University of Milano Bicocca

Department of Earth and Environmental Sciences

PhD Course in Environmental Sciences - XXVI Cycle

Doctoral Dissertation

Development of methodologies for the evaluation of sustainability to support the local scale planning of forest-wood-energy supply chains

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Salvatore Martire

CONTENTS

INTRODUCTION

“'Local character' is thus no mere accidental old-world quaintness, as its mimics think and say. It is attained only in course of adequate grasp and treatment of the whole environment, and in active sympathy with the essential and characteristic life of the place concerned.”[Patrick Geddes - Cities in Evolution - 1915]

“The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil.”[Sheikh Zaki Yamani - former Saudi Arabian oil minister - 1973]

“Don't you believe in flying saucers, they ask me? Don't you believe in telepathy? — in ancient astronauts? — in the Bermuda triangle? — in life after death? - No, I reply. No, no, no, no, and again no. - One person recently, goaded into desperation by the litany of unrelieved negation, burst out "Don't you believe in anything?". "Yes", I said. "I believe in evidence. I believe in observation, measurement, and reasoning, confirmed by independent observers. I'll believe anything, no matter how wild and ridiculous, if there is evidence for it. The wilder and more ridiculous something is, however, the firmer and more solid the evidence will have to be."[Isaac Asimov - The Roving Mind - 1997]

“People need new tools to work with rather than new tools that work for them.” [Ivan Illich – Tools for conviviality - 1973]

The Thesis is the result of analyzing the sustainability science paradigm through the application of research findings to real society needs.

The Thesis deals with sustainability assessment methods for supporting energy policies at local scale. Methodologies and tools should adapt to local (policy) needs, and bring benefits to local stakeholders and decision-makers. Necessarily, a multi-disciplinary approach is needed: the variety of involved fields and actors imposes to frame the study under different perspectives.

A productive system, as a forest-wood-energy supply chain, has to face with society, economy and environment systems. A comprehensive assessment should be able to quantify the relationships of the productive system within the economic, social and environmental systems, and its benefits and disadvantages towards them (Figure 1). And it should allow to define trade-offs and off-sets between the different components. The use of natural resources and related ecosystem services as well as land use should be evaluated accounting for the social, economic and environmental dimensions. Then, the natural system and environment should play a central role in planning policies (Arrow et al., 1995) for ensuring sustainability.

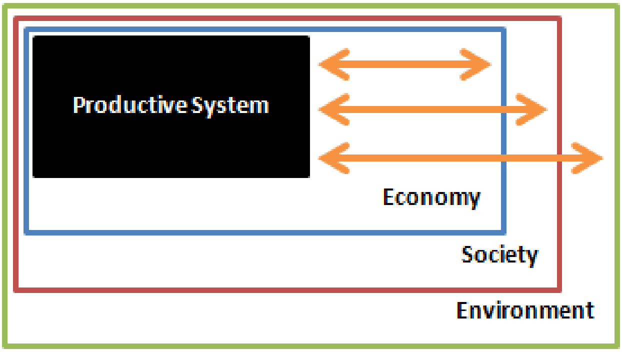


Figure 1 – Thesis' perspective(s)

On one hand, strategies for achieving sustainability goals are framed at international (European) level; on the other the implementation of sustainability assessments for driving productive processes, plans and programs, comes across some hurdles at local scale.

A careful local planning can make the difference for ensuring a sustainable future, for this reason the Thesis focuses on the local scale decision support.

The Thesis aims to contribute to bring innovative sustainability assessment methods into local level decision processes, and to develop a comprehensive method to support energy, environmental and rural policies at local scale. It originates from the following research questions:

- How should scientific assessment methods have to be adapted to local policy needs?
- What are benefits and limitations for the involved actors in applying sustainability assessments at local scale?

The opportunity to apply the research findings and face the (academic) research to the real societal needs have been given by the involvement in different Projects of the University of Milano Bicocca, dealing with energy planning at local scale.

Key concepts of the Thesis are shown in Figure 2. Different methods and tools are defined or used in specific case studies with the aim of supporting the decision-making at local scale, on issues related to forests and energy. On one hand methods must be adapted to site-specific characteristics and needs of decision makers, on the other hand developed tools should be flexible enough to adapt to specific features of available data, and to interoperate with other tools.

In the first chapter an overview of the context of the Thesis is given. In the second, the methodology developed to define a Spatial Decision Support System Tool is presented and applied for the Como Province area. It aims to evaluate the Carrying Capacity of forests at local scale. In the third chapter a Sustainability Impact Assessment has been carried out for the area of Como Province, through the application of the software ToSIA. The fourth chapter describes the adaptation of a methodology for the GHG Emissions accounting at Municipal level, for supporting climate-energy policy. A tool has been developed and provided to the local decision makers for emission accounting and for monitoring the planned actions for emission reduction. Feedbacks for integrating the different methods are provided in the Conclusions. The different works provide some findings to enhance the Science-Policy link, with a focus on local energy policy.

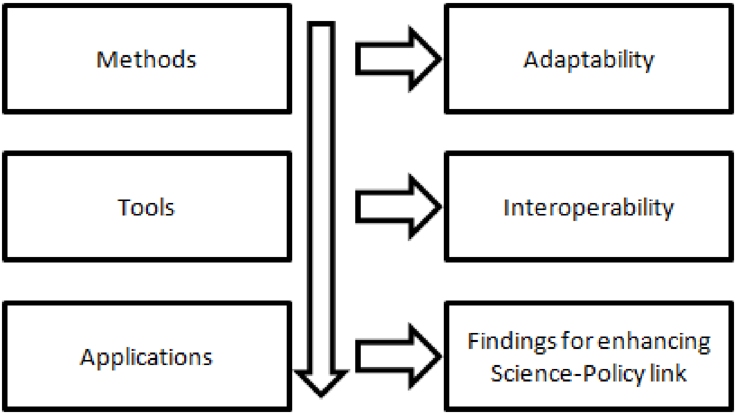


Figure 2 - Thesis' key concepts

CHAPTER 1 - CONTEXT

1.1 - INTRODUCTION

Sustainability and its scientific paradigm emerged as a necessity and as a challenge for scientific research (Clark & Dickson, 2003; Kajikawa, 2008; Kates et al., 2001; Komiyama & Takeuchi, 2006). Disciplines, methodologies and tools need to be defined in a formal way to be able to compare and evaluate and, therefore, pursue the environmental, social and economic sustainability of products, processes and technologies, as well as policies, plans and programs.

The term "sustainability" is generally associated with environmental, social and economic issues relatively to a process, a product or a service. And, in the field of natural resource management, it can be associated with the concept of "maximum sustained yield" (Larkin, 1977). The concept has been introduced in 1713 by Hans Carl Von Carlowitz, through the publication "Sylvicultura oeconomica, oder haußwirthliche Nachricht und Naturmäßige Anweisung zur wilden Baum-Zucht".

Later, the term "sustainable development" (SD) has entered the lexicon of research and policy. It has been defined first by the Brundtland Commission: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). The Sustainable Forest Management (SFM) concept is based on SD principles: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems"(MCPFE, 1993). To achieve this goal a range of forest institutions practice several forms of SFM. Methods and tools applied in these systems are being developed over the time.

A milestone for further developing the concept of sustainability is the Earth Summit of 1992. It introduced the United Nations Framework Convention on Climate Change (UNFCCC) and the Agenda 21 programme. Through the introduction of Agenda 21, the local dimension assumes a crucial role to achieve the SD objectives. Local dimension goes with the principle of subsidiarity, that states that a central authority should have a subsidiary function respect a more local authority, and EU governance is inspired to that principle (European Union, 2002). According to that, local authorities should handle different policy needs in terms of sectors of interests (e.g. energy, environment, rural development), and in terms of objective scales (e.g. needs of local populations, or aims of national or international policies).

The concepts of sustainability and sustainable development are still matter of debate (Bell & Morse, 2008; Glavič & Lukman, 2007; Pezzoli, 1997). For example, in (Myllyviita, 2013) is emphasized the challenge of "sustainable development" expression, due to the contradiction of having something to develop and to sustain at the same time. That contradiction becomes only apparent if the term "development" is not anymore linked only to the "growth" in terms of production, consumption or GDP.

In order to give an overview on how the concept of sustainability has evolved, Figure 3 shows how different views of sustainability can be pictured.

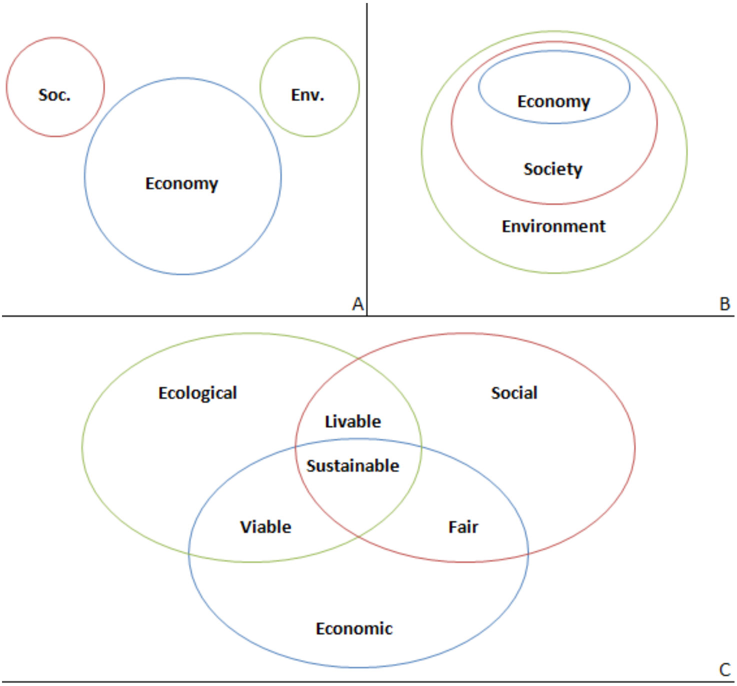


Figure 3 – Concepts of Sustainability. Modified from (Myllyviita, 2013). A. "Mickey Mouse" model, Economy has a predominant value for achieving sustainability. B. "Russian Doll" model, Economy is the basis for wealth creation; Environment and Society are constraints. C. Venn diagram, the multi-dimensional approach is highlighted (Mann, 2011)

The interest in sustainability and sustainable development affected also the concept of impact assessment, from considering only environmental impacts of a project to taking into account different aspects (Pope, Annandale, & Morrison-Saunders, 2004). In (Devuyst, Hens, & De Lannoy, 2001) the sustainability assessment is defined as a tool that can help decision-makers and policy-makers decide what action they should take and not take to make society more sustainable. According to (Verheem, 2002), the aim of sustainability assessment is to ensure that "plans and activities make an optimal contribution to sustainable development". In (Pope et al., 2004) is described how the concept of sustainability assessment is still too generic and further research is needed to better frame it and to develop proper procedures to assess the sustainability. Particularly, a key concept to further develop methods and tools for sustainability assessment is to consider the trade-offs between environmental, social and economic aspects (Morrison-Saunders & Pope, 2013).

1.2 - FORESTS AND ENERGY POLICY

The exploitation of biotic renewable resources, such as forest biomass, is recognized as a crucial element for sustainable development, towards a transition to bio-economy (OECD, 2009). The role of forests and the forest-based sector in the context of energy policies as source of fuel is well-known (European Commission, 2013a): wood is traditionally an important fuel especially in rural areas rich in forests, and the demand of wood is increasing due to rising oil prices and to fulfil renewable energy targets of the European Union by 2020 (Beursekens, Hekkenberg, & Vethman, 2011; European Commission, 2005, 2008a, 2012).

The overall wood energy accounts for 3.3% of the total primary energy supply and 38.4% of the renewable energy supply in 28 UNECE member countries in 2011 (UNECE, 2011), and the volume of wood used for energy purposes grew with an annual increase of 4% for 13 European countries between 2007 and 2011.

Despite being renewable resources, the use of wood is not per se sustainable if the ecosystem carrying capacity is surpassed (Lafleur & Fraanje, 1997; Sala & Castellani, 2010). Since, a sustainable management of forests is crucial for maintaining their potential and their ecosystem services (Grumbine, 1994; Martire, Castellani, & Sala, 2011; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005).

The concept of Sustainable Forest Management (SFM) has existed in the forestry sector since the 19th Century, but forests were perceived as a source of timber and rather little attention was paid to other forest products and services. Then, a peculiarity of a correct use of forestry resources is to ensure the multi-functionality of forests: it is one of the most important challenges in the coming years. Forests can ensure several ecosystem services: providing raw materials for goods, regulating local and global climates, buffering weather events, regulating the hydrological cycles, and protecting watersheds (Nasi, Wunder, & Campos A., 2002). Therefore, an evaluation of the trade-off between the benefits coming from forest resource use and the requirements in terms of conservation of forest ecosystems is needed (Pedroli et al., 2013).

Although globally a vast majority of forests are threatened by overexploitation (e.g. heightened rate of deforestation in tropical forests), many others are at risk of abandonment, due to being unmanaged (e.g. forests in many areas of the Alpine system in Europe) (FAO, 2010; Italian Ministry for Economic Development, 2010; Toniolo, 1937). Achieving a sustainable use of forests requires to find a balance between exploitation and abandonment of the forests as both processes may imply significant environmental as well as socio-economic impacts. At the international level, standards such as the Programme for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) have been developed for supporting a sustainable use of forest resources.

Once a forest is certified it is important to be able to trace the use of the resource (e.g. for product manufacturing or for energy production) throughout the supply chain to ensure that any claims on the origin of the product are credible and verifiable.

At Italian level, the low profitability of raw material from forests and the pulverized forest ownership lead the abandonment of forests (Brun, 1998). More recently the interest for forests has been growing: in (Italian Ministry of Agricolture, 2012) forests are recognized as one of the main economic pillars of last decades, however their productive function is gradually declined due to the depopulation of rural and montane areas. National wood supply is highly dependent from importation: more than 60% of the raw material is from abroad (Italian Ministry of Agricolture, 2012). Biomass exploitation is one of the lower in Europe (Italian Ministry of Agricolture, 2012), however national statistics are not reliable and the actual use of resource can be underestimated (Italian Ministry of Agricolture, 2012; Pettenella & Andrighetto, 2011).

In the Biomass Action Plan, European Commission claims "Energy is key in helping Europe achieve its objectives for growth, jobs and sustainability" (European Commission, 2005). The "Climate Change Package" (European Commission, 2008a) sets targets for Europe in terms of using renewable energy sources, promoting energy efficiency and reducing emissions of greenhouse gases. Forests could play a key role in Energy Policy, because forests and other wooded land cover 178 Mha in Europe (42% of the European land), and their growing stock is estimated in 23 Mm^3 in 2005, moreover 60% of the net annual increment in forestry biomass is available for wood supply (FAO, 2010).

Since the 80s, the role of energy for rural development is proved: the European Commission's policy document of 1988 "The Future of Rural Society" (European Commission, 1988) emphasized the "multiple links" between energy and rural development, based on the need of energy for rural activities, while forestry and agriculture sectors are source of renewable energy. These aspects are confirmed and emphasized by the EU Forestry Strategy 2013 (European Commission, 2013a): the use of local resources can provide leverage at local population, and increasing local employment opportunities (Alpine Convention, 1994; FAO, 2006; Kuvan, 2005; Pimentel, Mcnair, Buck, & Pimentel, 1997; Remedio & Domac, 2003).

At the Italian level, the National Action Plan for Renewable Energy (Italian Ministry for Economic Development, 2010) was presented by the Italian government following the 2009/28/EC Directive and the European Commission Decision of 30 June 2009. The Plan outlines a key role for biomass in Italy. It assumes a consumption of biomass by 44% in 2020 compared to total consumption from renewable sources, amounting to 22.3 Mtoe. The biomass will contribute to 58% of heat generation from renewable sources and to 20% of electricity from renewable sources (Table 1).

Table 1 – Forecast scenario by 2020 for Italy. (Italian Ministry for Economic Development, 2010)

Consumption of RES (Mtoe)		Share of biomass (%)
Power	9112	20
Heat	9520	58
Transport	2530	84
Import	1144	
Total	22306	44

Therefore, the heat generation from renewable sources becomes important, although the production of electricity from renewable sources has been further stimulated in the last years. Indeed, the production of electricity from forestry biomass was boosted during 2010 through the mechanism of "inclusive fee" and the "green certificates". On the contrary, the only effective system of incentives for the production of heat, since few years ago, was the mechanism of the Energy Efficiency Credits (EEC or White Certificates) which is applicable only for large size systems (Energy & Strategy Group, 2011). Recently, also the production of heat from renewable resources by small-sized plants is promoted (GSE, 2013).

The importance of developing bio-energy supply chains in the forestry sector has been confirmed by a number of national reference regulations, such as the National Program for Promotion of Agriculture and Forestry Biomass of 1998 and Forestry Programming (DM 16/6/2005). At the level of the Lombardy Region, the Unified Text of Regional Laws on Agriculture, Forests, Fisheries and Rural Development (LR n.31, 5/12/2008) and the Rural Development Programme 2007-2013 are in the same direction.

The planning of an energy policy has the aims of ensuring the security of the energy supply, promoting affordable energy prices for all consumers, and respecting environmental constraints (Helm, 2002; Turton & Barreto, 2006). These three aspects are crucial also for energy planning at the local scale: the development of local chains should be economic, social and environmental sustainable. In addition, local development can be considered a fourth aspect which supports the three listed above. In other words, the development of local supply chains can lead to increased employment levels, and a stronger local economy (Figure 4).

Additionally, the use of local resources for energy production can boost the security of the energy supply, which is usually an aim of national energy policies (Awerbuch, 2006).

At European level a policy framework for climate and energy for the period 2020-2030 is under definition (European Commission, 2014b). The objectives of the framework are:

- To reduce GHG Emissions cost effectively, to achieve the 2050 goal of reducing the GHG Emissions of 80-95% compared to 1990 level (European Commission, 2011a);
- To ensure the security of EU energy supplies, considering that EU oil and gas imports are € 400 million per year (European Commission, 2014a);
- To promote new growth and jobs, considering that eco-industry already employs 4.2 million in 2013 (European Commission, 2014a);
- To contribute to international agreement on GHG reduction.

Current EU plans (European Commission, 2014b) are based on forecasting a high mobilization of wood for energy; this will cause a pressure on European and world forests. A recent study states that "fundamental to sustainable bioenergy use is to reduce demand by implementing stringent energy efficiency targets" (IINAS, EFI, & JR, 2014) because forecasted biomass demand may exceed the availability of wood and land for energy crops in the EU (Eräjää & Abrahams, 2014), if resource efficient cascades (Keegan, Kretschmer, Elbersen, & Panoutsou, 2013) and stringent energy efficiency measures are not implemented (EFI, 2014a). Moreover, the increasing interest in bioenergy and biofuels is leading a wide ethical debate (Gamborg, Millar, Shortall, & Sandøe, 2011) about environmental and social implication of producing bioenergy.

Therefore, further research on bioenergy, in terms of availability and its social, economic and environmental implications is needed to provide effective tools to policy and decision makers.

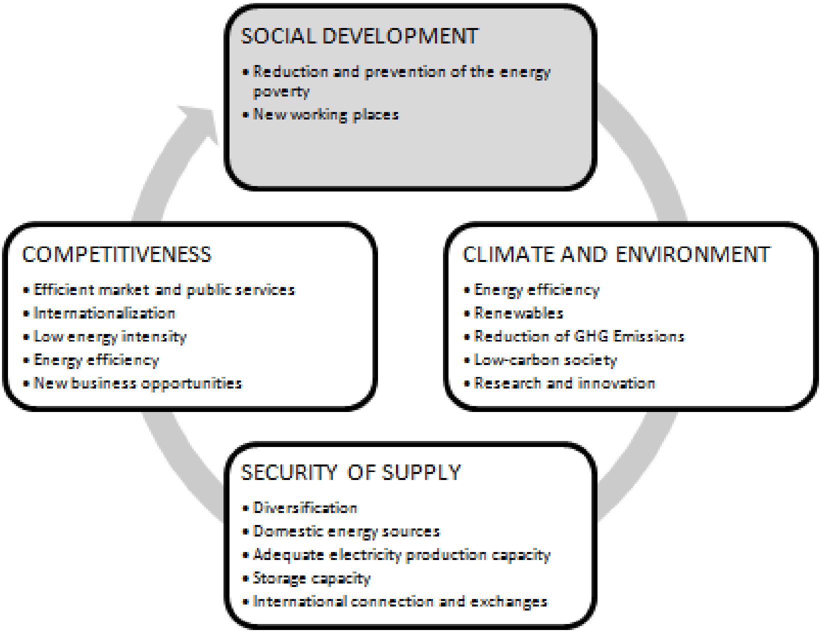


Figure 4 - Energy Policy pillars and social development. Modified from (Sucic, 2011)

1.3 - DECISION-SUPPORT FOR BIOENERGY PLANNING

Analysis on environmental, social and economic aspects are needed to provide comprehensive information to local decision makers (Govindan, Rajendran, Sarkis, & Murugesan, 2013; Kasprzyk, Nataraj, Reed, & Lempert, 2013; Matthies, Giupponi, & Ostendorf, 2007; Päivinen, Lindner, Rosén, & Lexer, 2010). In (Kersten, Mikolajuk, & Gar-On Yeh, 2000) five factors have been identified in designing a Decision Support System (DSS) for sustainable development:

- *Decision makers.* Decision makers should be solicited beyond the reliance of public authority.
- *Decisions.* Decision making in sustainable development should embrace all economic, social, political and environmental components.
- *DSS Modeling approach.* Modeling sustainable development requires an exhaustive search and gathering of economic and ecological information. And it implies the management of interdependencies of multiple and conflicting goals.
- *Database requirements.* Quality data are required for successfully putting modeling into practice.
- *Visualization and interface requirements.* Decision algorithms should be transparent to policy makers.

DSSs have developed across many disciplines for supporting decision-making (Keen, 1980). A crucial benefit to the progress of DSSs has been given by the development of IT technologies (Power, 2007).

