not be a good strategy, because most of the people do not have the necessary scientific knowledge to take informative decisions. In such situations, precautionary principle should be applied and decisions are probably more effective if taken upon experts' judgement.

Chapter 7

Conclusions

7.1 Synthesis

This Doctoral thesis attempted to address the issue of sustainability, by presenting a methodology for forest bioenergy planning at regional scale. In particular, it has been shown how GIS techniques for the analysis of environmental data can be associated with economic tools, in order to explore welfare effects of projects in the REs field. At first, the local energy potential, obtainable from forest biomass, has been estimated. At the same time, a suitable neighbourhood to supply was identified, based on expected energy consumption. Thanks to this information and topographical data, in a second step a DHP has been located and the capacity determined. In order to explore the economic convenience of the DHP, the most important inflows and outflows were identified and estimated. In particular, investment costs were stochastically estimated by means of a linear function, while operating costs and expected incomes were assessed by their market values. In addition, social benefits and environmental externalities were estimated, to better understand the global effect of the project on society and environment. Finally, a CBA has been carried out, to foresee the economic convenience of such a project. Four scenarios were hypothesized and presented with different assumptions on discount rate. The procedure was applied to a case study in the Italian Alps, Gesso and Vermenagna valleys. Results suggested that NPV is positive, in particular when time preferences favours future flows, i.e. when the interest rate is low. Despite this, scenarios involving private investors were found to be less likely to be pursued. On the other hand, when looking at the societal welfare, a DHP seems to be welfare increasing, thus a local public administration might be interested in the project. By means of the proposed methodloogy, it is possible to evaluate the feasibility of forest bioenergy for DHPs on a wide range of situations and local contexts. Each case study is highly specific and deserves *ad hoc* evaluations, because economic convenience depends on local environmental situation and local prices.

7.2 Advantages of the proposed approach

The proposed methodology has the advantage of increasing the efficiency of decision-making, providing data and indicators to take informative decisions.

There are manifold benefits in adopting the described approach. Concerning forest activities, an ex-ante estimation of the bioenergy potential allows understanding how much timber and woodchip is available in a given area, identifying which areas can be easily reached by forest contractors and those in which extraction might be difficult. Such estimation is carried out considering a large number of environmental data simultaneously, so that the problem can be faced in a holistic way. The increased efficiency in residual collection represents also an additional source of income for forest workers, which may sell woodchip. Thus, the overall efficiency of the forest-timber-energy chain may be improved. Benefits are also available for an efficient location and capacity of the DHP. A reasonable size, in terms of installed power, helps owners of the DHP not to incur in high and unnecessary investment costs, which is typical in case of plant over-sizing. The CBA conducted in the DHP allows assessing the economic feasibility of the project. Calculation of NPV is quite straightforward and the interpretation is easy. In this contribution, CBA was presented evaluating only one DHP across four scenarios. However, this tool has multiple application that can be done. In particular, CBA is suitable to evaluate alternatives. The NPV of forest biomass could be compared to the performance of other energy sources, for example hydro power or solar photovoltaic. The **r.green** modules for the other sources are in development and will be soon available as GRASS add-ons. This would allow identifying the most efficient energy source, or energy mix, for the territory. Moreover, evaluation might regard the number of DHPs to be created. In this thesis, it was decided to focus on the creation of just one DHP. However, this solution may be compared with a two or three DHPs solution, in particular where forested area is particularly large. For example, in the study area it could be hypothesized one plant per valley. In this case, the NPV of one DHP alternative could be compared with the NPV obtained with two or three DHPs.
Another considerable advantage is the realization of the tool in an free and open source environment, because it facilitates the usage and the possibility to modify the code. In particular, this study was applied using Italian data but, with only an additional small effort, functions may be tailored to face different situations in different countries, in particular modifying expected prices for input materials and workers.
It is important to remark that DSS and other tools like this are very useful in providing information, but final choices depends on judgements and values of

decision-makers. There are a number of reasons for which suggestions derived from this tool might not be followed, including lack of money, unexpected variation of environmental or social conditions, legal constrains. However, tools like this are important to highlight opportunities and treats of plans and programmes, allowing the decision-makers to obtain a clear picture of the situation and future possibilities.

7.3 Disadvantages of the proposed approach

The described methodology has, of course, some disadvantages and critical aspects the user has to be aware of. First of all, it has to be stressed that the quality of results largely depends on quality of input data. Energy planning affects several aspects of the environment and society, for this reason the number of data to collect for a comprehensive analysis is really high and not always available. If the method is applied with incorrect or approximated data, results will suffer of the same approximation (the ”garbage in - garbage out” effect).

Negative aspects are not only related to input data quality but also to specific limitations of the study. It was attempted to include as many variables as possible in the study, but there is always space for improvements. In particular, two main limitations are worth noting. The first regards the identification of the supplied area of the DHP, i.e. in the creation of district heating network. At present, buildings are linked from edge to edge and it is not considered that it actually crosses the building, thus network length is under estimated. This drawback might bias decisions, in particular for what concerns the economic aspects, given that network costs are extremely high. For example, if the network already exist, then a new DHP only requires a connection, while the investment function would include cost for network creation overestimating the initial costs. To circumvent this limitation, cost for network were included in the investment cost function.

Another aspect to be considered is how to deal with energy demand peaks. It is well known that bioenergy is useful to assure a constant provision of energy, but it is less efficient in periods in which the demand is really high. To address this issue, DHPs are usually created with additional boiler running with fossil fuel. In Italy, boilers fuelled with natural gas are most common. It is very difficult to foresee how big and how many these boilers will be, because choices are very case-specific. In addition, costs are uncertain. This

study do not consider such additional boilers but, in this way, both financial costs and benefits risk to be incomplete; costs do not include expenses for their purchase, while incomes do not include earnings derived from this additional heat supply.
Other possible source of errors are represented by environmental and health effects that were not considered. This limitation is actually related to result quality of the case study, not to the methodology. This particularly matters in the context of public policy. Concerning health, it was already stressed the importance of reducing GHG emissions for air quality, reducing the likelihood of illness and diseases. Environmental impacts might also involve soil fertility, risk fire prevention etc. Including these values in CBA would provide more reliable pictures of the global effects of biomass use for energy. However, it is difficult to include such environmental values in this study, mainly because ESs were valued without considering the stock. Annual increment of forests allow a straightforward estimation of some ESs, but the above-mentioned services follow multi-annual dynamics and are therefore difficult to estimate in terms of annual variations.

7.4 Open questions and Future developments

The project of this doctoral thesis started with the identification of some knowledge gaps, at which it was attempted to answer. The estimation of energy potential was calculated with the inclusion of economic effects for forest contractors, this basically means that the economic potential was considered in the analysis. ESs and individuals' WTP were included in CBA to account for forest values and social preferences of the project. The NPV allowed assessing the economic performance of the project and, finally, the use of open source software facilitates the diffusion among interested users. The tool described in this contribution has the advantage to cover these aspects, however there is still space for unanswered questions and future improvements. Insights about possible upgrades may be derived from the previous section, in which weaknesses of the approach are listed. The estimation of the "real" network may be included in the next version of the model. In addition, boilers fuelled with fossils may be included as well. Moreover, the estimation of additional externalities may be considered. This DSS is multidisciplinary, to better address the various aspects of bioenergy development, however the expertise of the author is mainly focused on the economic aspects of this approach. For this reason, users with different backgrounds may find additional comments, non-linearities or negative aspects that were not considered due to lack of knowledge. The usefulness of an open source approach is visible in this context, because allows potential modellers to explore the logic of the work and related algorithm. Therefore, improvements may be implemented by any interested user.

Stage of development The University of Trento, together with Eurac Research, are to my knowledge the two main developers of the suite of DSS **r.green**, in which this model is included. Several r.green modules are already available online while others are under construction. In this contribution, the author focused on the identification of commands and function writing in GRASS GIS and R. In order to be automatized and become freely downloadable, this procedure will be translated in python language in the next months.

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