The spatial dimension assumes a peculiar importance in relation to forests and energy planning: forests are raw material sources spread on the territory, and also final users are generally distributed in the case of local energy supply (Frombo, Minciardi, Robba, & Sacile, 2009). Moreover, forests data consist in a variety of datasets that need to be managed, updated and analyzed. For those reasons it is necessary to utilize computer-based tools (Sugumaran & Degroote, 2010). In (Sugumaran & Degroote, 2010) technologies and tools for supporting spatial-related decisions are identified, as Geographic Information System (GIS), Decision Support System (DSS), Expert System (ES). GIS is a special-purpose digital database in which a common spatial coordinate system is the primary means of reference (Foote & Lynch, 1995). Comprehensive GIS require a means of:

- Data input, from maps, aerial photos, satellites, surveys, and other sources;
- Data storage, retrieval, and query;
- Data transformation, analysis, and modeling, including spatial statistics;
- Data reporting, such as maps, reports, and plans.

ES are often built into DSS, in order to incorporate knowledge into the system and to provide humanlike reasoning within the system. As a result, complex problems can be analyzed and “what-if” analyses can be carried out with the help of computer power and organization knowledge (Sugumaran & Degroote, 2010).

The goal of sustainability assessment should be an evaluation of the integrated nature-society system (Ness, Urbel-Piirsalu, Anderberg,

& Olsson, 2007). However, an overall generic tool for sustainability assessment has not being yet developed (Rotmans, 2006). Nevertheless the linkage between science and decision-making is still an open challenge (Cash et al., 2002; Guldin, Parrotta, & Hellström, 2005; Liu, Gupta, Springer, & Wagener, 2008). In (Ness et al., 2007), three main features of sustainability assessment tools are identified:

- Temporal characteristics. For example, if the tool evaluates past development (ex-post or descriptive), or if it is used for predicting future outcomes (ex-ante or change-oriented) such as policy change or an improvement in a production process.
- The focus (coverage areas). For example, if their focus is at the product level, or on a proposed change in policy.
- Integration of nature–society systems. For example, to what extent the tool fuses environmental, social and/or economic aspects.

In (Ness et al., 2007) are also defined three categories of tools:

- Based on indexes and indicators. Indicators are measures (quantitative or qualitative) related to a state of economic, social and/or environmental development in a defined region. When indicators are aggregated the result is an index.
- Based on the product analysis. The tools in this category focus on evaluating different flows in relation to products or services. They evaluate resource use and environmental

impacts along the production chain or through the life cycle of a product (from cradle to grave approach).

- Integrated. They are used to support decisions relatively to a policy. Project related tools are used for local scale assessments, whereas the policy related focus on local to global scale assessments. Integrated assessment tools have an ex-ante focus and often are carried out in the form of scenarios. Integrated assessment consists of the wide-array of tools for managing complex issues (C. Gough, Castells, & Funtowicz, 1998). In 2002 the integrated assessment method has been introduced at European level, to "help and improve to quality and the coherence of the policy planning, and also the transparency, the communication and the information on the Commission's proposals" (Commission of the European Communities, 2002).

As highlight in (Myllyviita, 2013), monetary valuation methods are widespread to assess sustainability. Using money as reference unit is easy to interpret and comprehensible to measure, however monetary valuation methods have been considered ethically questionable and can include significant uncertainties related to the generalization of studies (Gasparatos, El-Haram, & Horner, 2008; Myllyviita, 2013).

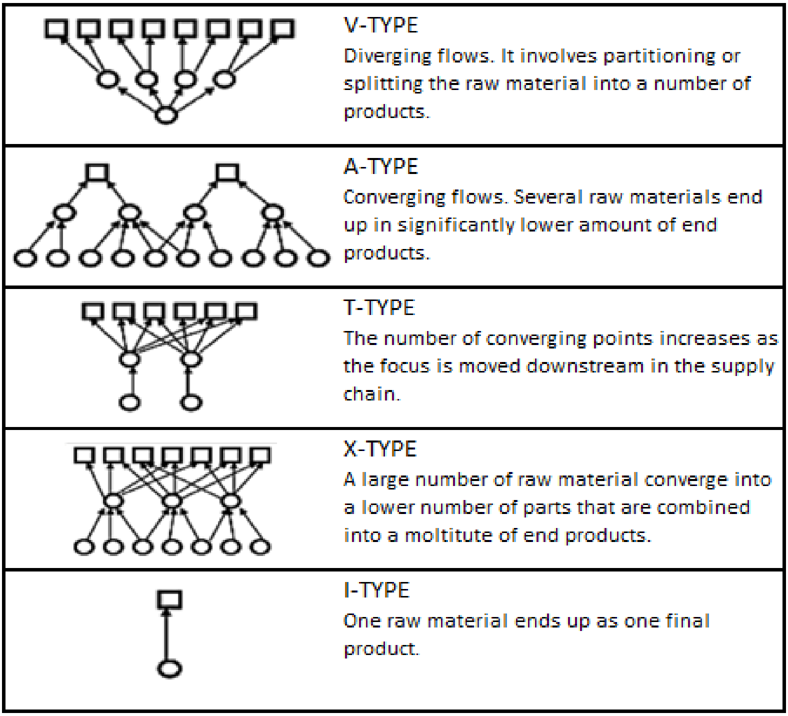
The multi-functionality of forests (Daily, 1997), can cause conflicts between different stakeholders and different needs: in (Brun, 2002) is highlighted the challenge of evaluate that with a focus on montane areas, and the author states that "in order to guide decision in a particularly sensitive environment, such as mountain forests, which are subject to numerous and changing demands of the general public, one must enlarge and mix competencies, and among other things, specify the rights and the duties of all concerned parties” (Brun, 2002). Forests are complex ecosystems (Spurr, 1964), while they are considered as “simply” stands from a silvicultural perspective. In (Puettmann, Coates, & Messier, 2008) the different perspectives of silviculturalists and ecologists are explained, and the authors believe that the “integration of aspects related to functioning of complex systems into management practices is still in its infancy”, and an effective linkage between the two disciplines is still lacking (Puettmann et al., 2008). However, it is generally accepted that ecological concepts - as biodiversity (Tansley, 1935), resilience (Holling, 1978) or ecosystem - should serve as the primary basis for forest management.

For an effective management of a forestry-based chain, not only forest management issues, but also the aspects related to the supply chain must be taken into account in a comprehensive decision-support tool.

A supply chain can be perceived as a flow in which a given raw material is transformed into products. That flow consists of one or several stages of manufacturing, storing and distribution before being used. One way of describing supply chain is to focus on the different activities involved, such as raw material extraction, production, distribution and consumption (Chang & Lee, 2003).

Materials and information flows can vary in structure. There is a variety of flow structures and each one of them has a direct impact in the supply chain organization. (Haartveit, Kozak, & Maness, 2004) presents five types of flows from points of origin to points of consumption, and supply chains are defined as combinations of these (Figure 5).

For the case of wood for energy, the raw material is one product that different processes transforms in fuels and finally in generated energy. The forest products sector traditionally has been made up of long and complex supply chains with several intermediaries occurring between resource extraction, manufacturing, and end use (Nerman, 2000). Then, structure, processes and products can change over the time, so changes must be considered in the scenario analyses.



V-TYPE
Diverging flows. It involves partitioning or splitting the raw material into a number of products.

A-TYPE
Converging flows. Several raw materials end up in significantly lower amount of end products.

T-TYPE
The number of converging points increases as the focus is moved downstream in the supply chain.

X-TYPE
A large number of raw material converge into a lower number of parts that are combined into a moltitute of end products.

I-TYPE
One raw material ends up as one final product.

Figure 5 - flows from points of origin to points of consumption (Haartveit et al., 2004)

As any complex system structure, the supply chain might need information at different structure levels, this includes general information (inventories, statistics, policy targets, etc.), and also specific information related to the considered processes.

In Figure 6 the different aspects related to the planning of a forest-energy supply chain are shown considering different steps of the supply itself, and which stakeholders/needs the planning process should face.

Relatively to the harvesting activities, a careful planning should consider the site-specific features of the forests not only to ensure the multi-functionality of forests, but also to accurately evaluate the actual raw material availability. Moreover, forestry enterprises can have different specifications in terms of machineries (types and quantity), number of employers, legal status, and expertise. Therefore, ways and efficiencies of harvesting activities may vary respect ideal or optimal conditions. In these steps also the aspects related to the forest ownerships must be considered: e.g. forest owners can have different behaviors or motivations in harvesting for producing bioenergy (Blennow, Persson, Lindner, Faias, & Hanewinkel, 2014).

Then, the logistic and the production of sub-products and fuels have different (environmental, social, economic) implications (Carlsson & Rönnqvist, 2005; Forsberg, 2000; Kilkenny, 1998; Koukkari & Nors, 2009; Laurent, Olsen, & Hauschild, 2012), and may involve different enterprises.

Finally, as final distribution, two main categories are identified: the distribution of energy, through district heating and electricity production (Genon, Torchio, Poggio, & Poggio, 2009; Torchio, Genon, Poggio, & Poggio, 2009) and the distribution of fuels for domestic consumption, and distributed energy generation (Alanne

& Saari, 2006; Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005).

Local policies must face not only the recommendations and the orientations of regional and supra-regional policies, but also the manifold site-specific aspects. For this reason local authorities need tools capable to support over the time a complex planning, generally with limited financial resources.

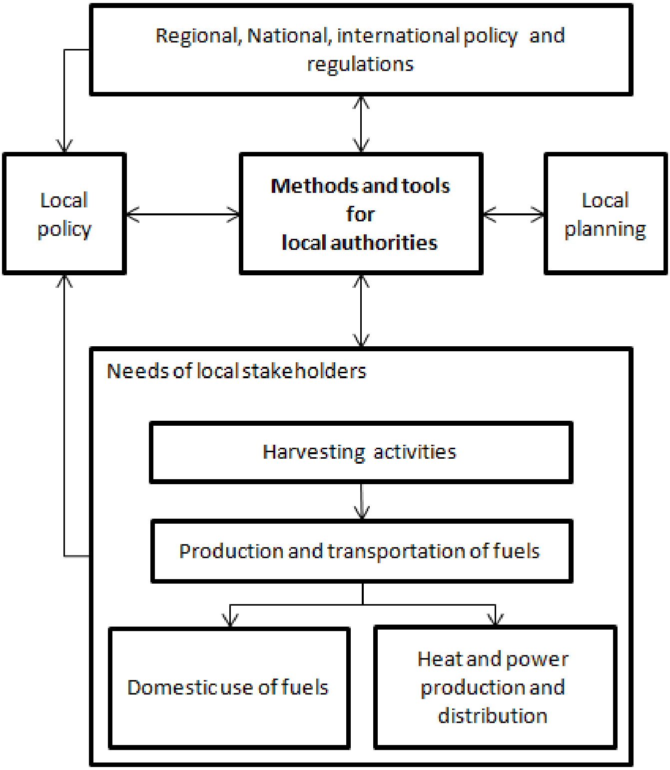


Figure 6 – Scheme of the main aspects to take into account for the case of forest-wood-energy planning

Nevertheless, the availability of scientific tools is not enough to ensure the sustainability of productive processes, if science remains separated from the practices and policy making (Guldin et al., 2005). Instruments must been seeing as interface between science and decision makers (Arvai et al., 2006; Bradshaw & Borchers, 2000; Janse & Konijnendijk, 2007). For instance, in the forest-based sector is valuable the ThinkForest forum, that aims to “provide an active and efficient science-policy interface and foster an inspiring and dynamic science-policy dialogue on strategic forest-related issues” (EFI, 2012).

CHAPTER 2 - CARRYING CAPACITY ASSESSMENT OF FOREST BIOMASS FOR SUSTAINABLE ENERGY PRODUCTION AT LOCAL SCALE

The Chapter is based on a submitted publication with Valentina Castellani, and Serenella Sala

2.1 - INTRODUCTION

The increasing demand of renewable energy, may imply in the future an increase in the demand of biomass from different sources, entailing forest biomass (Verkerk, Anttila, Eggers, Lindner, & Asikainen, 2011). At present, in Europe the use of wood in energy production covers more than 50% of the gross inland energy consumption from renewables, although that share varies from country to country (Gómez, Zubizarreta, Rodrigues, Dopazo, & Fueyo, 2010; Mantau et al., 2010). Forests can ensure several ecosystem services: providing raw materials for goods, regulating local and global climates, buffering weather events, regulating the hydrological cycles, and protecting watersheds (Lamarque, Quétier, & Lavorel, 2011; Nasi et al., 2002). A sustainable management of forests is crucial for mantaining their potential and their ecosystem services (Martire et al., 2011; Stupak, Lattimore, Titus, & Tattersall Smith, 2010), and a balance between exploitation and abandonment of the forests as both processes may imply significant environmental as well as socio-economic impacts (Vidal, Kozak, & Cohen, 2005).

The need for a multidimensional approach to Sustainable Forest Management has been increasingly discussed in recent years (Lindner et al., 2010; Nussbaum, Bass, Morrison, & Speechly, 1996; Peter Hall, 2001). This has led to the development and the implementation of methodologies to support the assessment of biomass availability in the context of forest and energy planning, in order to ensure the protection of forest ecosystem services and goods (Viglia, Nienartowicz, & Franzese, 2014). Criteria and indicators are normally accepted as appropriate tools for defining, assessing and monitoring the effects of forest management interventions over time and the progress towards Sustainable Forest Management (Castaneda, 2000; Castellani & Sala, 2010; A. D. Gough, Innes, & Allen, 2008; Hickey & Innes, 2005; Sacramento-Rivero, Romero-Bquedanoa, & Blanco-Rosete, 2009).

Sustainability assessment of forest biomass should be based on the evaluation of the Carrying Capacity (CC) of the forest ecosystem, to ensure renewability of the resource (Costanza, 2009). CC concept is considered a cornerstone of the management of renewable resources (Hilborn, Walters, & Ludwig, 1995). CC of an ecosystem is considered as the limit of exploitation of a resource that does not affect the functions of the system itself. Then, different analysis methodologies must be applied to comprehensively consider economic, environmental and social aspects (Palosuo, Suominen, Werhahn-Mees, Garcia-Gonzalo, & Lindner, 2010): e.g. the multi-criteria analysis should be combined with life cycle based approaches to the supply chain, identifying the processes of the whole supply chain, and calculating the impacts for each of them (Myllyviita, Hujala, Kangas, & Leskinen, 2011).

In literature, the evaluation of biomass availability for energy is commonly recognized as one of the first steps to plan the installation of combustion plants (A. A. Boccardi et al., 2012; Italian Termotechnical Committee, 2011). The methodologies are refferred to existing (Alfonso et al., 2009) or potential (Fiorese & Guariso, 2010) energy crops, to the calculation of agricultural residues (A. Boccardi & Maffeis, 2011), or considering a wider definition than only forestry biomass (Viana, Cohen, & Lopes, 2010), or focusing on economic viability (Noon & Daly, 1996; Voivontas, Assimacopoulos, & Koukios, 2001).

In the case of natural mixed forests, local forest management plans define the criteria to be adopted in the management of forests and identify the main functions of the forest plots (considering the tree species, the type of management, i.e. coppice or high stands, and the accessibility of the area in terms of distance from the forest roads). On the basis of the forest management plans, the specific interventions to harvest biomass are planned and approved. At italian level, as proposed by (Oliveri, 2010), those plans can be the ideal basis to calculate the biomass potential with an high geometric definition. Specifically, in the case of bioenergy planning the knowledge of the available biomass according to local planning criteria can secure the (local) supply, because it is estimated in accordance with local plans. However, the plans have been designed to provide guidelines for forestry operations and, moreover, they differ eachother in selecting criteria for forest management. There is not any standardized procedure to calculate the quantity of wood potentially available (Baskent & Keles, 2005; Kurttila, 2001), and especially, available for energy purposes (Fiorese & Guariso, 2010; Gómez et al., 2010; Sacchelli, Fagarazzi, & Bernetti, 2013; Tenerelli & Carver, 2012).

In this chapter the definition and the application of a method for implementing a GIS-based tool is described. It is capable to calculate different indicators and the energy potentials achievable from biomass exploitation, considering local plans criteria. The aim is to give a contribution in discussing the feasibility of a comprehensive and site-specific approach to calculate forestry resource availability in relation to existing data at the local scale. Specifically, an expeditious methology to calculate raw material potentials is defined from the original data, to be used as a valuable support for local policy related to wood-based chains, with a focus on woody chips production.

The methodology presented in this study is part of a wider sustainability assessment project in which a DDS is under development according to (Castellani & Sala, 2010), within the Interreg project "SAPALP – Saperi Alpini". In (Castellani & Sala, 2010) the most important aspects to be considered in order to evaluate sustainability of different management options of a local bio-energy supply chain are listed as follows: availability and quality of forest resources; raw-material quality; environmental impacts; transformation-process performance; economic performance; substitution capacity and social influence.

2.2 - METHODOLOGY

The proposed methodology allows designing a GIS-based tool, in order to calculate the biomass availability to support the local planning with a focus on the bio-energy production.

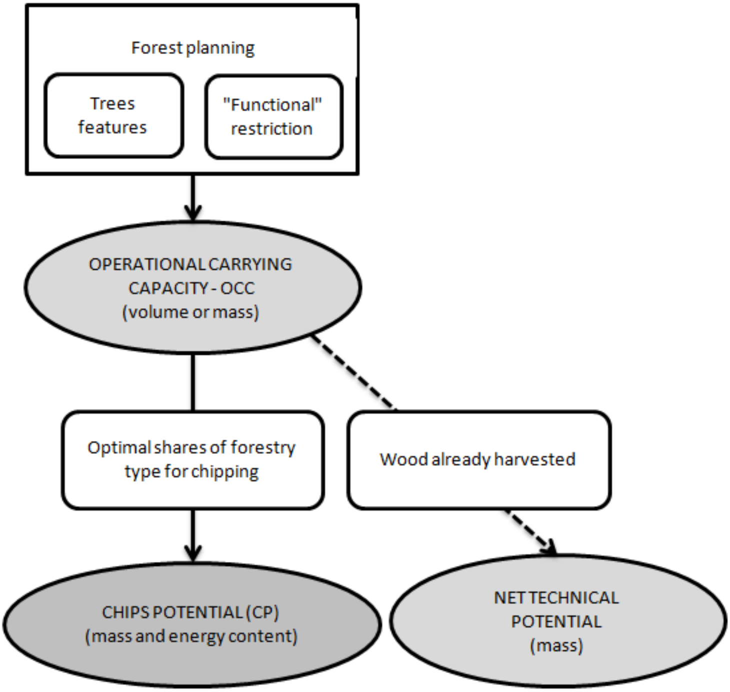


Figure 7 – Methodology to support local forest-energy planning

The methodology considers:

- The local forestry plans in order to ensure the coherence with local planning criteria and so the multi-functionality of the forests in terms of different resources and ecosystem services provided;

- The amount of wood that is currently harvested in order to have a big picture of the local forestry sector;
- The final use of the resource as woody chips, for considering the energy destination of the wood as planned by local authorities (Provincia di Como, 2011);
- The potential in terms of substitution of fossil fuels.

The results are intended to support the decision making process in the energy planning at local scale, while considering forestry plans.

It calculates the Operational Carrying Capacity (OCC) that is the availability of wood from forests according to local plans criteria: annual increment due to forest features and harvesting restriction due to the multi-functionality of forests determine that amount of biomass.

Then, it calculates the potential of woody chips production from the OCC in terms of mass and potential of substitution of fossil fuels. That quantity is defined as Chips Potential (CP).

Finally, it compares the OCC with actual uses of the resource, to support local planners in having a big picture of the forestry sector and possible development. The Technical Potential (TP) is the resulting quantity from subtracting the current use from the OCC.

The methodology is outlined in Figure 7 and the Indicators are detailed below.

2.2.1 - OPERATIONAL CARRYING CAPACITY

The Operational Carrying Capacity (OCC) is defined as the biomass that can be harvested annually without affecting the resource and as it is stated by local forest planning. Specific OCC (SOCC) is the OCC per unit of area, derived from the data about forest managements.

The OCC accounts for the multi-functionality of the forests in terms of different resources and provided ecosystem services. OCC adds more constraints to annual allowable cut, based on the functional restrictions defined by the local forestry plans. The annual allowable cut is a characteristic of the ecosystem itself.

The planning criteria adopted by local authorities in the development of forest plans define which functions are performed by different forest areas (e.g.: protective, touristic, productive), and the functions depend on the characteristics of the forests themselves, and on the characteristics of the local system (e.g.: accessibility, landscape features, ownership). The renewal rate of forests and the wood features are influenced by the forestry species; not only in terms of profitability for the market, but also with regard to the energy content, affected by the chemical and physical properties of the wood.

2.2.2 - CHIPS POTENTIAL

The Chips Potential (CP) accounts for the different forest types that can be more or less suitable for producing chips. For this reason, the analysis of the biomass potential for energy purposes is completed by calculating the chips production on the basis of the forest type. Different types of wood can be more or less profitable for woody chips production (Corintea, 2003; Regione Liguria, 2011; Riba, Piazzi, Tresso, & Bussone, 2012). The quality of the chips depends on the specific energy content and on a low production of ash, for those reasons hardwood is recognized as a good source for chips. For this reason the Chips Potential (CP) is an estimation of the amount of biomass that is suitable to produce chips, and it is a share of the OCC (or the SOCC).

2.2.3 - TECHNICAL POTENTIAL

The Technical Potential (TP) depends on the current uses of the biomass and on the possible biomass losses that can occur along the supply chain. For example, in the case of bio-energy supply, losses can occur in the pre-treatment processes to obtain the fuel, and some parts of the trees could not be used (such as branches in the production of wood logs). So the total amount of biomass effectively available is lower than the amount that results from subtracting the current use from the OCC.

Therefore, the TP corresponds to the available biomass, calculated subtracting the technical losses (TL) and the current use (CU) from the OCC:

$$TP=OCC-TL-CU \qquad \textit{Equation 1}$$

2.3 - CASE STUDIES

To achieve bioenergy and forestry policy goals, local plans are developed by different authorities. For the case of the Province of Como, the Energy Plan (Provincia di Como, 2011) plays a key role and it identifies a number of actions to promote energy efficiency and energy saving, to foster renewable sources, to develop the energy market, and to implement regulations and administrative measures to achieve its objectives. In particular, the Plan identifies the development of production and consumption of woody chips as crucial to achieve local forestry and energy policies goals. Particularly, local policies are oriented at the development of small sized heating plants (Power below 500 kWt) fueled by woody chips, because it is considered an effective balance between emission control and the use of local wood in short supply chains (Caserini et al., 2003)

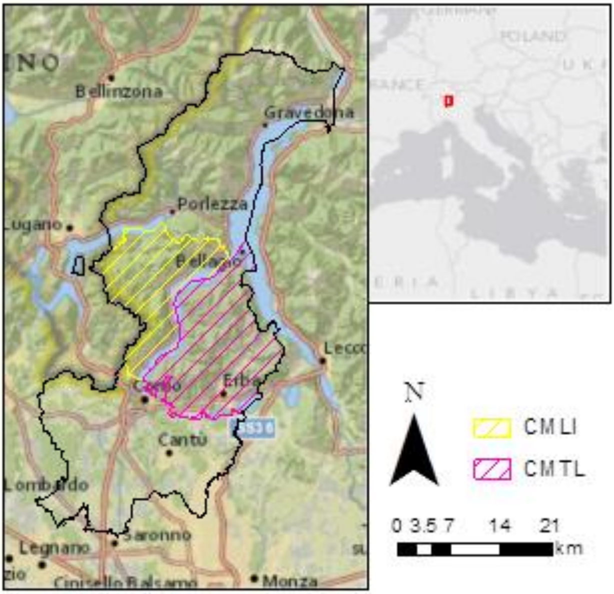


Figure 8 – Areas of study. Projection: Gauss-Boaga – Datum: Roma 40

The case studies are related to two mountains areas in northern Italy (Figure 8): Comunità Montana Triangolo Lariano (CMTL) and Comunità Montana Lario Intelvese (CMLI). Each area is managed by a local authority (Comunità Montana[1] - CM): the CMTL includes 31 Municipalities, and it extends for 25273 ha, of which 62% is covered by forests; the CMLI includes 26 Municipalities, it extends

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[1] A Comunità Montana is a territorial local authority established by Italian law. It is a public institution with compulsory membership of montane Municipalities. The aim is the enhancement of mountain areas.

for 15775 ha, of which 64% is covered by forests. The two CMs were identified as interesting areas for the study because both intend to develop local and sustainable biomass supply chains, in order to answer to the abandonment of rural areas, the underutilization of forests, and the weakness of forestry enterprises of the areas. CMLI's territory is the Intelvi Valley and surrounding municipalities bordering on the western shore of Lake Como; CMTL's territory is the triangular land formed by the two southern branches of Lake Como, limited to the south by the small lakes of Alserio, Pusiano and Annone.

2.4 - DATASETS

In this section the data used for applying the methodology are described and discussed.

2.4.1 - FORESTRY PLANS

Each CM defines the planning criteria applied in the Forest Plans (Piani di Indirizzo Forestale - PIF) for its own forest areas. The estimated amount of biomass that can be harvested from a forest depends on the CM's criteria. PIF and vectorial data are available for both areas (CMLI and CMTL). They show location and extent of different forest types and their nominal scale is 1:10000.

The forest features and functions are defined considering: tree typology, the location of the forest parcels, the accessibility (roads, slopes) of the parcels, the specific growth rate for each tree type (depending also by the management, i.e. high stand or coppice), and the presence of protected areas and of sites with high natural or cultural value. The planning criteria can be different for each CM area: each authority (e.g. CMTL and CMLI) sets different criteria to estimate forest production on the basis of the spatial features and the functions of the forests. Besides, the informative layers of forest functions are given in different forms by each local authority. Therefore the GIS-based tool should be flexible enough to fit to the different input data. The definitions of the functions of the forests for the two areas are detailed in Table 2.

Table 2 – Definition of functions for the two areas (CMLI and CMTL)

CMLI	CMTL
Productive: these areas provide wood and non-wood goods such as resins, tannins, mushrooms;	Productive: these areas provide wood and non-wood products;
Protective: these areas provide services such as protection from erosion, wind, avalanches, floods;	Protective: these areas provide protection from erosion, infrastructure protection in case of landslides and avalanches, protection from wind and flooding, protection of river banks;
Naturalistic: these areas provide services such as the conservation of nature (species protection, ecosystem diversity), and evolutionary processes;	Naturalistic: these area provide the protection of habitats, protection of species, the conservation and the development of ecological networks in large-scale, biodiversity of ecosystems, evolutionary process development, de-pollution, to maintain suitable habitat for the protection of wildlife;
Wildlife Hunting: these areas provide services such as the maintenance of suitable habitats for biological assets and the development of wildlife;	Touristic and Recreational: these areas provide tourism and sport, hunting and fishing, environmental education and culture.

Landscape: these areas provide services such as maintaining the quality of places and landscapes;	
Touristic-Recreational: these areas provide services such as tourism and sport, hunting and fishing, education and environmental culture.	

For evaluating the raw material availability, the analysis should focus on the productive function (called “attitude” in the CMTL PIF). The definitions of functions for the two areas have negligible differences. However, the way in which every plan assigns and manages the functions is different:

- The CMLI PIF defines silvicultural guidelines based on forest types, and these are defined only for the Protective Function and the Productive Function. The CMLI PIF reports the extension (ha) for each category listed. Several attitudinal features are also planned, including more than one for each category. They define the features of the best silvicultural interventions suited to each function. Therefore, the availability of biomass can be calculated for productive and protective areas. Forests perform several functions at one time and in the allocation of categories, where use conflicts can be envisaged, planners assign a higher weight to one function over the others. The functions assigned to the forests are listed in the PIF.

- In the case of the CMTL PIF, the analysis of the functions, developed by local authorities, was conducted separately for each function or potential attitude: Naturalistic, Protective, Productive, Touristic and Recreational,

> Landscape. Function is defined as the establishment of a forest to provide specific services. Indexes are defined for each function on the basis of provided goods and services. Given the indexes, information layers are selected to contribute to the score that determines the attitudes of the forest areas. For example, the conservation of species, habitats and ecological networks are some of the indexes of naturalistic attitude, in this case Natura 2000 network is one of the informative layers used: the presence of a Natura 2000 site in a forest area (in a polygon) assigns a high score to the Naturalistic Function of the forest area. The prevalent attitude for a forest area is defined as the attitude with the highest score in the area, and the same forest area can be characterized by more than one function with maximum value, or by more than one function with the same value.

The PIFs divide forest land on the basis of forest types and subtypes as they are defined by the national classification of forest types. And the different planning criteria differently define as productive the forest types. The types considered in the evaluation are shown in Table 3.

The CMLI PIF provides data on specific cutting rounds and annual production (m^3/ha) for each forest type; this information is given only for the forest plots that are assigned Productive or Protective Function. The information about cutting rounds and the available amount of mass are not offered for the forest plots that are assigned the remaining Functions (Naturalistic Function; Wildlife Hunting Function; Landscape Function; Touristic-Recreational Function): specific silvicultural interventions are planned for these areas.

Table 3 – Forest types considered in the evaluation for the two areas

CMLI	CMTL
Chestnut	Chestnut
Ornus	Ornus
Maple (Ash and Lime)	Maple (Ash and Lime)
Birch	Birch
Sub-mountain Beech	Beech
Mountain Beech	Beech Spruce
Top-mountain Beech	Spruce
Beech	Alder
	Rowan
	Hazel
	Scots Pine
	Robinia
	Reforestation of coniferous trees

Data on the cutting rounds and the available mass are not available for some forest types (Oak, Hazel, Alder, and Reforestation categories). Therefore, it is not possible to determine the biomass availability for these categories in the CMLI area. However, neglecting those plots in the estimation of biomass does not lead to a significant difference in biomass availability because the area covered by these categories is less than 7.5% of the total forest area.

In the case of CMTL PIF the annual production data are provided for a higher number of forest types and the values given as annual production in CMTL are independent of the Function of the area. A value for the different functions is given for each polygon (from 1 to 10 in the case of the Productive Function). In other words the CMTL

PIF defines the plots as more or less productive, instead – as the CMLI PIF – of defining the plots as productive or not productive.

2.4.2 - CHIPS PRODUCTION

The available wood can be more or less suitable for chipping, because other uses than chips production can be more economically viable. According to studies in similar areas (Corintea, 2003; Regione Liguria, 2011; Riba et al., 2012) and local expert opinion it has been estimated for Lombardy Region the desirable shares of chips for each forest type, considering already biomass losses that may occur along the supply chain (Table 4).

Table 4 – Desirable share of chips from harvested biomass (Share) for different forestry types of the Lombardy Region

Forest type	Share (%)
Chestnut	60
Ornus	40
Maple (Ash and Lime)	30
Birch	80
Beech	25
Spruce	0
Alder	70
Salix	70
Hazel	70
Scots Pine	0
Robinia	30
Reforestation of coniferous trees	40
Beech	25
Oak	25

2.4.3 - CURRENT USES

The Forest Activity Statements (DIAF – Dichiarazioni di Inizio Attività Forestale) provide the information about the amount of wood already harvested. DIAF are self-declarations of forest owners to the local authority regarding the forest harvesting activities that will be done in the following season. For the case study data from the DIAF of the year 2008 and the year 2011, have been elaborated to estimate the amount of annually harvested wood. There are some limitations:

- Data are affected by uncertainty: the statements are made before the cutting season. So the values can be under-estimated to avoid surcharges (there is a higher price a certain threshold of withdrawal), or over-estimated to avoid sanctions[2];
- Data are difficult to manage:
    - For 2008 data every statement is a record in the table, and it does not have a primary key, but each statement is uniquely identified by a combination of two fields (part of the body to which it was presented, and the sequence number of the statement with respect to which the entity was submitted);

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[2] If the amount that is harvested is not precisely defined, the owner could prefer to declare an over-estimation of the quantity to avoid sanctions which are due if the real amount cut is higher than the one declared.

- Statements of 2008 do not provide the coordinates of the area covered by forest or cutting, but only the parcel and the Municipality;
- For 2011 data every statement provides a list of forest species, but it does not provide the information on the forest type that can allow a direct comparison with the PIF data.

For these reasons, the amount of wood already devoted to some other use, i.e. not available for chip boilers, can only be roughly estimated. Therefore, the data about current use are considered only for a comparison within the presented methodology, and the main data used for energy use planning refer to chips production indicator.

According to local expert opinion and DIAF elaboration, over than 85% of harvested wood is to produce logs for domestic fireplaces, and it is harvested for own consumption of the forest owners over than 60% of the wood used for the production of logs.

2.5 - IMPLEMENTATION

The methodology has been applied to the two areas using the GIS software ESRI ArcGIS v.9. An overview on how the external data are related to the resulted layer is shown in Figure 9.

PIF data are used to evaluate the SOCC, OCC is obtained multiplying SOCC with the areas of forests, given as polygonal shapefiles. Considering the moisture content of wood and forest types, a volume to mass conversion is implemented to obtain *OCC* in terms of mass related to each forest polygon. Local plans provide cutting rounds and maximum and minimum amounts of mass that can be harvested in the time between two subsequent cuts.

The minimum annual available rate is the ratio between minimum withdrawable mass and maximum cutting round while the maximum annual available rate is the ratio between maximum withdrawable mass and minimum cutting round. The range of variability is the difference between the two values.

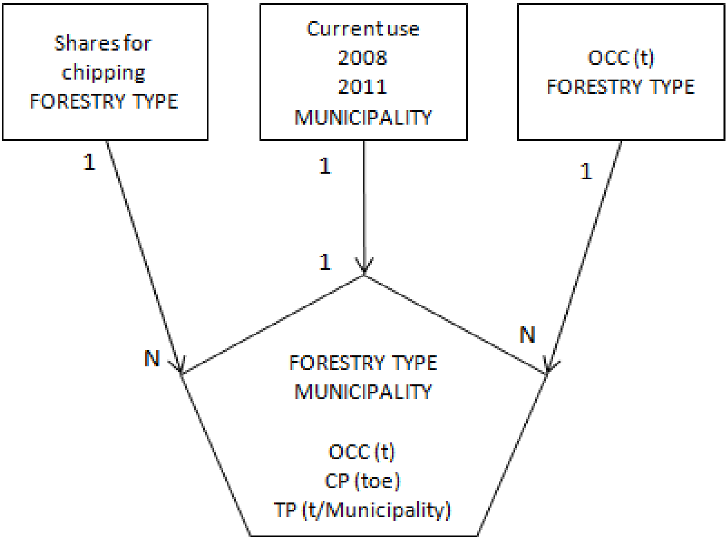


Figure 9 – Entity-Relationships model of the data

So, the proposed formula identifies an average annual production, and it is expressed as volume per hectare:

$$SOCC = \frac{\frac{(m_{max} + m_{min})}{2}}{\frac{(t_{max} + t_{min})}{2}}$$

Equation 2
Source: (Hellrigl, 2006)

- $SOCC$ is Specific Operational Carrying Capacity (m^3/ha);

- m_{max} is the maximum withdrawable mass over time between two cutting rounds (m^3/ha);
- m_{min} is the minimum withdrawable mass over time between two cutting rounds (m^3/ha);
- t_{max} is the maximum cutting round (years);
- t_{min} is the minimum cutting round (years).

Forestry plans assign m and t on the basis of the forest function and type. The forest areas that contribute to the biomass potential are considered managed as coppice.

SOCC is determined by function and forest category or type; these parameters affect m and t. It is possible to estimate the OCC in terms of volume (usually in m^3). The potential in terms of mass is, therefore, deducted from the volumic mass of the biomass, based on the density of tree species (expressed as a ratio of mass and volume of the wood: kg/m^3 or t/m^3). The volumic mass depends on the moisture of the wood and the swelling factor, as in Equation 3:

$$\rho_w = \rho_0 \frac{1 + \frac{u}{100}}{1 + \frac{a_v}{100}}$$

Equation 3
Source: (Hellrigl, 2006)

- ρ_w is the volumic mass referred to the moisture content (t/m^3);
- ρ_0 is the volumic mass referred to the anhydrous status (u=0);
- a_v is the total volumetric swelling factor (%);

- u is the wood humidity (%).

ρ_0 and a_v values depend on wood species considered, and values are available in the literature (Francescato & Zuccoli Bergomi, 2008; Hellrigl, 2006).

When a_v values are not available, Equation 4 has to be used (Francescato & Zuccoli Bergomi, 2008):

$$a_v = \frac{100 \cdot \beta_v}{100 - \beta_v}$$

Equation 4
Source: (Hellrigl, 2006)

- a_v is the total volumetric swelling factor (%);
- β_v is the total volumetric shrinkage factor (%).

In general, the total amount of water in the wood can be expressed as water content (w - compared to the percentage of water with wet or "as it is" mass), or as moisture (u – amount of water in percentage compared to the dry or anhydrous mass). The volumic masses are calculated by considering two different values of moisture, a minimum value of 25% of moisture and a maximum value of 67%, corresponding to a water content of 20% and 40% respectively.

They have been chosen because they are minimum and maximum values for the wood chips typically used in small-medium burning plants (power below 1MW). In general, using wood chips with humidity below 25% is possible, but this requires proper treatment of drying, since the seasoning process alone is not enough. Such interventions may have a significant impact on supply chain costs.

Data on cutting rounds and the mass quantity per hectare that can be harvested are used to calculate the OCC of each category. After the calculating procedure a value of OCC can be assigned to each polygon in terms of volume per hectare. The estimation of the OCC in terms of mass is calculated with respect to the moisture contents.

The amount of wood mass (t/ha per year) for the two different moisture contents is obtained multiplying the volumic masses (t/m^3) of each forest category for their volumetric amount obtainable annually (m^3/ha per year). This leads to a variation of the mass potential of ± 14%.

For the case of CMLI, it is not possible to know the detailed composition of each forest type, so only the dominant species of each forest type has been considered, as they are defined by the Guide of forest types of the Lombardy Region (Lombardy Region, 2014a), and parameter values from the literature have been assigned (Francescato & Zuccoli Bergomi, 2008; Hellrigl, 2006).

Shares for chipping depends on the forestry type, they are associated to the OCC/SOCC layer. Values of CP in terms of tons and tons per hectare are calculated by multiplying OCC and SOCC with the assigned share for chipping.

The lower calorific value is considered to obtain the CP as e*nergy potential*. The lower calorific value expresses the amount of heat energy inferred from the complete combustion of 1 kg of wood if the water has been released in combustion into steam. For the proposed methodology, the lower calorific value assumes a unique value for all types of wood, and it depends primarily on the water content and then on the wood species considered. For the calculation of the lower calorific value an average water content of 30% has been assumed.

Generally, the lower calorific value of wood (expressed in MJ/kg) decreases with water content according to Equation 5:

$$pc_w = \frac{pc_0 \cdot (100 - w) - 2{,}44 \cdot w}{100}$$

Equation 5
Source: (Hellrigl, 2006)

- pc_w is the lower calorific value with water content w;
- w is the water content;
- pc_0 is the calorific value of dry wood substance (MJ/kg);
- *2,44* (MJ/kg_{H_2O}) expresses the latent heat of vaporization of water referred to 25°C.

In order to calculate the energy potential, the lower calorific value assumes an average value of 18 MJ/kg. Increasing the moisture content, the lower calorific value decreases, and mass and volume increase. This leads to a variation of the energy potential of ± 3%. Finally, by converting the value of the energy potential in terms of tonnes of oil equivalent, it is possible to calculate the potential of substitution of fossil fuels.

DIAF of 2008 and 2011 datasets have been elaborated to calculate the Current Use. Since in one case the Current Use data are not geo-referred, the comparison has been done considering the values of quantities of wood (mass or volume) reported at the Municipal level. *Municipality* shapefile and *OCC* shapefiles are merged in order to split the OCC shapefiles according to the municipal borders, and to assign to the new polygons the attribute related to the Municipality and the SOCC. Then, the OCC is calculated at Municipal level from the SOCC values and the new polygon areas; then, the Current Use and the technical losses are subtracted, to obtain the *TP* values at Municipal level. The technical losses depend on the specific supply chain: an average value of biomass losses of 20% for energy supply chain is considered, according to the national statistics (ITABIA, 2008). After subtracting the Current Use (for the year 2008 and for the year 2011) from the OCC, 20% is further subtracted to calculate the TP. The TP is not necessarily profitable for energy purposes, but implementing the technical losses as parameter could be beneficial in using the defined GIS-based tool with more detailed data on the possible supply chains that can be developed, according to the profitability of the potential available biomass.

To implement the described model, a Geodatabase has been built, and operation-flows have been defined within the ESRI ArcCatalog software. The ESRI Geodatabase is the common data storage and management framework for ArcGIS. It combines "geo" (spatial data) with "database" (data repository) to create a central data repository for spatial data storage and management, and the Geodatabase is a more robust and extendable data model compared to shapefiles and coverages.

An operation flow has been modeled in order to get the results by using the data stored into the Geodatabase, which can be updated. The application ModelBuilder has been used to design the operation flow. ModelBuilder allows creating, editing, and managing models. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input, it can also be thought of as a visual programming language for building workflows. The use of this application allows setting workflows to calculate automatically the indicators. In particular, the data format used by the local authorities was taken into account defining the calculation processes, so making the data consistent with the required specifications.

2.6 - RESULTS

The maps of availability of biomass in terms of Operational Carrying Capacity and Chips Potential are shown in Figure 10 and Figure 11.

The forest areas in which the biomass is available are less fragmented in the case of CMTL, because the CMTL forestry plan defines the forest plots as more or less productive, conversely the CMLI plan define the forest plots as productive or not productive. This fact is compensated by different management guidelines for the two areas: higher values per hectare of OCC and CP are in the productive forests of the CMLI area.

Average results of the indicators for the two areas of investigation are compared in Figure 12. The OCC is about 22 600 t for the CMLI area and about 27 300 t for the CMTL area. The calculated OCC is a significant figure for both areas of investigation.

The Chips Potential corresponds to about the 32% of the OCC for the CMLI area, and about 38% of the OCC for the CMTL area. For the CMLI the CP is about 7 283 t (about 85 TJ), and it is about 10 465 t (about 122.5 TJ) for the CMTL area.

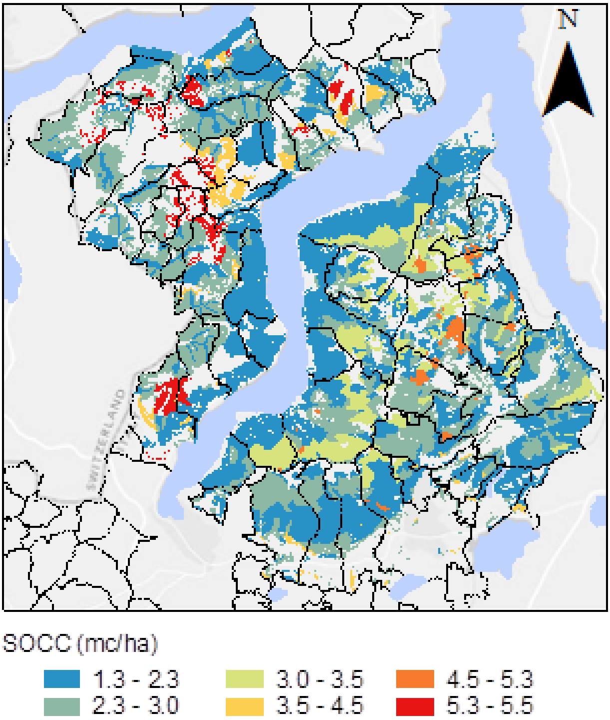


Figure 10 – SOCC Values. Borders of Municipalities are shown. Scale 1:350000. Projection: Gauss-Boaga. Datum: Roma 40.

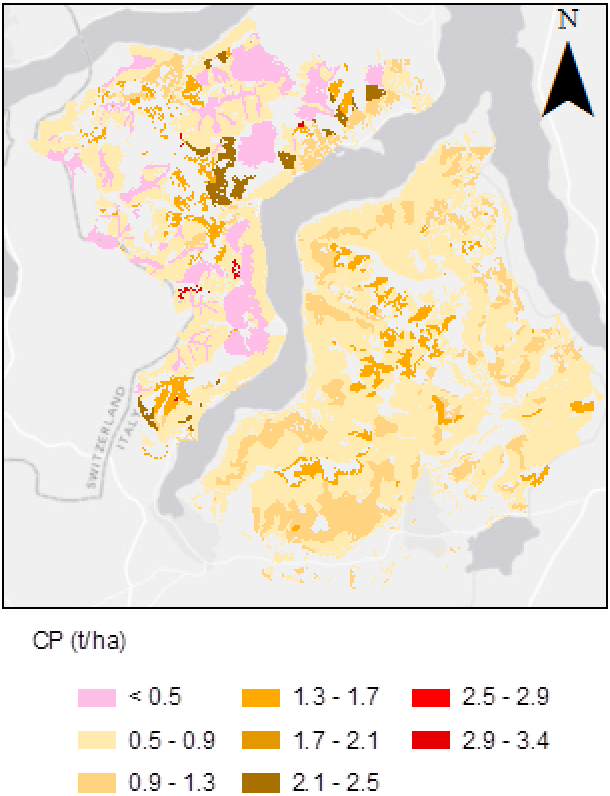


Figure 11 – CP Values. Scale 1:350000. Projection: Gauss-Boaga. Datum: Roma 40

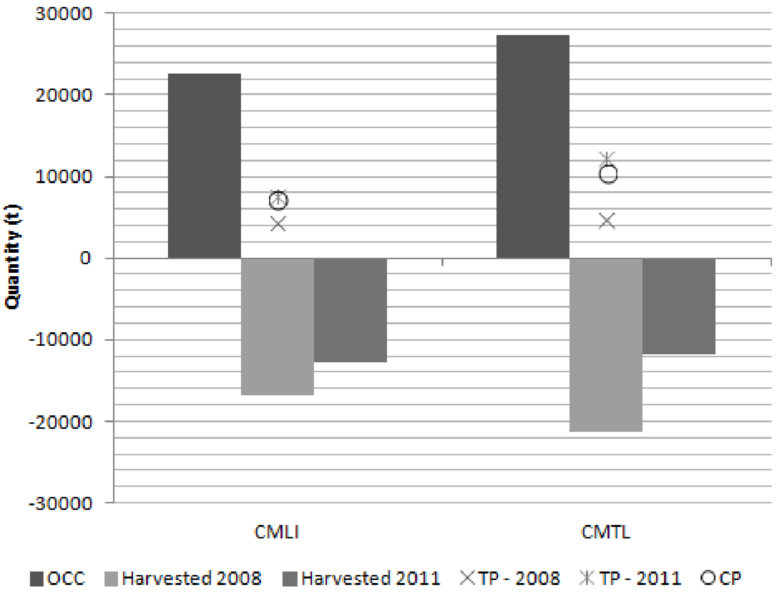


Figure 12 – Results of the Indicators for the two areas

In order to highlight the magnitude of the potential fossil fuel replacement at local scale, the energy potentials can be compared with energy demand and supply at local scale. Local inventory of energy data is available throughout the regional database SIRENA (Lombardy Region, 2014b), providing the consumption of energy from Natural Gas, LPG and Diesel for the residential sector, that is the most energy-consuming sector in these areas. In the case of CMLI the amount of these consumptions is 20 157 toe, and the calculated CP covers about 10% of energy from fossil fuel consumption of the household sector of the area. In the case of CMTL area the amount of the consumptions of energy from Natural Gas, LPG and Diesel for the household sector is 48 787 toe, and the calculated CP covers about 6% of energy from fossil fuel consumption of the household sector of the area.

The harvested wood has been about 75% in 2008 and 55% in 2011 of the OCC in CMLI area; and about 78% in 2008 and 43% in 2011 of the OCC in the CMTL area. These results show a high variability of the annual harvested quantity. The accumulation of wood in the forests is not taken into account in calculating the OCC: the harvesting activities in coppice stands generally happen at the end of the cutting round, the OCC is an annual average availability. For this reason in case of some Municipalities the TP value is negative (see Annex I).

In order to further support local decision-making needs, an estimation of the number of plants, which can be fueled with the estimated potential, can be obtained by considering consumption data. As stated before, local policies are oriented at the development of chip boilers to substitute older fossil fueled boilers for heating purposes. The results can be compared with the consumption of an existing plant: it is located in CMLI area, and has a capacity of 240 kWt, it is fueled by forest chips, and its purpose is for heating a public swimming pool. It consumes about 300 tons of chips per year: the average CP allows supplying about 59 similar plants (24 in CMLI area and 45 in CMTL area).

2.7 - DISCUSSION

The proposed methodology estimates the quantity of raw materials that can be provided by the local forests, while considering the local forestry plans. On one hand, the methodology gives an added value to local plans calculating timber and chips potentials, on the other hand, it can stimulate a harmonization of planning criteria and a standardization of dataset between similar, or nearby, areas.

The main limitation of the application of the methodology lies in the data format. Although it is important to standardize the data, documents drawn up by the local authorities still suffer from some degree of arbitrariness by local planners.

The presented methodology focuses on raw material supply, and the forestry plans aim to guide altogether the management of forests, for this reason it is not possible to define which way of setting guidelines is better. However, both plans present components that could positively contribute in defining a suitable procedure to set-up forestry plans that can easily allow an evaluation of chips and timber potentials.

The CMTL plan is more detailed in defining the management guidelines for the different forestry types. But the procedure followed by CMLI plan in defining how functions affect the biomass availability seems to be more suitable, because the CMLI plan define the areas as productive or non-productive, and management guidelines of the forest plots depend on the type and on the function. For those reasons results obtained for the CMLI can be considered much more consistent than the results obtained for the CMTL area.

Despite this, the CMTL PIF assigns different level for the productive function to the areas (from 1 to 10): the possibility of setting a threshold of productivity in order to define the productive areas can give more flexibility to the methodology, nevertheless criteria to set that threshold must be defined.

Some forest species (or types) can be more profitable for timber production instead fuels, therefore obtaining the Chips Potential by considering shares of biomass for chipping is crucial to plan a chips-based bio-energy chain.

The combined use of data on forest planning (by PIF) and data on the use of wood (by DIAF) for calculating the TP leads to lower quality in data detail and the TP does not represent what can be harvested in that year. However, the ratio between the resource availability and the resource usage is useful for developing local policies dealing with local resource use. The analysis of available and harvested biomass is useful to plan further biomass exploitation considering how forest owners use their forests for wood production (Jumppanen, Kurttila, Pukkala, & Uuttera, 2003; Pykalainen, Pukkala, & Kangas, 2001).

This assessment is based on the calculation of an annual average availability of wood, weighted on the cutting rounds of the forests. So, it answers the questions of “where” and “how much” wood is available; but it does not consider the starting year and the ending year of the cutting rounds, so it does not answer the question of “when” the wood is available. In other words, it estimates the annual availability in an ideal condition: a forest plot - with a cutting round of x years - is divided in x parts and each year is harvested one part. For this reason, the participation of the forest owners to the local energy plans is helpful to secure the fuel supply to the local plants.

2.8 - CONCLUSIONS AND FUTURE DEVELOPMENTS

Forestry resource assessment at local scale is crucial to achieve the energy and forest policy objectives: the methodology allows for a preliminary assessment of the possibility to consider woody biomass in energy planning at local level, using existing forestry planning data. Besides, the geo-referred results help in defining the optimal location and size of chips plants.

Methods and tools to evaluate the resource availability must be able to adapt to local needs and possible lack of data and/or data standardization. The main challenge in developing and applying the method has been to adapt it to the quality and the detail of the data provided.

It has been shown how to give value added to existing dataset in order to support local decision-makers, providing a tool to calculate timber and wood chips availability. It would motivate the definition of common criteria for wider areas to define local forestry plans. The approach presented would give a contribution in facing the local resource assessment and planning, specifically linking forest plans and local energy policy.

The proposed indicators can be used in various decision-making processes: analyzing their trends over time or by defining scenarios. The Operational Carrying Capacity is a partial measure of protection of forests: if it remains stable over time means that the capacity of the forests of providing raw material is ensured. The

Chips Potential concerns only the use of wood as chips, and it is a key element in energy policy at the local scale. The Technical Potential takes into account the used wood, so it indicates the wood potentially available on the market; however – considering the high variability of current use data - longer time series should be elaborated in order to better estimate the resource usage over the years.

The information resulting from the methodology implementation should support local planners, which for the present case are the forestry experts of the Como Province. A unique model of forest management does not exist, neither a register of all forestry activities carried out. Therefore, common planning criteria for the local areas should be identified by local experts. In particular, the questions that should be addressed are related to the forest management which affects the assessment of the availability of wood identifying "when" the biomass can be harvested.

The opinion of local experts is that missing information of PIFs can be taken from other documents that are referring to specific forest plots (PAF – Forest Assessment Plan). For the area of Como Province, those documents are mainly in hardcopy archive and sometimes out of date. However, PAFs can provide more detailed information about the forest management practices and forest types.

To adapt the tool to the new requirements, it has been reframed. Instead of considering as geometric reference the forest plots as defined by PIFs, the basis on which implement the operations to get the indicators results are squared cells (side of 50 meters) of a netfish that covers the whole interested area. Each cell grabs the information about forest type and management practice, and, on the basis of these, some equations are performed to get the data about annual availability of wood. Then, further restrictions can be added to further limit the biomass availability as accessibility of forests, profitability of harvesting, profitability of chipping, need of limiting the harvesting for ensuring other functions (as protective, naturalistic, touristic, aesthetical etc). Further details are given in Annex II. Figure 13 shows a first result of this assessment: the average annual production of biomass for the area of the Como Province, without taking into account the further restriction sketched before.

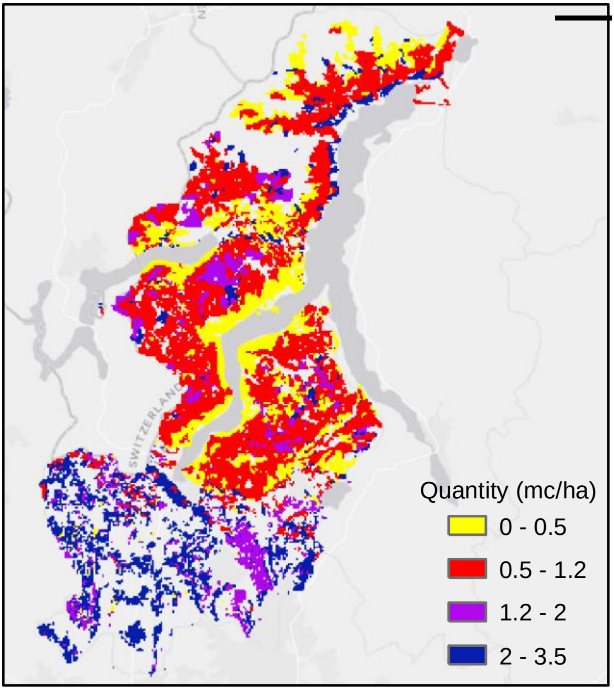


Figure 13 – Biomass availability for the Como Province. Scale: 1:750000. Projection: Gauss-Boaga. Datum: Roma 40

CHAPTER 3 - SUSTAINABILITY IMPACT ASSESSMENT FOR LOCAL ENERGY SUPPLIES' DEVELOPMENT

The Chapter is based on a submitted publication with Marcus Lindner, Diana Tuomasjukka, Joanne Fitzgerald and Valentina Castellani

3.1 - INTRODUCTION

Decision making at local scale should be supported by assessment tools able to take into account different aspects related to the sustainability of processes (Govindan et al., 2013; Kasprzyk et al., 2013; Matthies et al., 2007; Murray, 2013; Tsoulfas & Pappis, 2008). Analyses on environmental, social and economic aspects are needed to provide comprehensive information to local decision makers (Frame & O'Connor, 2011; Päivinen et al., 2010): they must rely on experts and data that provide comprehensive knowledge on the impacts of potential decisions. The inclusion of economic, environmental and social aspects of consequences from decision making helps rural development and local decision makers. Moreover, different studies (Garrod, Wornell, & Youell, 2006; Schultink, 2000) confirm the linkage between rural development and sustainable planning and the need of exploring trade-offs of different development options.

Usually, local policies aim to merge needs of the local community with the objectives of regional, national and international regulations. Rural development, that is usually a target of local policies, is framed within the use of local resources to provide leverage at local population, and to prevent the depopulation of rural areas thorough increasing local employment opportunities

(FAO, 2006; Kuvan, 2005; Pimentel et al., 1997; Remedio & Domac, 2003). The use of local resources for energy production can boost the security of the energy supply, and that is usually an aim of national energy policies (Awerbuch, 2006; Helm, 2002; Turton & Barreto, 2006).

The main constraints to the development of local energy generation and consumption is the economic feasibility and the need for investment in infrastructure (Alanne & Saari, 2006; Lopes, Hatziargyriou, Mutale, Djapic, & Jenkins, 2007; Pepermans et al., 2005).

In addition to this, the development of local energy chains causes environmental impacts along the whole supply chain. In the case of forest-energy chains, direct impacts from harvesting activities, transportation, transformation of raw materials, and energy generation must be evaluated. Several studies in Europe show a growing contribution of wood fuel towards domestic heating in urban areas and the impacts of this on the environment, especially on air quality (Castro, Pio, Harrison, & Smith, 1999; Jankowski, Schmidl, Marr, Bauer, & Puxbaum, 2008; Kukkonen et al., 2005; Piazzalunga et al., 2011; Schmidl et al., 2008).

In this context, local decision-making processes must be guided by a careful evaluation of the economic, environmental and social sustainability of production chains and alternative choices. The aim of the study is to explore if and how an integrated assessment can quantify to what extent bio-energy supply chain development contributes to rural development and energy policy objectives under different scenarios.

In this study, the application of a Sustainability Impact Assessment (SIA) of energy development for an alpine region is described. It has being done to measure how different bio-energy scenarios impact on rural development and energy policy aims. The SIA's findings should support the planning of a local forest-energy supply chain in the rural area of Como Province in Italy. Local authorities believe that the improvement of local bio-energy chains can stimulate development in rural areas and aid in meeting regional goals by 2020 (Italian Ministry for Economic Development, 2012; Lombardy Region, 2006, 2010). Generally, studies in the same context were related to single aspects, focusing on availability of natural resources (A. Boccardi & Maffeis, 2011), economic profitability and forestry harvesting activities (Spinelli & Magagnotti, 2011), environmental aspects (Cespi et al., 2013; Marra et al., 2011; Piazzalunga et al., 2011). However, there is a lack of knowledge of the local forestry and energy systems in local plans: frequently data are inconsistent or outdated.

SIA can bring some benefits to local decision-makers in quantifying impacts on environment, economy and society of a supply chain, and aiding in evaluation of the effects of planned actions over time. SIA can also help in handling heterogeneous datasets for obtaining a big picture of the local forest-energy sector. Specifically, the study considers:

- Biomass utilization and energy generation technologies -- The quantity of energy (heat and power) depends on the quantity (and quality) of used biomass and on the efficiency of the combustion processes, therefore different inputs in terms of biomass and different combustion technologies must be compared to estimate the (actual and potential) contribution to energy production from forestry sources;

- Mechanization levels -- Harvesting machinery owned by and available to local enterprises have been considered in the different scenarios in order to define different mechanization levels;

- Economic aspects -- Economic impacts of baseline and different scenarios have been analyzed. The focus is on subsidies for energy from renewable sources, because they determine the economic feasibility of local energy production and also bring additional profit to local enterprises. However a good investment cannot rely on long-term subsidies. Therefore, the role of subsidies in the different development options must be evaluated;

- Social aspects -- Developing local productions can prevent depopulation of rural areas; therefore it is important to estimate the direct impact on employment of the different options;

- Environmental aspects -- As mentioned before, assessing the environmental compatibility of biomass use for energy of the different options is one of the aims of the study. The study particularly focuses on direct emissions.

3.2 - MATERIALS AND METHODS

3.2.1 - STUDY REGION

The Province of Como is a province in the north of the Lombardy Region of Italy and borders the Swiss Cantons of Ticino and Grisons to the North. The central and northern parts of the Province are montane, and with a large forest cover (45% of the total area of the Province). Total population is around 600000, and is concentrated in the plains and along the shores of Lake Como. The local economy is based on industry and tourism. The rural and montane areas have a low population density. At present, depopulation is not a threat, as it is in other rural and montane areas of the Alps (Perlik & Messerli, 2004), because many of the people work in Switzerland as daily commuters. Nevertheless, the political acceptance of Italian commuters among Swiss communities has been questioned recently and policies aimed at limiting the access of foreign workers has been proposed (Reuters, 2014); therefore depopulation due to more limited employment opportunities could become a threat for the region in the coming years.

In spite of the high availability of wood as a raw material, forestry operations are limited and often need to be subsidized. The overall management of the forests is hampered by the extreme fragmentation of property ownership (between public and private owners) and the limited economic power of public owners (mainly municipalities). In addition, the topography of the sites (steep terrain with limited accessibility) and the characteristics of local forestry firms (small businesses, family managed, with limited equipment) limit the use of highly mechanized systems and reduce the productivity and the value added by harvesting activities.

As a result, the forest area is increasing over time and many forests are not being managed. Unmanaged forests are a threat for landslides and fires and cannot be used for recreational purposes as the costs of trail maintenance are not covered by the value added by forest operations.

The development of wood-energy chains can be a way to pursue substitution of fossil fuels and better management of the local forests, in addition to the generation of local added value; the creation of new employment and the improvement of social conditions (e.g. no more need for commuting or emigration due to work needs).

The development of forest-local energy supply chains is an important action listed in the Como Energy Plan (Provincia di Como, 2011) to increase the share of energy from renewable resources, as fixed in Europe 2020 Strategy and to improve the security of the energy supply. Local authorities' interest for a wider assessment is confirmed by the Interreg project "Saperi Alpini" (SAPALP – www.sapalp.eu), that aims at the sustainable development of the territories, and high priority is given to the sustainable use of local wood for energy.

Conversely, environmental aspects, and particularly air pollution, play a significant role for local planning. Specifically, the Lombardy region is one of the most polluted European areas by particulate matters; due mainly to the geographic mountainous features which hinder air exchange. Biomass combustion is now more tightly regulated, (Regional Law: DGR n. 7635 - 11/07/2008), since the combustion of wood produces an important share of particulate matters (about 30% of PM10 emissions in the region during 2003) (Lombardy Region, 2007): incomplete combustion can produce pyrogenic emission of trace gases and aerosol precursors that influence atmospheric chemistry and radiative balance. Therefore a sustainability impact assessment needs to be performed in order to ensure the most profitable, efficient and environmentally sound development of wood-based chains in the region that highlights annual operation impacts for the region.

3.2.2 - SUSTAINABILITY IMPACT ASSESSMENT OF FOREST-ENERGY CHAINS IN THE COMO REGION

The Sustainability Impact Assessment (SIA) method has been chosen for a comprehensive assessment of environmental, social and economic impacts of different scenarios related to the development of local forest-energy chains. This assessment will give valuable information for addressing policy objectives and for supporting the decision making process relative to the development of forest-wood-energy supply chains for the rural areas of Como Province. Therefore the present assessment comprehensively investigates the impacts of different development scenarios of bio-energy chains on rural development, regional 2020 objectives, and environmental compatibility of the involved processes.

The Tool for Sustainability Impact Assessment (ToSIA) (Lindner et al., 2010, 2012; EFORWOOD Consortium, 2010) has been applied for the case study. ToSIA has been chosen due to its user-driven focus on tailoring system boundaries and assessment focus, its flexibility in merging various data, and in modeling local supply chains. ToSIA is a tool based on comparing scenarios and calculation of carbon flows and economic, social, and environmental indicators, and it has been proven as a good framework for local, national and literature data collection (Den Herder et al., 2012; Lindner et al., 2012).

In ToSIA the forest-based sector is described as Forest-Wood-Chains (FWCs) of value-adding production processes by which forest resources are converted into products and services. The chains may extend from forest resource management to the end-of-life of a wood product (Lindner et al., 2012). ToSIA addresses three sustainability dimensions: environmental, economic and social. The Sustainability impacts are described with indicators that are linked to production processes (Lindner et al., 2010). The steps to apply ToSIA can be summarized as follows:

1. Study design: Goal and scope of the study are set, and system boundaries are defined;
2. FWC structure: the topology of the chain is created, and processes and products of the chain are specified;
3. Material flows: the material flow calculations are initialized, and the material flows are calculated;
4. Indicator calculation: indicators are selected according to goal and scope set, and their values are calculated for the processes, the FWC segments, and the whole FWC;
5. FWC comparison: the sustainability impacts of the FWCs are compared, and the results are evaluated.

ToSIA interfaces with the ToSIA Database Client (TDC) developed by IFER (Institute of Forest Ecosystem Research): data entry and chain design are carried out in the TDC environment. Then, data are exported from TDC and imported in ToSIA, which calculates material flows and indicators. In the end it is possible to report the results, or to perform the Multicriteria Analysis (MCA), the Cost-Benefit Analysis, or the Policy Analysis.

3.2.2.1 - SYSTEM BOUNDARIES

The Sustainability Impact Assessment (SIA) aims to give support to the local policy-making process, by showing the environmental, social and economic implications of the development of different local forest-energy chains in the rural and montane area of Como Province.

In order to fix the system boundaries, only the local production and consumption of logs and wood chips are considered. Scenarios are based on wood chip production, and logs, as they are the most common wood fuels produced by local forest resources. Local authorities believe that harvesting for timber purposes (as opposed to energy) from local forests is not profitable at the moment, and that pellet production is not economically feasible for the area. The objective is to activate the forest-based sector with wood chips supply, due to the technology level of machinery owned by local enterprises and to the available subsidies for energy production from renewable sources. Assessing other production options could be useful as well, but they are beyond the scope of this analysis.

3.2.2.2 - CHAIN TOPOLOGY DEFINITION

The topology of the chain is built with three distinct components: processes, products and links. A process represents an action, aimed at increasing the value/utility of a product. It either changes a product's physical properties or moves it to another location. Input and output products define how a process can be connected. Input products for each process in a chain receive material from matching output products of previous processes. From these processes, connected by products and links, a chain topology is formed; focusing on the needs of the study, and it must allow the implementation of the different scenarios described in the following text.

The defined topology is shown in Figure 14. In according to the study's objectives, three different paths relative to forestry mechanization are provided:

- Low mechanization 1: felling with chainsaw, skidding with cable crane, delimbing with chainsaw;
- Low mechanization 2: felling with chainsaw, skidding with winch, delimbing with chainsaw;
- High mechanization: harvester and forwarder.

The chain topology is based on the production of two fuel types: wood chips, and logs. Chips are produced on roadside (forest site) or at a terminal, and this will affect the fuel quality: chips from a terminal generally have a better quality than the chips from on-site chipping in terms of water content, (and thus in terms of calorific value). Then, the energy use has been modeled defining four different combustion processes:

- TYPE IA. Own produced logs are used for heat generation in small (< 50 kW) low-efficiency plants such as boilers, fireplaces, stoves, cookers. The heat output is the 45% of the energy input.
- TYPE IB. Logs from the market are used for heat generation in small (< 50 kW) low-efficiency plants such as boilers, fireplaces, stoves, cookers. The heat output is the 45% of the energy input.

- TYPE II. Chips are used in residential plants. In this category, small (<50 kW) and bigger (<1MW) residential plants are considered, as well as advanced (such as advanced stoves and advanced fireplaces) and basic combustion techniques. The heat output is the 75% of the energy input.
- TYPE III. Chips are used in co-generation plants for public electricity and heat production. 0.25 kWh of electricity and 0.6 kWh of heat are produced from 1 kWh of energy input. In this category, plants from 1 MWe are considered, as well as small-size advanced CHP plants from 200 kW.

The defined topology allows the variation and combination of different mechanization levels of harvesting activities, different shares of produced logs and chips and different combustion technologies as described in the baseline and scenarios definition. The amount of harvested biomass is defined as “material input”, so it does not affect the definition of the topology.

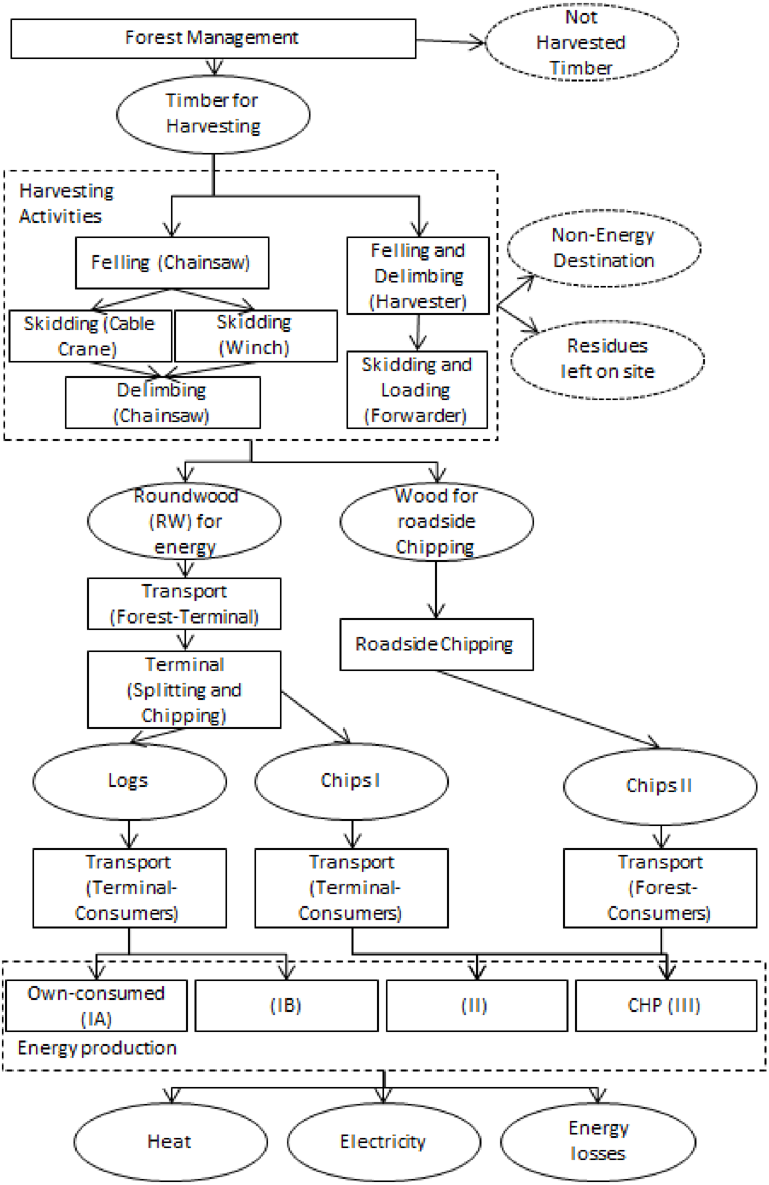


Figure 14 – Chain Topology for Como Lake case study

3.2.2.3 - MATERIAL FLOW AND PROCESS CHAIN DEFINITION

SIA is a process-based assessment. The Forest-Wood-Chain (FWC) is understood in ToSIA as a flexible structure linking production processes with input and output products. This structure is flexible due to the fact that it can be altered in shape (i.e. the arrangement and amount of processes) according to the needs of the user, while still using the same static information on processes and products.

Materials are tracked by the products which are produced along the process chain. The software internal material flow is based on the carbon flow along the chain in those products. Indicators are calculated relatively to each process, and then multiplied with the material that flows within the process. Therefore ToSIA gives three types of information: material flow in process units and in tons of carbon, relative indicator values per process, and absolute indicator impacts per process, per module and per chain.

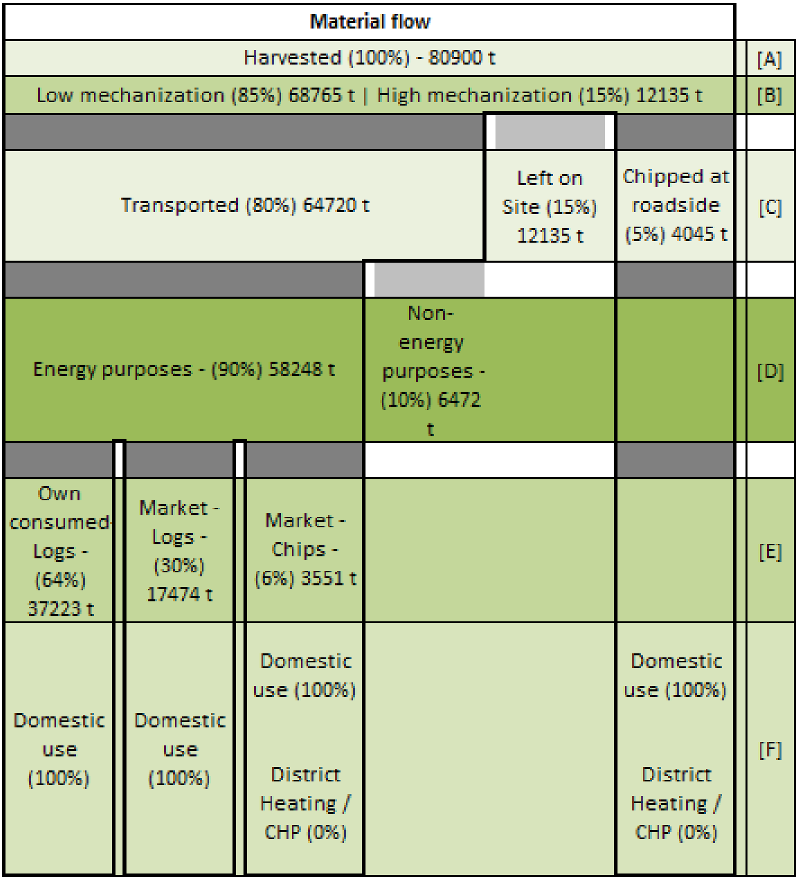
Considering different data sources, the chain of local wood for energy in the Como Province has been defined for the baseline year 2008. The estimations made for calculating the material flow for the baseline are described below (Figure 15), and for this different data sources were utilized to give for each process the best information available:

[A] The harvested biomass has been calculated by elaborating data of *Forestry Activity Statements of 2008* (*DIAF – Dichiarazioni di Inizio Attività Forestale*). DIAF are annual self-declarations by forest owners to the local authority about forest harvesting activities that will be carried out during the following harvesting season. For the case study, data from the DIAF of the year 2008 have been elaborated to estimate the amount of harvested biomass during the year by summing up the wood quantities. The statements are not updated after the harvesting season, so the final values are based on the estimation made by the forest owners. These statements can under-estimate the harvest to avoid surcharges or over-estimate it to avoid sanctions, because there is a higher fee for harvesting over a certain threshold (see also Chapter 2).

[B] and [D]. Data from a s*tudy on local forestry enterprises for the period 2008-2010* (Mielesi, 2012) have been elaborated to estimate the quantity of produced fuels (wood chips or logs) and to get information about the machineries and the forest enterprises involved in the local chain.

[C] and [F]. *National statistics* (ISTAT, 2012; ITABIA, 2008) and *opinions of local experts* supported the definition of the chain, estimating the quantity of harvested biomass for energy purposes and the combustion technologies in 2008.

[E]. An elaboration of data from a s*tudy on domestic wood combustion conducted in 2008 by JRC (European Joint Research Centre) and Lombardy Region* (Pastorello, 2008) has been made to define the local wood-energy chain. In particular, the study is useful to estimate the share of wood used for domestic own consumption as logs and the assortment of domestic means of combustion (e.g.: small boilers, fireplaces, wood stoves, etc). Wood for own consumption represents the fuel that is not sold or bought on the market, but produced for own consumption by forest owners.



Material flow					
Harvested (100%) - 80900 t					[A]
Low mechanization (85%) 68765 t | High mechanization (15%) 12135 t					[B]
Transported (80%) 64720 t			Left on Site (15%) 12135 t	Chipped at roadside (5%) 4045 t	[C]
Energy purposes - (90%) 58248 t			Non-energy purposes - (10%) 6472 t		[D]
Own consumed Logs - (64%) 37223 t	Market - Logs - (30%) 17474 t	Market - Chips - (6%) 3551 t			[E]
Domestic use (100%)	Domestic use (100%)	Domestic use (100%) District Heating / CHP (0%)		Domestic use (100%) District Heating / CHP (0%)	[F]

Figure 15 – Estimation of the wood usage in the Como Province in 2008: percentages and tons of wood are reported. Data sources: [A] Forestry Activity Statements (DIAF), [B] local statistics on forestry enterprises, [C] national statistics on forestry chains, [D] local statistics on forestry enterprises, [E] the JRC and Lombardy Region's study, [F] local experts judgment

3.2.2.4 - BASELINE AND REFERENCE FUTURES DEFINITION

The main strength of SIA in decision making is to show quantified impacts of decision alternatives and how these alternatives vary from the business as usual case ("baseline"). For this reason, indicators and material flows along FWCs are calculated for the baseline, and for each alternative, to be compared against the baseline and against each other. An alternative can be a Reference Future or a scenario. A *Reference Future* is a narrative that describes the future under specified assumptions, e.g. as it is done in the IPCC reports for A1, A2, B1 or B2 Reference Futures. In ToSIA these Reference Futures can be defined and specified by the user. A *scenario* is a combination of internal or external drivers and their impacts to the FWC. The scenarios result in alternative FWCs with different sustainability impacts compared to the current FWCs. Scenarios can be also combined with Reference Futures. In that case the Reference Future describes impacts as they are assumed for future development; the future scenario is calculated as affecting on top of these changes. Scenarios may differ against the background of different Reference Futures, and also scenarios are user-defined.

For the study at hand, the baseline and different scenarios of the local forest-energy chain have been defined according to local plans and national and European trends. The chain definition and scenario options are based on the Energy Action Plan of the Como Province and on the Regional Framework for Rural Development. The Baseline year is 2008, and two Reference Futures for 2020 have been chosen (2020CHP and 2020HEAT). Baseline and Reference Futures are the temporal basis on which the scenarios have been defined, their features are detailed below.

The choice of 2008 for the Baseline is due to the data availability for the forestry-sector of the Como Province. National statistics, local data and studies, local experts' judgment have been considered to outline the local wood-energy chain of the Lake Como area.

Fuel and energy costs vary in 2020 with respect to the baseline. For the Reference Future 2020CHP, subsidies for electricity production as for 2008 have been hypothesized: the assumption is that CHP plants are promoted. For the Reference Future 2020HEAT, subsidies for electricity production have been hypothesized: the assumption is that heating plants are promoted. Table 5 shows subsidies and energy and fuels costs assumed for the Baseline and the two Reference Futures. Products are defined in Annex III.

Table 5 – Subsidies and energy and fuels costs assumed for the Baseline and the Reference Futures. Price indexation is not accounted: euros are at constant level in 2008 value

	2008	**2020 CHP**	**2020 HEAT**	**Data sources and notes**
Subsidies for electricity production (euro/kWh$_e$)	0.13	0.13		Green Certificates (Energy & Strategy Group, 2011)
Subsidies for heat production (euro/kWh$_t$)			0.02	UK regulation (Energy & Strategy Group, 2011)
Cost of logs (euro/t)	135.00	140.95	140.95	(Francescato, Paniz, Negrin, Antonini, & Zuccoli Bergomi, 2012)
Cost of chips from terminal*	26.51	27.68	27.68	Assuming water content of 20% (Francescato et al., 2012), and an increase in

(euro/m^3)				2020 of 5 euro/MWh (European Commission, 2008b)
Cost of chips from roadside** (euro/m^3)	22.72	23.72	23.72	Assuming water content of 30% (Francescato et al., 2012), and an increase in 2020 of 5 euro/MWh (European Commission, 2008b)
Cost of electricity (euro/kWh)	0.16	0.22	0.22	For 2008, data for Italy from (GSE, 2008). For 2020, assuming an increase of 33% (UK Department of Energy and Climate Change, 2011).
Cost of Natural gas (euro/kWh)	0.07	0.08	0.08	For 2008, data for Italy from (Europe's Energy Portal, 2012). For 2020, assuming an increase of 18% (UK Department of Energy and Climate Change, 2011)

*The operation of splitting, logging and chipping are carried out in *terminals*, where wood is stored and processed.

**It has been assumed that the chips produced on the roadside have lower quality according to literature data.

3.2.2.5 - SCENARIO DEFINITIONS

Four different chain foci have been defined: Actual condition, Mechanization focus, Biomass focus and Technology focus. For each of these foci a Baseline and the two Reference Futures have been calculated, resulting in a total of twelve alternatives. Scenarios are based on the variation of three variables - biomass use, mechanization levels, and combustion plant technologies – and they are affected by the year (Baseline or Reference Future) which they are based on. On the whole, and for ToSIA implementation, the differences between the alternative chains result from a variation of chain structures, indicator and product values, and material flow. The acronyms used for the twelve scenarios are specified in Table 6.

Table 6 – Acronyms of the 12 scenarios

	Actual condition (A)	Mechanization (M)	Biomass (B)	Technology (T)
Baseline 2008	2008A	2008M	2008B	2008T
Reference Future 2020 CHP	2020CHPA	2020CHPM	2020CHPB	2020CHPT
Reference Future 2020 HEAT	2020HEATA	2020HEATM	2020HEATB	2020HEATT ("Grande Stufa")

Figure 16 shows the quantity of fuel produced in each scenario and its usage. The scenarios are detailed below.

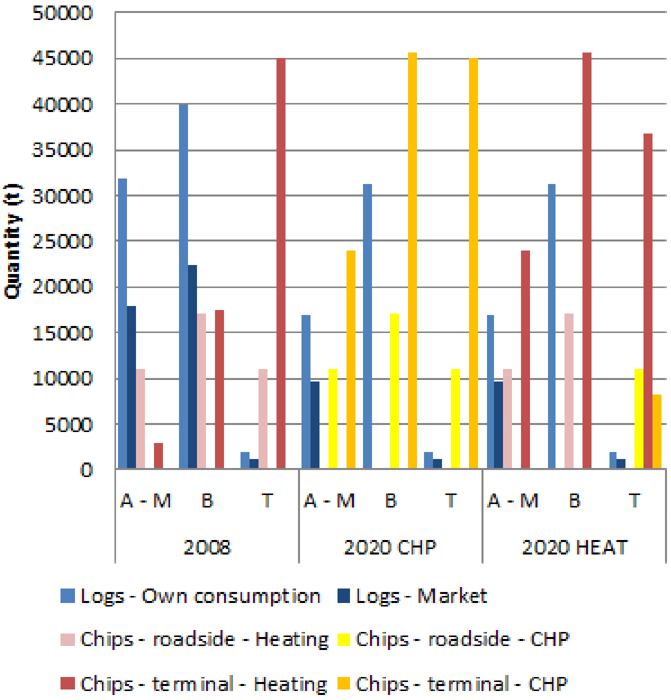


Figure 16 – Production of fuels and their destination for the 12 scenarios. A: "Actual condition" scenarios – M: "Mechanization" scenarios – B: "Biomass" scenarios – T: "Technology" scenarios

3.2.2.5.1"ACTUAL CONDITIONS" BASELINE AND SCENARIOS

A so called "Actual condition" chain (A) has been defined for the Baseline year (2008A) and the Reference Futures (2020CHPA and 2020HEATA).

The 2008A (Baseline) represents a picture of the forest-energy sector of the Como Province for the baseline year: about 81000 tons of wood are harvested from forests of Como Province. 80% of harvested wood is transported to the terminal, 15% is chipped on the roadside, and the remaining is left in the forest. Harvesting activities are generally carried out with a low level of mechanization: 85% of the wood is harvested with chainsaw, and cable crane or winch system: 50% of that share is harvested with chainsaw and cable crane system, and 50% with chainsaw and winch system. The remaining 15% is harvested by a high mechanization system: harvester and forwarder. 90% of transported quantity is used as logs or chips for burning processes: 94% as logs (of which 64% for own consumption), 6% as chips.

For the 2020 “Actual conditions” scenarios the share of fuel production from the terminal changes with respect to 2008A: 50% as chips and 50% as logs. The share of logs used in market and for own consumption remain stable, but the total amount of local wood used for those purposes decreases. The chips from terminal are 70.59% of total chips, chips from roadside chipping are about 30%.

For the 2020CHP Reference Future, the promotion of power generation is assumed, so it is assumed that for 2020CHPA scenario all the produced chips are used in CHP plants, conversely, considering the subsidies defined for the 2020HEAT Reference Future, it is assumed that for 2020HEATA scenario all the produced chips are used in heating plants.

3.2.2.5.2“MECHANIZATION” SCENARIOS

Using the A scenarios as a basis, “Mechanization” scenarios (M) were defined. In the M scenarios forestry activities are mainly carried out with a high level of mechanization: 85% of the wood is harvested with harvester and forwarder. Chainsaw and cable crane or winch systems are used to harvest the remaining 15% of the wood and of that share 50% is harvested with chainsaw and cable crane, and 50% with chainsaw and winch.

3.2.2.5.3 "BIOMASS" SCENARIOS

Using the A alternatives as a basis, "Biomass" scenarios (B) were defined. In the B scenarios about 125000 tons of wood are harvested from the forests of Como Province.

For the Biomass scenario of 2008 (2008B), the share of fuels and their destination remain the same as for 2008A.

The hypothesis for the 2020B scenarios is that the biomass is harvested for producing wood chips and the demand and consequently the production of logs decrease. According to the baseline data, 64% of produced logs are for own consumption in private domestic plants. For 2020CHPB scenarios a slight decrease has been defined: the 38.15% of wood processed in terminal is used as logs.

For the 2020CHP Reference Future, the promotion of power generation is assumed, so it is assumed that for 2020CHPB scenario all the produced chips are used in CHP plants, conversely, considering the subsidies defined for the 2020HEAT Reference Future, it is assumed that for 2020HEATB scenario all the produced chips are used in heating plants.

3.2.2.5.4 "TECHNOLOGY" SCENARIOS

On the basis of every A alternative, a "Technology" scenario (T) was defined. T scenarios are characterized by a drastic increase in using chip plants instead of traditional log plants. In T scenarios the produced fuel is mainly chips. In particular the share of produced chips has been defined equal to 94% of wood processed at terminal and logs are 6% of wood processed at terminal. The division between logs for own consumption and logs for market remain the same as in the A alternatives, but the quantity is significantly lower.

In order to assess different technologies (CHP and heating plants) combined with different subsidies (for electricity or heat production), the three T scenarios have been defined as follows:

- For "Technology" scenario of 2008 (2008T), the chips are used for fuelling heating plants;
- For "Technology" scenario of CHP Reference Future (2020CHPT), the chips are used for fuelling CHP plants;
- For "Technology" scenario of Heat Reference Future (2020HEATT), the chips are used for heating and for CHP plants. The CHP process has been defined to mimic the consumption and production of "Grande Stufa" plant[3]. For defining the chain in ToSIA, and according to the estimated annual biomass supply, the roadside produced chips are transported to the CHP process, and 18.3% of chips from terminal are transported to the CHP process also. Procurement costs and revenues are estimated considering the actual subsidies, focused on electricity production.

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[3] "Grande Stufa" (ETATEC, 2007) is the name of a project that aims to develop a local biomass-energy supply throughout the implementation of a chips CHP plant; it will be supplied by the local timber obtained from agricultural activities and forests of the surrounding area. From September 2012 a temporary unit for heat production has been installed, the power size is 1 MW. In the near future, production of heat and electricity is planned with 14 MW for heat and 6 MW for electricity production.

3.2.3 - INDICATOR CHOICE AND DATA SET FOR INDICATORS

To provide decision makers with meaningful help, information covering more than one dimension of sustainability is needed, as decision makers need to balance multiple concerns. Therefore the following environmental, social, and economic indicators have been chosen on the basis of the aim of the study, of the decision-makers' needs, the policy relevance and the data availability: (Local) Gross Value Added (LGVA), Production costs, Employment, Energy Use, Greenhouse Gas (GHG) emission, and Air Pollution.

Indicators were selected from the ToSIA indicator framework which was developed in the EFORWOOD project (EFORWOOD, 2010; Rametsteiner, Pulzl, & Puustjarvi, 2006), which is based on IPCC and MCPFE (now Forest Europe) indicators. For ToSIA applications it is possible to add new indicators and to calculate user-defined indicators. This gives the possibility for tailor-made studies to meet the needs and purpose of the research and decision questions at hand. The format and requirements for adding new indicators are specified in (Berg, 2008).

In one case, an adaptation of these indicators was requested to suit the stakeholders' regional interest: instead of GVA, only the economic impact remaining in the region was of particular interest as Local Gross Value Added.

In addition to the "Air Pollution" Indicator, the environmental sub-indicator "Particulate Matter Emission" has been defined, due to the importance of air pollution control in Lombardy Region. Generally, the main anthropogenic sources of PM (Particulate Matter) are the burning processes in vehicles, power plants and various industrial processes. PM can be directly emitted (Primary) or precursors may lead to the formation of it into the atmosphere (Secondary). The defined PM indicator will consider only emissions of Primary PM. Secondary particles derive from the oxidation of primary gases such as sulphur oxides and nitrogen oxides into sulphuric acid (liquid) and nitric acid (gaseous). Those pollutants are already considered under the air pollution indicator, so the PM Indicator refers exclusively to the Primary PM. Typically, measurements or estimations of PM emissions are related to the inhalable share of particulate, namely the particles with diameter of 10 micrometers or less (PM10).

Table 7 – Case specific features of the transport processes

From	To	Distance (km)	Material	Density (t/mc)	Loading Rate (including backhaul) (%)
Forests	Terminals	15	Round wood	0.89	50
Terminal	Consumers	15	Logs	0.39	80
Forests	Consumers	25	Chips from Forests	0.26	60
Terminal	Consumers	15	Chips from Terminal	0.22	90

Indicator data were calculated manually for every process by following the instruction given for ToSIA indicator data format requirements (Berg, 2008), except for the transport processes. The Transport Tool (FCBA, 2005) was used to get indicator values for transport processes. It combines national statistics and specific data to estimate values for the considered indicators, and in general also for other indicators that can be used in ToSIA. Common input data for all the process are Country (Italy), Maximum Gross Vehicle Weight (13 tons), and Fuel (Diesel). Specific data for each process are listed in Table 7; those are based on the knowledge about the area.

Environmental, social, and economic Indicators for the case study are described in Table 8.

Table 8 - Indicators for the case study. Details about data sources and assumption are described in Annex IV

Indicator	Measurement unit	Description
Local Gross Value Added (LGVA)	Euro	The Gross Value Added remaining in the Como Province in euro at 2008 value. It is calculated as: Local Value Added = consumer price of the finished product – production costs + subsidies. (Den Herder et al. 2012)
Employment	Absolute Number	Absolute number (in full-time equivalents per year) which can be allocated to the specific process
Energy Use	kWh	Direct fossil fuel and Electricity use

Greenhouse Gas Emissions (GHG)		kg	Carbon dioxide emissions calculated as Global Warming Potential (GWP) for 100 years according to the IPCC guidelines. Direct emissions from fuel combustion in the case of forestry machinery
Air Pollution	Non-GHG Emissions - CO	kg	Non-greenhouse gas emissions of kg of Carbon Monoxide (CO), Nitrogen Oxide (NOx), Sulfur Dioxide (SO2), Non-Methane Volatile Organic Compounds (NMVOC) into air, and Primary particle matter (PM10) emissions in kg into air per reporting unit
	Non-GHG Emissions - NO_X	kg	
	Non-GHG Emissions - SO_2	kg	
	Non-GHG Emissions - NMVOC	kg	
	Primary PM Emissions	kg	

3.3 - RESULTS

Process outputs and Indicator values for the different options were calculated though the application of the software ToSIA. All the indicators have been defined focusing on the local perspective of the study, in order to provide valuable information to local planners for designing a suitable bio-energy chain to achieve policy aims.

3.3.1 - ENERGY GENERATION

ToSIA calculated the amount of energy generated as heat and power. Those values are given according to the products' measurement unit (e.g.: kWh of heat produced in domestic plants), and in terms of tons of Carbon. The heat and power productions of the chains are shown in Table 9.

Table 9 - Heat and Power production for each scenario considered in ToSIA. "I" is the increment in heat production with respect to the baseline (2008A)

Scenario	Heat (MWh)	Power (MWh)	I (%)
2008A	112 201	0	-
2008M	112 201	0	0
2008B	189 409	0	69
2008T	166 475	0	48
2020CHPA	119 524	33 023	6
2020CHPM	119 524	33 023	6
2020CHPB	189 939	59 446	69
2020CHPT	134 146	53 881	20
2020HEATA	139 338	0	24
2020HEATM	139 338	0	24
2020HEATB	225 610	0	101
2020HEATT	155 989	17 476	39

The heat production for the baseline (2008A) is about 112 201 MWh. As expected, the highest heat production results from the utilization of all available biomass ("B" scenarios). The increase was determined by not only the increase in biomass, but also by the more efficient combustion technologies. The comparison between 2008B and 2008T shows that it is possible to increase heat production by changing the energy production technologies. In the case of 2020HEATT chain, the use of logs is sharply reduced, and wood chips are used in domestic heating and in CHP generation, this allows an increase of heat production of about 40% and a yearly power production of about 17 476 MWh. 2020HEATB scenario provides the maximum heat production.

The use of higher efficiency domestic systems causes an increase of heat production also for 2020HEAT scenarios. Electricity is generated from CHP plants; those are considered for 2020CHP and 2020HEATT scenarios, and the power generation depends on the amount of fuel (chips) used in that process. The highest value of produced power is in the case of 2020CHPB chain, this represents an increase of 80% compared to the power production without increasing the biomass use (2020CHPA and 2020CHPM).

3.3.2 - ECONOMIC ASPECTS AND THE ROLE OF SUBSIDIES IN RENEWABLE ENERGY PRODUCTION

The Local Gross Value Added (LGVA) results are shown in Figure 17. The Total LGVA has a positive value in every chain: the defined bio-energy chains have a positive economic impact on the local area.

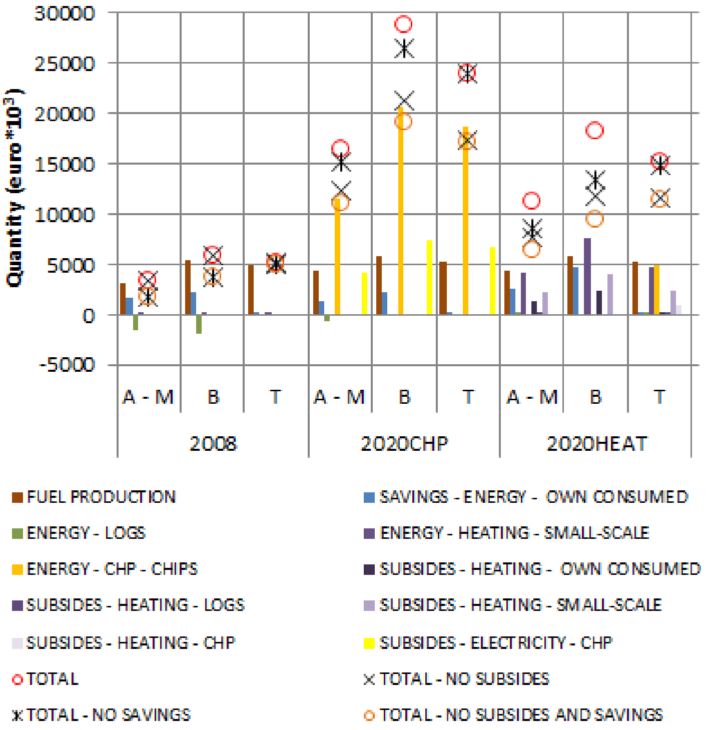

Figure 17 - Gross Value Added (GVA) Indicator

However, for 2008 chains the LGVA values are lower than for 2020 chains, and the prominent share of LGVA comes from local fuel production. This accounts for more than 90% of the LGVA for 2008 chains, between 20% and 26% for the 2020CHP chains, and between 31% and 38% for the 2020HEAT chains.

When chip production is increased, the LGVA values also increase, because the assumed efficiency for chip plants is higher and so the energy losses are lower. Electricity generation significantly affects LGVA values, due to the higher price of electricity compared with heat. The resulting highest LGVA value is for the 2020CHPB chain: as there is higher fuel production and usage in CHP plants is predominant.

For 2008 alternatives, the usage of logs provides a positive added value in the case of own consumption: forest owners save money because fossil fuels for heating are not bought. Conversely, the LGVA has a negative value when logs are purchased from the market: the assumed efficiency of 45% for log plants does not confer an economic advantage in buying logs at the assumed market price compared with Natural Gas.

Considering scenarios with electricity production, and especially comparing 2020CHP and 2020HEAT scenarios, it is evident that CHP production significantly affects economic performance, increasing the LGVA value.

Positive LGVA values are also realized without subsidies for energy generation. The LGVA is higher with electricity generation than without, and for the case of 2020HEATA and 2020HEATB (subsidized heat generation without electricity generation) the share of total LGVA covered by subsidies is higher than 30%, and it is between 23% and 28% for the other 2020 chains.

An efficiency of 45% for domestic plants fueled with logs has been assumed considering the technology assortments listed in (Pastorello, 2008). However there is no detailed knowledge of the installed domestic plants of the area, so a sensitivity analysis on the plant efficiency has been carried out. The LGVA at the process level for energy generation from plants fueled with logs has been calculated for different combustion efficiencies. Results are shown in Figure 18.

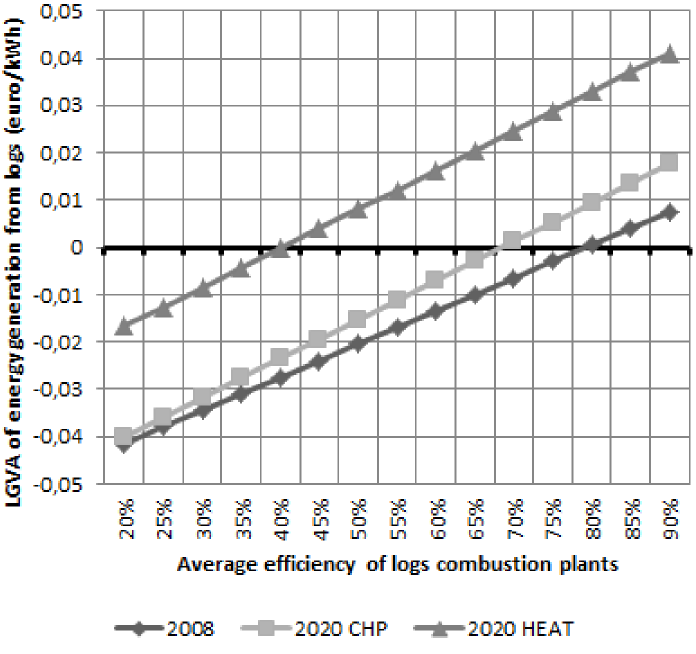

Figure 18 – Sensitivity analysis that shows the LGVA at the process level for the energy generation from plants fueled with logs depending on the combustion efficiency

Considering the economic parameters of 2008, combustion efficiency higher than 80% is needed to obtain positive LGVA values for the domestic consumption of logs bought on the market.

For 2020 CHP options, an efficiency higher than 70% is enough to obtain a positive LGVA, due to the increase of energy prices more than fuel prices respect to 2008 values. For the 2020 HEAT options, the LGVA has positive values with combustion efficiency over 40%, due to the use of subsidies for heat production.

3.3.3 - CONTRIBUTION TO PREVENT THE DEPOPULATION OF RURAL AREAS

The social Indicator Employment represents the number of workers per year involved by the processes along the production chain in the area of Como Province. It has been chosen because creation of new jobs can prevent the depopulation of rural areas.

Results are shown in Figure 19. Biomass use significantly affects the number of persons involved in the chain: the increase of biomass use (“B” scenarios) can lead an increase of up to 50% of workers compared to the current forest-wood chains. The mechanization level adversely affects the indicator: less people are employed with a high mechanization level (“M” scenarios). Moreover, the use of more advanced technologies leads to relatively lower levels of employment (“T” scenarios). Here the business as usual Reference Futures would offer most employment per kWh produced.

Transportation processes contribute between 68% and 78% in employment for the various chains, and harvesting activities contribute between 16% and 23% of employment levels. The fuels production chain is a key element for having an impact on employment levels of the bio-energy chain.

The number of unemployed people in the Como Province was 8606 during 2012 (ISTAT, 2014), and in ToSIA, the Indicator

'Employment' reaches around 16000 workers per year for the "B" scenarios (in 2020), with an increase of about 5500 workers directly involved in the chain. Therefore, the expansion of the local forest-energy sector can significantly affect unemployment levels at the Provincial level. This is even more important considering that unemployment rate has increased from 3.16% of 2007 to 5.24% of 2012 (ISTAT, 2014).

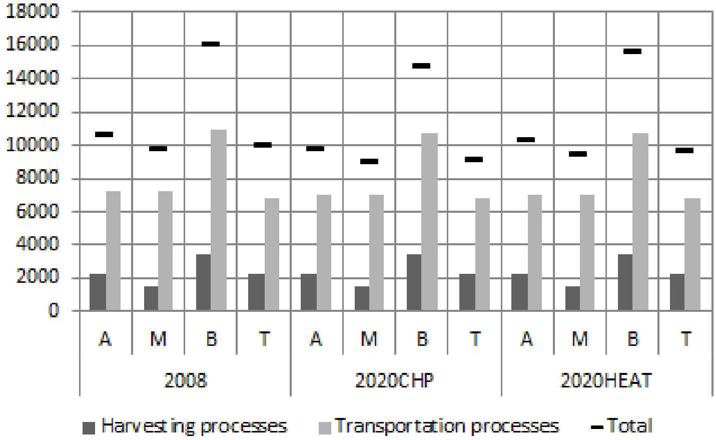

Figure 19 - Employment Indicator (workers)

3.3.4 - ENVIRONMENTAL COMPATIBILITY

3.3.4.1 - ENERGY USE

Direct use of fossil fuels has been assumed for every process with an energy use, except for production of chips and logs in the terminal. In this case a consumption of electricity from the grid has been assumed. Energy use has been defined as an environmental indicator, but it affects also economic performance though the production costs.

As expected, the amount of harvested biomass plays a key role relative to the Energy Use. The mechanization level of harvesting activities affects the results only slightly, for example in the 2008M scenario Energy Use decreases only by 10% compared to the baseline (2008A). Figure 20 shows relative results for the Energy Use Indicator (Used kWh per Produced kWh). Considering relative results, the combustion technology assumes a significant role for the relative usage of energy: higher combustion efficiency causes lower energy use per kWh produced.

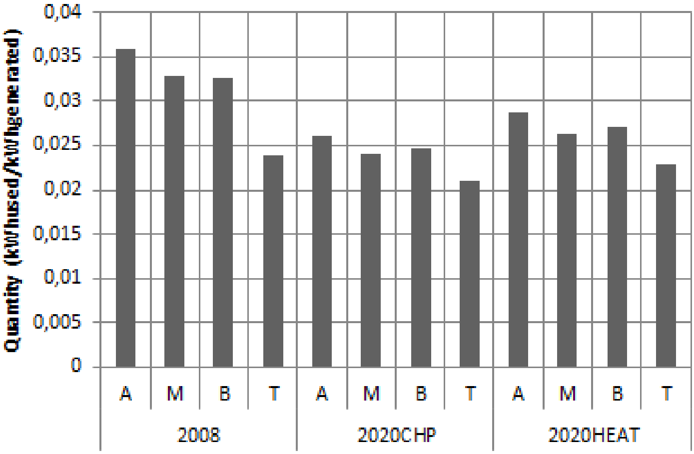

Figure 20 - Energy Use Indicator

3.3.4.2 - GREENHOUSE GASES EMISSIONS

The environmental Indicator Greenhouse Gas (GHG) Emissions quantifies carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_x) released during the processes in the chains.

GHG Emissions depend on biomass use: greater biomass combustion causes higher emissions. For the case study, GHG emissions from burning processes accounted for a significant share of emissions.

The capacity of woody biomass to reduce the anthropogenic emissions in the atmosphere compared to continued use of fossil fuel depends on the source of biomass that is utilized and time horizon considered (Zanchi, Pena, & Bird, 2012), and different studies confirmed that bio-energy is not always carbon neutral (Cherubini, Peters, Berntsen, Strømman, & Hertwich, 2011; Repo, Tuomi, & Liski, 2011; Schlamadinger, Spitzer, Kohlmaier, & Lüdeke, 1995).

However, the actual UNFCCC accounting system (UNFCCC, 2006) assumes carbon neutrality i.e. the carbon released when the biomass is burnt will be recaptured by plant re-growth.

Absolute and relative results to produced energy are shown in Figure 21. More emissions come from scenarios with a high level of mechanization in forestry activities ("M" scenarios). Relative to the heat produced, emissions are affected by the combustion technology: a sharp decrease can be seen for 2020 scenarios.

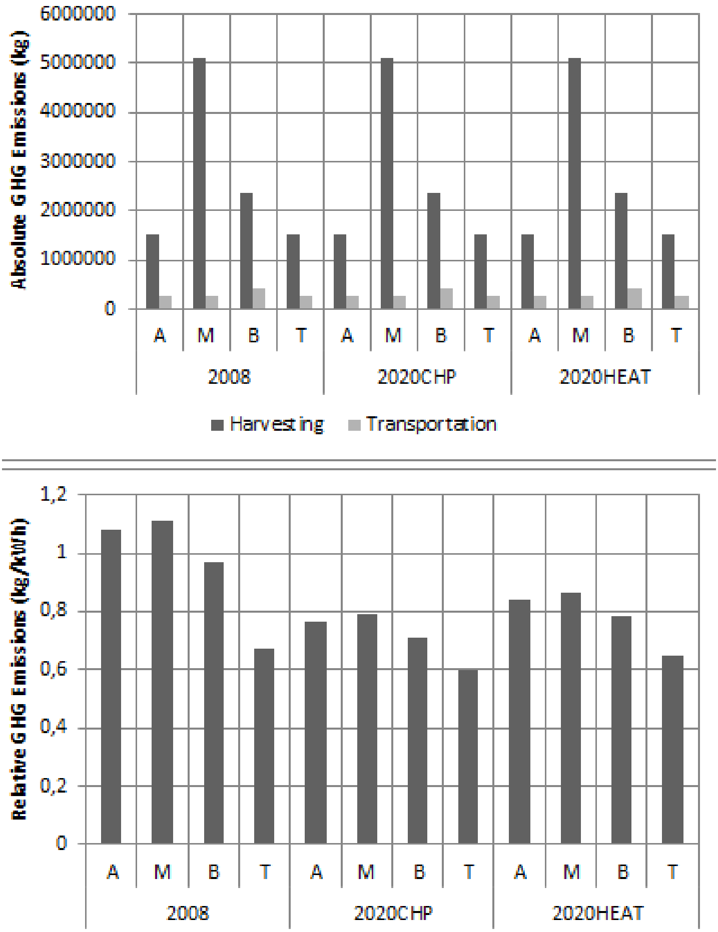

Figure 21 - Greenhouse Gas Emissions Indicator

3.3.4.3 - AIR POLLUTION

Five Indicators related to air pollution have been chosen: Emissions of Carbon Monoxide (CO), Emissions of Nitrogen Oxide (NO_x), Emissions of Sulfur Dioxide (SO_2), Emissions of Non-Methane Volatile Organic Compounds (NMVOC), and the Indicator Emissions of Primary Particulate Matter (PM10). The evaluation of Non-GHG Emissions quantifies the impacts on the environmental performance of the different scenarios. In Figure 22 the results are expressed as the percentage variation from the baseline (2008A).

More technologically advanced combustion plants lead to reduced emissions of CO, SO_2 and NMVOC. And, as expected, an increased use of biomass causes higher emissions respect to the baseline. Traditional domestic systems, such as fireplaces or boilers, are responsible for much of the production of SO_2: in the 2008B scenario, more than 90% of SO_2 comes from the burning process of own consumed logs. A significant reduction of CO Emissions occurs only when more efficient plants are considered. NMVOC Emissions depend mainly on plants fuelled with logs.

NO_x Emissions increase for more efficient combustion technologies, because the production of NO_x depends on atmospheric nitrogen. The process of production of Thermal NO_x is related to the temperatures of a combustion chamber, so larger plants will generally produce greater quantities of NO_x. Usually, the main source of NO_x is transportation, but for the present case, the short distances make negligible NO_x emissions from traffic.

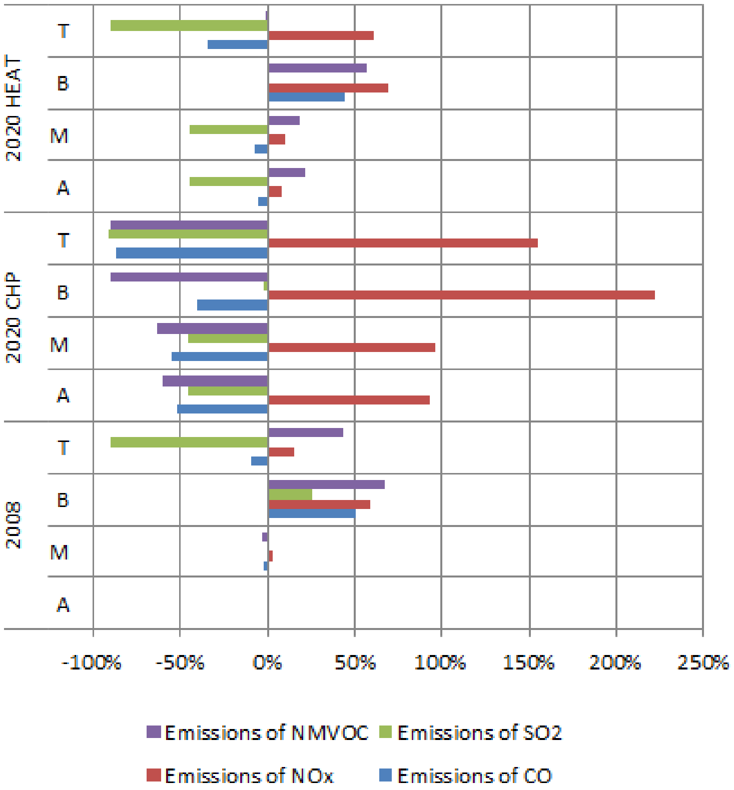

Figure 22 - Non-GHG Emissions Indicator Results. The values are expressed as percentage compared to 2008A chain. 2008A is 0%

PM Indicator results are shown in Figure 23. They depend on the biomass used, and on the type of combustion technology. The lowest value is for the 2020CHPT scenario, because the logs usage is residual and the CHP plants are modeled as the most efficient in terms of emissions abatement.

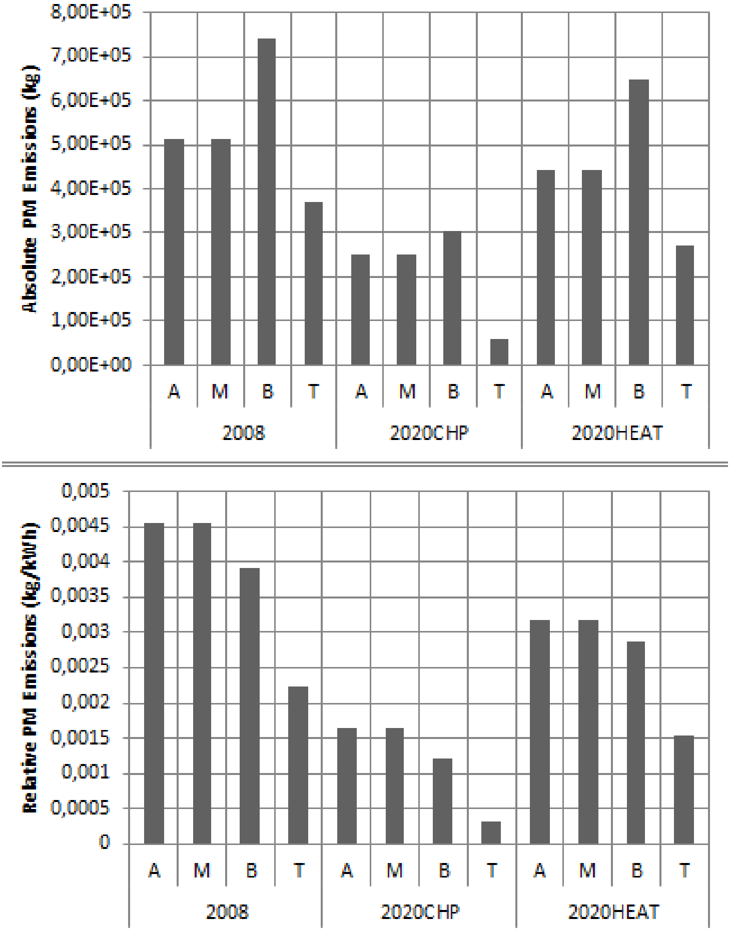

Figure 23 - PM Emissions Indicator

PM emission reduction is determined by the combustion process, and technologies for emission reduction of the energy generation plants. In the case of 2020CHPB, emissions are lower than the emissions of all scenarios of 2008. Therefore, an increase in use of biomass is compatible with a reduction of the particulate matter emissions, as long as there is a modernization of the current combustion technologies.

3.4 - DISCUSSION

The 2020 target for the share of renewable sources in total energy consumption for the Lombardy Region is 11.3%. The maximum estimated heat production (2020HEATB) covers around 12% of Natural Gas[4] consumption of households of Como Province, but it exceeds 16% when the four biggest cities located in the lowland areas of the Province are excluded. Considering that the per capita consumption of Natural Gas of households in Como Province is 3.18 MWh per year, the calculated produced heat for 2020HEATB scenario covers around 60% of consumption in rural areas. So, the development of bio-energy chains is crucial towards achieving renewable energy targets.

For every scenario of forest energy supply development, economically viable chains were generated. However the log consumption processes present negative LGVA values due to the low efficiency of the combustion process assumed in this study. Efficiency of combustion technologies results a key element for ensuring positive economic performance of the bio-energy chain. The production of wood chips for combined heat and power generation was the best economic performer in this case study.

The LGVA is affected mainly by the energy generation process and is positive also without subsidies. However, energy generation subsidies are generally useful for reducing the payback times for

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[4] Usually Natural Gas is used for heating and cooking. Elaboration from SIRENA database (Lombardy Region, 2014b).

investments into plant installations. That could stimulate decision makers to consider different criteria to allocate subsidies. On one hand, promoting more efficient combustion technologies and allocating subsidies on the basis of energy efficiency (Montanari, 2004), could ensure good economic performance of the end use of logs due to a more efficient combustion process. On the other hand, boosting the local production of fuel could ensure the development of the whole supply in the area, distributing the profits among the different actors along the supply chain.

The employment rate in the Como Province was 62.6% in 2012, close to the national average of 61%, from a workforce of 164218 people. The population living in montane areas of the Province is about 120000. Assuming the same share of workforce and the same employment and unemployment rate of the provincial level, the number of employed people is about 21400 and the number of people seeking work is about 1800. Considering an increase of 5500 workers with respect to 2012 levels, the employment rate of the Como Province would be about 66%, and about 78% for the montane areas. The target for Italy fixed by EU 2020 strategy is 67-69% employment rate by 2020 (European Commission, 2011b), and for this reason developing bio-energy supply chains seems to have potential to contribute to this target at the local level. However, the work positions created by the supply chain development would not necessarily involve the unemployed of the local area. Further investigations are needed to understand how much of the local workforce could be employed in a forest-energy chain.

Environmental impacts are mainly affected by final use processes: burning processes produce more than 95% of the direct GHG Emissions (depending on the considered chain).

Emissions of air pollutants (different from GHGs) may also be limited by using a larger quantity of biomass, as long as there is an improvement in combustion technologies. Detailed studies may lead to the choice of appropriate systems for emission abatement. For example, innovative boilers or stoves can achieve much higher combustion efficiencies than what was estimated in this assessment. Moreover, the development of large size systems may involve the importation of fuels or the use of urban waste, and this may lead to different impacts on air quality and emissions.

Energy Use is affected mainly by forestry activities. Therefore, the use of non-fossil fuels for harvesting machinery can reduce the environmental impacts of forestry activities in terms of energy use, GHG and non-GHG emissions.

Both energy generation technology and the quantity of harvested biomass are crucial in affecting the sustainability impacts of the assessed bio-energy supply chains. The upgrade of the actual combustion technologies could ensure better environmental performance from using the (local) biomass for energy.

There are no significant advantages in using high mechanization forest harvesting systems. Site-specific features, such as a sparse forest road network and steep topography, limit the productivity of high mechanization systems. Transport processes do not significantly affect sustainability for the case study, and it has a predominant and positive impact on the employment level.

This assessment may support the decision-process through showing which aspects are crucial for different policy aims and in helping to define objectives and roadmaps for the bio-energy development of the area. The available data and the assumptions of this study cause some level of uncertainty, however developing efficient CHP production results the best option for achieving the different policy objectives and to ensure a subsidy-free business.

Bio-energy supply development is crucial for achieving 2020 renewable energy targets at the regional scale. It can also be a driving force for the local economy, because efficient bio-energy chains are economically suitable for the area and positively affect employment levels. Moreover, the development of local forest-energy supply chains is environmentally compatible. Upgrade of combustion technologies would cause a considerable reduction in emissions, despite the increase in harvested, transported and used biomass.

3.5 - CONCLUSIONS

The energy production and indicator results give valuable information to support the decision-making process. The case study showed how the development of local forest-energy supply chains is likely to affect environmental, social and economic aspects, considering different development scenarios.

This study gives an overview of the forest-energy sector of the area, and frames possible development scenarios. The results generate also a database of quantitative information on the availability of raw material, the technologies involved in the various processes, and the features of the resulting products. The same framework and method can be used and updated in the future for monitoring the actual impacts of the actions implemented by decision makers. The results do not provide “the best” possible option, but show what can happen in different possible scenarios, and how much different aspects affect the sustainability of the production process.

The argument of this study is to show how rural development policies can be supported by Sustainability Impact Assessment, in order to frame local planning with a holistic approach, which considers different sectors. In this specific case rural development, energy issues and the environmental compatibility of developing a productive chain have been examined with a comprehensive analysis. The Sustainability Impact Assessment approach allows the scientific analysis of trade-offs in rural development issues. It confirms its effectiveness for supporting decision-making process and can lead to innovative solutions for reaching policy goals.

The increasing interest in renewable energy sources and decentralized energy generation requires an effective local energy policy. That needs to be supported by tools capable to quantify the impacts of different measures and to clearly show how to make it effective. Especially at local scale, the energy policy should take into account how and to what extent certain policy objectives can affect other sectors, as rural development, in term of social and economic aspects, and as environmental protection and forestry issues, when raw material from forests can play a role for producing wood fuels.

The proposed holistic approach shows and quantifies the positive impacts that a measure can have in the light of different (economic, social, environmental) implications, and, in this way, strengthen and account for the measure itself. It also highlighted the need of exploring trade-offs between economic, social and environmental aspects in order to set harmonious, concrete and achievable policy aims.

Local policy makers and planners can use it as a platform to integrate and support their decisions through solid scientific bases, also in terms of acceptability (e.g.: an efficient local energy supply improves the environmental impacts of the baseline, and increases working opportunities) and effectiveness (e.g.: a suitable allocation of subsides can help to tackle the weakness of a certain energy supply).

CHAPTER 4 - SUPPORTING ENERGY POLICY AT MUNICIPAL LEVEL

4.1 - INTRODUCTION

“Before the Industrial Revolution in the 19th century, global average CO_2 was about 280 ppm. During the last 800 000 years, CO_2 fluctuated between about 180 ppm during ice ages and 280 ppm during interglacial warm periods. Today’s rate of increase is more than 100 times faster than the increase that occurred when the last ice age ended” (NOAA, 2013).

Greenhouse gases (CO_2, CH_4, N_2O, O_3, CFCs) affect Climate Change strengthened the *greenhouse effect*. They are also measured as equivalents of CO_2, on the basis of their Global Warming Potential (GWP). GWP depends on the radiative forcing of the gas and on its lifetime, it is assumed that CO_2 has a GWP equal to 1 over all time periods.

Combustion processes for energy generation largely affect the GHG emissions (EEA, 2013c). For this reason the energy planning and policy are highly related with climate policy.

It is difficult to establish when the energy issues started to be related with the environmental protection and resource depletion. However it is suggestive to cite the publication “The Limit to Growth” of 1972, that is chronologically close to the oil crisis of 70s. The book is about modelling economic and population growth with finite resource supplies, and probably it has become popular because the resource scarcity started to closely concern people and life styles.

From 70s many international initiatives have been taken, especially by the United Nations. The most important result was the Kyoto Protocol: it is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties (Countries) by setting internationally binding emission reduction targets.

Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Kyoto Protocol places a heavier burden on developed nations under the principle of *common but differentiated responsibilities*. The Kyoto Protocol was adopted in 1997 and it entered into force on 16th February 2005. Its first commitment period started in 2008 and ended in 2012 (UNFCCC, 2014b). Post-Kyoto commitments are still an open issue, at the end of 2012 the Protocol have been extended through the Doha Amendment (UNFCCC, 2014a).

At European level, the Europe 2020 Strategy has been defined. It consists in targets to be reached by 2020 on employment, innovation, education, social inclusion and climate/energy (European Commission, 2013b). The EU Climate and Energy package (European Commission, 2008a, 2010a) aims to develop a low-carbon economy, and it fixes targets for increasing the share of consumed energy from renewable resources, decreasing the GHG emissions, and decreasing the consumed energy through the improvement of energy efficiency. Targets for EU and Italy are reported in Table 10.

Table 10 – Target of European Union and Italy for 2020 Strategy. Source: (European Commission, 2011b)

	EU target	**Italy target**
Employment rate	75%	67-69%
R&D in % of GDP	3%	1.53%
CO2 Emission reduction	-20% compared to 1990	-13%
Share of renewables	20%	17%
Reduction of energy consumption	368 Mtoe (20% increasing of energy efficiency)	27.9 Mtoe
Early school leaving	10%	15-16%
Tertiary education	40%	26-27%
Reduction of population at risk of poverty or social exclusion	20 000 persons	2 200 persons

RES contributed 13% of gross final energy consumption in the EU-28 in 2011. The EU has therefore met its 10.8% indicative target for 2011–2012 and is therefore currently on track towards its target of 20% of renewable energy consumption in 2020 (EEA, 2013c). Figure 24 shows emissions' trends for all EU countries, the sharp reduction from 2009 could be caused also by the European economic crisis, for this reason the emission reduction depends not only on *cleaner* productions, but also on the reduction of the productions themselves.

In Italy, there is not an energy plan, however the Italian National Renewable Energy Action Plan (Italian Ministry for Economic Development, 2010) follows the EU directives and communications, and the "Burden sharing" law (Italian Ministry for Economic Development, 2012) fixes regional targets for 2020. In Italy, Regions and State are responsible for the energy policy, and that causes some controversies between the two parts (Paris, 2013; Servizio studi del Senato, 2011).

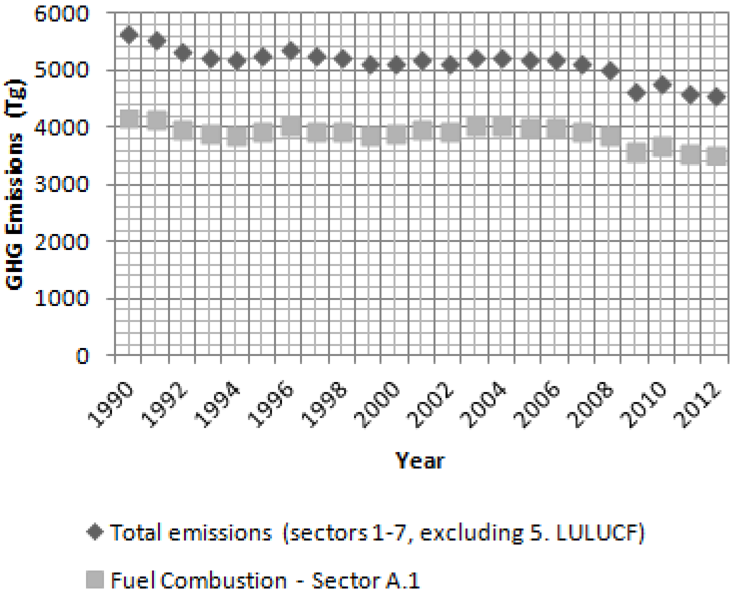

Figure 24 – Total GHG Emissions in the EU in $CO_{2\text{-}eq}$. IPCC sectors. Source: (EEA, 2013a)

At regional level several actions have been taken to achieve international and national objectives. For the Lombardy Region the energy-environment issue is mainly ruled by the Energy Action plan focusing on renewable sources' targets (Lombardy Region, 2008), the Technologies plan focusing on energy efficiency (Lombardy Region, 2009), and the Sustainable Lombardy plan (Lombardy Region, 2010) focusing on short and long term actions.

Local authorities play a key role in the achievement of the EU's energy and climate objectives. The Covenant of Mayors (CoM) is an European initiative by which towns, cities and regions voluntarily commit to reduce their GHG emissions beyond the 20% target (European Commission, 2010b). The initiative has been successful especially in the Mediterranean Europe, since "the Country with the biggest number of inhabitants involved in this action is Italy (30 million inhabitants), followed closely by Spain (24 million inhabitants)" (Cerutti et al., 2013).

The Research Group on Sustainable Development of the University of Milano Bicocca supported Fondazione Idra in leading 16 municipalities of Lombardy Region to adhere to the CoM (Fondazione Idra, 2011). This formal commitment is to be achieved through the implementation of Sustainable Energy Action Plans (SEAPs), those show how the CoM signatory will reach its commitment by 2020.

Key element to define actions and plans is a big picture of the actual situation, for this reason it is crucial to know sectors and vectors that cause the emissions. In the context of the Covenant of Mayors, the Baseline Emission Inventory (BEI) is defined as the quantification of the amount of GHG emitted due to energy consumption in the territory of a Covenant signatory within a given period of time. The BEI allows identifying the principal sources of GHG emissions and their respective reduction potentials. In other words, the SEAP uses the results of the BEI to identify the best fields of action and opportunities for reaching the local authority's GHG reduction target.

In this way, the SEAP defines concrete reduction measures, together with time frames and assigned responsibilities, which translate the long-term strategy into actions. Signatories commit themselves to submitting their SEAPs within the year following the adhesion. The CoM concerns actions at local level within the competence of the local authority. The SEAP should concentrate on measures aimed at reducing the GHG emissions and final energy consumption by end users. The CoM's commitments cover the whole geographical area of the local authority. Therefore the SEAP should include actions concerning both the public and private sectors (European Commission, 2010b).

A methodology has been developed to define the BEI, and it has been applied to 16 Municipalities of Lombardy Region. Besides the BEI, a tool has been developed and provided to the Municipalities in order to collect data for reviewing the baseline, updating the emission inventory and for monitoring the SEAP's actions and their impacts on the emission inventory.

The support for adhering to the Covenant of Mayor has been given to 16 municipalities of Lombardy Region: Vimercate, Agrate Brianza, Burago di Molgora, Bellusco, Mezzago, Sulbiate, Cornate d'Adda, Carnate, Ronco Briantino, Pessano con Bornago, Bussero, Uboldo, Molteno, Bosisio Parini, Annone, and Ornago.

In the following text, first the methodology for calculating the BEI is presented and then the results are given. Then, the provided tools are described. Later, the role of forests in the local GHG emissions accounting is described. Finally, conclusions are given.

4.2 - GHG EMISSIONS ACCOUNTING OF LOMBARDY REGION'S MUNICIPALITIES

4.2.1 - INTRODUCTION

Approaches to GHG accounting can be different. In (EEA, 2013b), three different accounting perspectives are identified, with reference to the scope of the emission inventory of a defined geographical area:

- **Territorial perspective.** Accounted emissions are released to the atmosphere from within a country's borders and from areas that are under a country's jurisdiction. It is the only method accepted by international environmental law, and adopted by the Intergovernmental Panel on Climate Change (IPCC) to account for a country's emissions and mitigation efforts (Bastianoni, Caro, Borghesi, & Pulselli, 2014). Territorial-emission data that focus on the physical location of emissions are also used as the basis for the atmospheric modeling of environmental impacts.

- **Production perspective**. Accounted emissions are from companies that have their economic interest within the economic territory of the country. It also considers emissions from resident households in relation to their productions, irrespective of the geographic location where these activities take place.

- **Consumption perspective**. Accounted emissions are from consumption of goods and services within a country, irrespective of the geographic location where production of these goods and services result in emissions. The consumption perspective complements the territorial accounting and the production perspective by relating environmental impacts to demand for goods and services by citizens. The consumption-based perspective is not addressed in international conventions, although consumption emissions are embedded in the EU's policy framework on sustainable production and consumption.

The emission accounting at municipal level usually considers as system boundaries the municipal administrative boundaries; however a significant trade of goods and services happen across different municipalities and many infrastructures cross administrative boundaries. For this reason in-boundary and trans-boundary emissions must be allocated. In (Ramaswami, Chavez, Ewing-Thiel, & Reeve, 2011) different allocation approaches for the "city scale" are described:

- **Purely geographic production-based GHG accounting**. It corresponds to the *territorial perspective* described in (EEA, 2013b).
- **Geographic-plus infrastructure supply chain GHG footprints**. This approach has been defined for GHG accounting for cities. It considers materials and energy used by cities facilities.
- **Pure consumption-based accounting**. It corresponds to the *consumption perspective* described in (EEA, 2013b).

(Ramaswami et al., 2011) believe that both geographic-plus and consumption-based approaches can provide different sets of useful GHG footprint information to communities based on their typology. In other words, the GHG emissions at municipal scale should be calculated on the basis of the consumed energy and materials by different sectors (household, industry, agriculture, transport, services) that (economically) happen within the municipal borders (Larsen & Hertwich, 2009).

4.2.2 - MATERIALS AND METHOD

Following literature's recommendations (Larsen & Hertwich, 2010; Wiedmann, 2009), a consumption-based approach to calculate the GHG emissions of a municipality is the most suitable to account emissions at local scale and to monitor the actions over the time.

Specifically, the presented methodology calculates the GHG emissions by consumed energy and goods within the municipal borders (Figure 25). The energy consumptions are obtained by available data and the goods consumption is based on the waste production. Local generation of renewable energy causes savings of GHG emissions as well as the waste recycling. Data used and methodology are further detailed below.

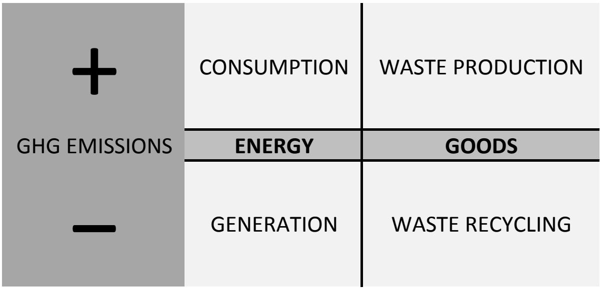

Figure 25 – Scheme for calculating the baseline emission inventory

4.2.2.1 - ENERGY CONSUMPTION

National and local databases can be used to consider energy consumptions. For the Lombardy Region, SIRENA (Regional Informative System for Environment and Energy) offers valuable data on fuel consumption and production and transmission/distribution of electricity. SIRENA was founded in 2007 with the specific aim of monitoring fuel consumption and production and transmission/distribution of electricity in Lombardy. With this objective, ensuring a high degree of updated information and communication in full transparency with a web service, the system provides all the information that, at different territorial levels and compared with other areas of interest, allow to delineate the energy dynamics of Lombardy (Lombardy Region, 2014b).

SIRENA provides data at the municipal scale and responds to the requirements for being the main data source for calculating the BEI of the Lombardy's municipalities: it gives statistics on energy consumption by sectors and by different energy sources.

The methodology for calculating energy consumptions in SIRENA database is described in (A. A. Boccardi et al., 2012). SIRENA provides at municipal level the energy consumptions by energy vectors (Biomass, Natural Gas, Petrol, Diesel, Electricity, Other fuels), and the energy consumption by energy sectors (Households, Not-ETS Industry, Urban Transports, Tertiary/Services, Agriculture). The Methodology is based on the effective consumptions of energy within the municipal borders; however disaggregation from Provincial or Regional level is needed for accounting all the consumptions. For example, consumptions of transport sector are based on data detailed at municipal level and data at a lower scale. In (A. A. Boccardi et al., 2012) it is stated that "the disaggregation at municipal level is calculated taking into account road infrastructures that cross the municipality (municipal roads, state highways and railways)", but it is not further detailed.

For the CoM, the local authority is expected to play an exemplary role and therefore to take outstanding measures related to the local authority's own buildings and facilities. For this reason it is important to separately consider the energy consumptions and their related GHG emissions of the Municipality.

Table 11 – Data for defining the Baseline Emission Inventory and sources used for the case study

Data		**Source**
Energy consumption by vector		Regional data (www.sirena.cestec.it)
Renewable energy production		Atlas of PV plants (www.atlasole.gse.it)
Energy consumption of the Municipality by vector	Buildings	Municipality's bills
	Public lighting	Municipality's bills
	Vechiles of the Municipality	Municipality's data
Waste production and separate collection		Municipality's data
Support data	Energy certifications of buildings	Municipality's data
	Year of construction of buildings	Statistics (www.istat.it)
	Thermal plants	Regional registry (www.curit.it)
	Vechile fleet	Statistics (www.aci.it)

According to the cited studies, it is assumed that considers only energy consumptions is not enough to account GHG emissions at

Municipal level. For example, materials "consumed" into the municipal borders cause GHG emissions. In particular, the contribution in developing a suitable methodology for the municipalities involved in the Project, it has been to consider also the use of goods, represented by production of waste, and the impact of the waste management system through the separated waste collection.

In order to define effective actions for reducing the GHG emissions, a good knowledge of *how much* has been emitted is not enough: the decision makers should know also *what* are the main sources of emissions. For this reason, it is important to collect data on energy certifications of buildings, thermal plants and boilers, vehicle fleets. These information are defined as "support data". Those can give an overview on the performance in terms of energy efficiency of different sectors and help to define proper actions.

An overview of the used data is given in Table 11.

4.2.2.2 - GHG EMISSIONS BY ENERGY AND GOODS CONSUMPTION

The estimation of GHG emissions from energy consumptions and use of goods does not represent an estimation of the "real" emissions from the (municipal) area. It represents the energy and goods consumption in terms of GHG emissions (expressed in Equivalents of CO_2 – CO_{2EQ}).

Regarding the energy consumptions, the emissions are derived from all energy consumptions including the share of imported electricity. Table 12 shows the Emission Factors considered for the different energy vectors. Emission Factors are calculated according to the IPCC methodology (IPCC, 2006), that converts GHG emissions to CO_{2EQ} with 100 year time horizon. For the case of fossil fuel combustion, the 2006 IPCC Guidelines estimates carbon emissions in terms of the species which are emitted. During the combustion process, most carbon is immediately emitted as CO_2. However, some carbon is released as carbon monoxide (CO), methane (CH_4) or non-methane volatile organic compounds (NMVOCs).

Regarding the electricity consumptions, the Emission Factor provided by (Italian Ministry of Environment, 2012) has been used, it considers that to produce one kWh of electricity it is necessary to consume the equivalent of 2.56 kWh of fossil fuels.

*Table 12 – Emission Factors for energy vectors. Source: (IPCC, 2006). *Source: (Italian Ministry of Environment, 2012)*

Energy vector	**EF (t_{CO2EQ}/MWh)**
Natural Gas	0.202
LPG	0.227
Petrol	0.249
Fuel Oil	0.264
Diesel	0.267
Biomass	0.403
Electricity*	0.531

In order to consider the emissions caused by the use of goods on the area of the Municipality, GHG emissions from the production of waste have been considered. According to (APAT, 2007) the Emission Factor is 2.2 kg of CO_{2EQ} per kg of waste.

4.2.2.3 - AVOIDED EMISSIONS BY WASTE RECYCLING

Separated collection of waste, and consequent recycling, causes less GHG emissions from goods' production, therefore a share of GHG emissions from goods' production can be considered as avoided thanks to the separate collection and recycling of waste (Weitz, Thorneloe, Nishtala, Yarkosky, & Zannes, 2002).

Emission Factors are based on the calculation of energy consumptions for producing goods using recycled materials, instead of raw materials with a life cycle approach. Considered Emission Factors are shown in Table 13.

*Table 13 - Emission Factors for different recycled materials. Source: (US EPA, 2006). *Source: (COBAT, 2004). **Source: (European Commission, 2001b). ***Source: (European Commission, 2001a)*

Material	**EF (t_{CO2EQ}/t_{waste})**
Biowaste	0.181
Glass	0.254
Paper	3.211
Cardboard	2.821
Plastic	1.352
Wood	2.322
Steel	1.624
Aluminum	12.311
Mixed metals	4.736
Copper	4.463
Lead*	0.89
Tires	0.51
Computers and electronic appl.	5.427
Refrigerators**	2.75
Lubricating oils	0.125
Inert***	0.01

4.2.2.4 - AVOIDED EMISSIONS BY PHOTOVOLTAIC POWER GENERATION

Photovoltaic (PV) plants produce electricity, avoiding consumptions from the national grid. On the basis of the installed capacity it is possible to estimate the energy production, and consequently the avoided GHG emissions. The equation that has been used is:

$$AE = C * 1100 * 0.531 \qquad \textit{Equation 6}$$

- AE is the avoided GHG emissions (t_{CO2EQ});
- C is the annual installed capacity (MW);
- 1100 is the operative hours of a plant in 1 year;
- 0.531 is the Emission Factor (t_{CO2EQ}/MWh) - Table 12

4.2.3 - RESULTS

The BEIs of the 16 municipalities are available on the official website of the CoM (www.covenantofmayors.eu), within their SEAPs. The year 2005 has been chosen as reference year for calculating the BEI, due to the data availability.

The minimum objective for the Covenant of Mayor is to reduce the GHG emissions of 20% by 2020. However, to ensure actions for different sectors, four “emission sources” have been identified and the Municipalities have been advised to reach the final objective of 20% in each of those sources, namely:

- Municipality’s. This category considers the GHG emissions caused by the activities directly related to the municipal institution. Fixing a reduction objective for this category will ensure the direct commitment of the Municipality for emission reduction.

- Energy consumption (no electricity). This category considers the GHG emissions caused by consumption of fuels. Fixing an objective for this category could lead in taking action in household, transport and industry/tertiary sectors. Especially, the reduction of Natural Gas consumptions in household sector can play a crucial role for reducing emissions from energy consumptions. According to SIRENA data, household sector covers about 40% of the GHG emissions from energy consumptions of the Lombardy Region in 2005, and Natural Gas is responsible of about 72% of the GHG emissions from energy consumption of the household sector of the Region. Additional sectioning of the overall objective in transport and other sectors could bring benefit in involving different sectors and actors to achieve the commitments.

- Electricity consumption. This category considers the GHG emissions caused by consumption of electricity. Improving the energy efficiency and increasing local production of electricity from renewable resources are the cornerstones to reduce emissions from electricity consumptions.

- Waste production and recycling. This category considers the GHG emissions caused by waste production and avoided emissions thanks to the separate collection. Keeping separated this category ensures to plan action only for the waste management, strengthening the benefits of the SEAP.

Figure 26 shows the emissions of the Municipalities. Those are related to the population: bigger municipalities (as Vimercate and Agrate Brianza) have bigger emissions. GHG emissions directly related to the Municipality activities cover a small share of the total value; however the Covenant of Mayor involves directly the municipal structure that should lead a process at local level for reducing the GHG emissions, so it should be a model for the other involved actors.

For the analyzed cases, the biggest contribution to GHG emissions comes from the consumption of the Natural Gas of the household sector. For example, as shown in Figure 27, for the Municipality of Vimercate household consumptions cover about 54% of the energy consumptions, and Natural Gas consumptions cover about 63% of the energy consumptions. In some cases, as for Agate Brianza, the electricity consumption covers an important share of GHG emissions, this depends mainly on the industry sector not involved in the Emission Trading Scheme of Kyoto Protocol (non-ETS) (Figure 27).

Analyzing the GHG Emissions of the considered municipalities, those vary from about 4.5 tons per habitant to 11.5 tons per habitant. Higher values could depend on the non-ETS industry and tertiary sector, which are correlated with the electricity consumptions. The scatter plot between the share of GHG Emissions from electricity and the GHG Emissions per habitant is shown in Figure 28: the 16 cases show a positive linear correlation of the two variables with a coefficient of determination of 0.25.

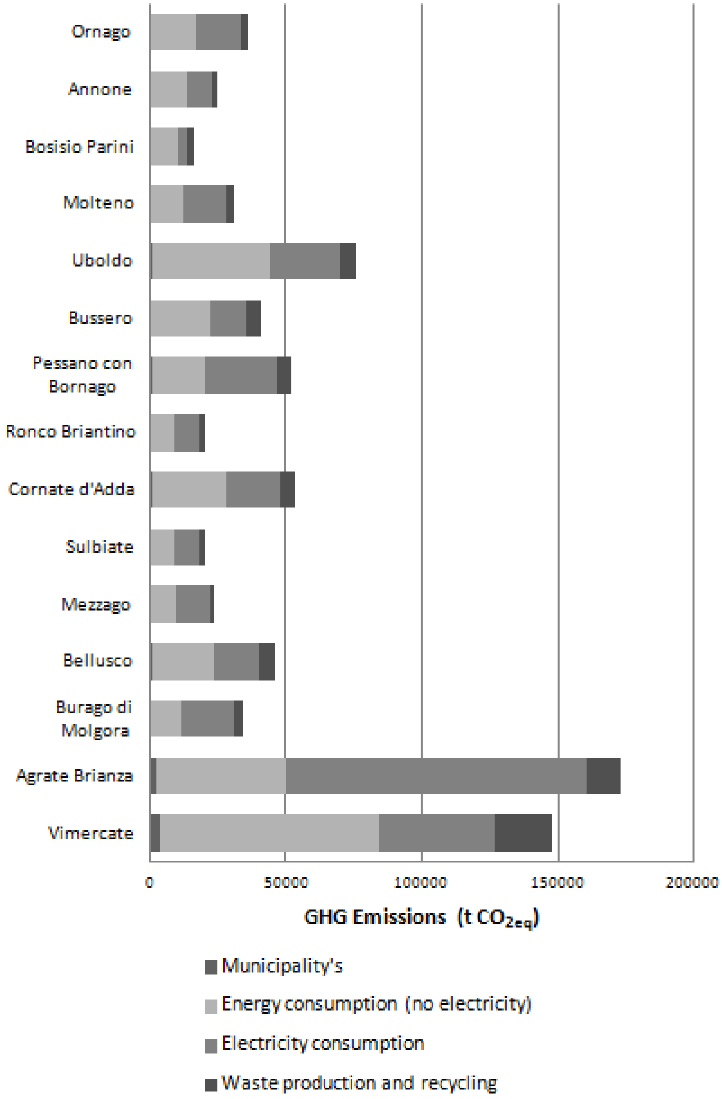

Figure 26 – GHG Emissions from energy consumptions and waste management in t of CO_{2EQ} by Municipality and Emission source

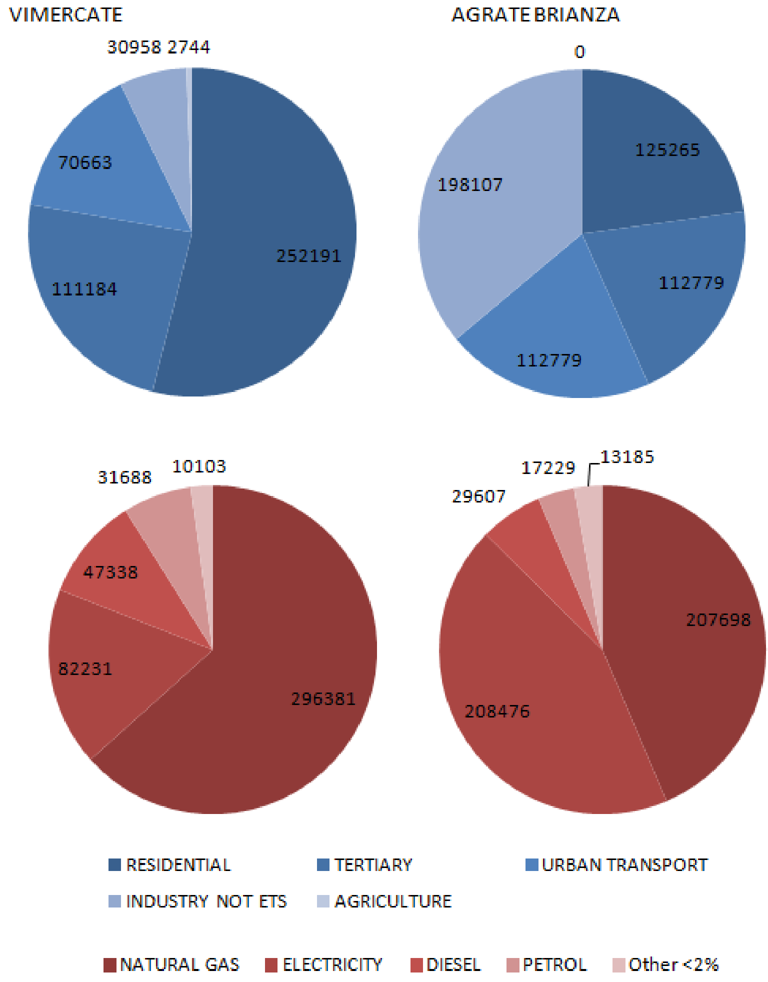

Figure 27 – Energy consumption in MWh by sector and by vector of Vimercate and Agrate Brianza for 2005

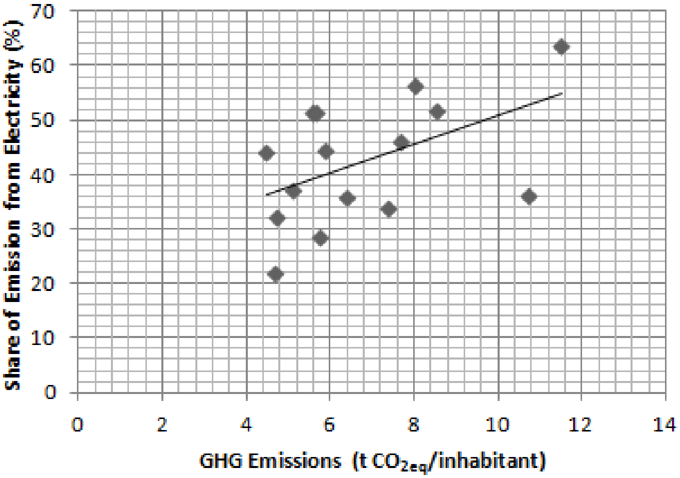

Figure 28 – Correlation between GHG Emissions and share of emission from electricity consumption

The CoM initiative directly involves the institutions of different Municipalities. The municipal structure and its motivation are crucial to achieve the commitment.

For defining the BEI many specific data were needed (Table 11), and the same it is for updating it and monitoring the actions. The municipal structure should be able to define procedures for data collection and management according to its (financial) capability.

The SEAP's actions must be defined only within the Covenant of Mayor commitment, an action defined "outside" should not being considered as contributing to achieve SEAP objective. Therefore, decision makers should know what is realistic and achievable within Covenant of Mayor initiative.

In (Cerutti et al., 2013), five years of CoM are assessed, and main statistics about the submitted SEAP are given. The majority of the signatories chose as BEI year the 2005 (or the 2007), despite the Guidelines recommend the 1990. Probably, as for the case studies, the lack of data did not allow choosing the 1990, and the year 2005 has been chosen as baseline also for the legally binding targets of the Europe 2020 strategy (for the non-ETS sectors). The main figures of the case study are confirmed by the five years assessment: the residential sector plays the main role (with some exceptions for Spain, Portugal and France); the emissions from the Municipality's facilities represent only the 2%, but those should be separately accounted because the Municipal administration has a driving role in the project, and so specific action to reduce GHG emissions from Municipality's activity should be planned within the CoM.

4.3 - DEVELOPED TOOLS

A toolkit called “Monitoraggio” has been developed and then provided to every Municipality together with the calculated BEI (Baseline Emission Inventory). The aim of the toolkit is to allow every Municipality to easily monitor and update the SEAP on the basis of the available data. The toolkit has been provided as joined MS Excel sheets’ collections to make it easy-to-use by the officers of all the municipalities. An overview of the tools is given in Table 14.

Table 14 – Overview of the Toolkit “MONITORAGGIO” provided for the “Patto dei Sindaci” Project

Tool name	Aim
MEI/MUNICIPALE	It calculates the emissions related to the activities of the Municipality (buildings, street lighting, and cars of the Municipality).
MEI/RIFIUTI	It calculates GHG emission from waste production and avoided GHG emission from recycling.
MEI/SIRENA	It automatically calculates the Emission Inventory from SIRENA data and MEI/MUNICIPALE and MEI/RIFIUTI outputs.
MAZIONI	It monitors the SEAP’s actions through a sheet for every action. It calculates, when it is possible, the avoided emissions due to the action.
SUPPORTO	Framework for data collection not related to quantifiable emissions/actions.

4.4 - ROLE OF LOCAL FORESTS IN CARBON ACCOUNTING

The previous Chapters focus on the role of forests as source of fuels, to develop local energy supply chains. At municipal level, using local sources for heating can decrease the share of energy from Natural Gas of the household sector. Clearly, it is necessary to evaluate the effective potential of local renewable resources. Forests and other green lands can contribute to absorb CO_2, with a positive impact on the local carbon balance.

The Project “CO2NTARE” (Sala, Meli, & Ciapponi, 2009) aimed to account the emissions of the Municipality of Carugate in Lombardy Region. Project results have been revised to develop a methodology suitable at local scale, to account:

- Direct emissions of CO_2;
- Emissions from heating consumption and efficiency of the household sector;
- Emissions from local transports;
- GHG emissions from electricity consumption;
- GHG emissions from waste and water management;
- CO_2 sequestration from local forests, on the basis of the land areas.

The sequestration capacity of the area has been estimated considering the sequestration for different types of land use. In particular sequestration values were collected for different types of land cover (as grass, trees, and agricultural crops). To associate each land cover to value of sequestered CO_2, studies and parameters related to Italian geographic and climatic conditions were considered (Pennati, Castellani, & Sala, 2009).

The calculation of the CO_2 sequestration was carried out considering the land use mapping provided by Lombardy Region for the territory of the Municipality of Carugate.

The method is based on the allocation to different land covers of the sequestration coefficients. The data used for the calculation are shown in Table 15.

Table 15 – CO_2 sequestration coefficient used in "CO2ntare" Project

Land cover	**Sequestration coefficient (t_{CO2} ha^{-1} $year^{-1}$)**	**Source**
Cropland	0	(Bongen, 2003)
Poplar	16.05	(Tedeschi et al., 2005)
Grassland	5.12	(Emmerich, 2003)
Broad-leaves forest	34.55	(De Lucia, Drake, Thomas, & Gonzales-Melers, 2007)
Coniferous forest	40.88	De Lucia, Drake, Thomas, & Gonzales-Melers, 2007)
Mixed forest	24.19	De Lucia, Drake, Thomas, & Gonzales-Melers, 2007)
Natural vegetation	2.93	(Emmerich, 2003)
Barren areas	0	
Lakes and rivers	10.46	(Emmerich, 2003)
built up land	0	

For the Municipality of Carugate, the annual sequestrated CO_2 is 358 t, it covers the 0.2% of the emitted CO_2. For the case study, the sequestration does not affect significantly the CO_2 balance; however in Municipalities with higher shares of green lands the sequestration can significantly affect the carbon balance.

However, this carbon accounting method cannot be directly embedded in the methodology to assess the GHG Emissions used for the CoM. Because it is related to *direct* emissions due to land use, and the methodology used for the CoM is based on consumptions of energy and goods and the consequent emissions calculated through emission factors.

4.5 - CONCLUSIONS

An expeditious methodology to calculate GHG emissions at municipal level has been developed on the basis of the CoM guidelines. The produced tool is based on simple equation to calculate GHG emissions from energy consumption and waste management. The methodology is forthwith applicable to municipalities of Lombardy Region, and it could be a suitable framework for other areas.

Regarding the application of the methodology to the 16 municipalities, the main challenge consisted in the data collection: some of the data are not available from Regional or National databases, for this reason the involvement of the Municipality is crucial. The municipalities already active on “green” policies have been more aware on the importance of defining a concrete emission reduction plan, and generally they can provide a more detailed picture regarding the sources of GHG Emissions, and a better vision on the actions to reduce them.

The Covenant of Mayors has been successful in Europe (Cerutti et al., 2013). Joining the Covenant of Mayors sounds politically beneficial for local administration but not all the Municipality are ready to set up concrete GHG reduction policies and only a long term commitment can achieve the defined goals. And, in some cases, the actions of the SEAP do not rely on solid bases in terms of specific assessments.

However, to join the CoM is a formal act, and it can stimulate innovative policies at local scale. It is a good framework to promote effective multi-level governance in relation to Climate Change policy implementation. It can stimulate the involvement of different stakeholders: the action for reducing the GHG Emissions could be planned with involved actors.

The approach proposed by the CoM is based on analyzing the final consumptions and on defining voluntary actions to reduce the emissions. It considers different sectors, the inclusion of local generation of energy, but the mandatory reduction target is on the total GHG emissions. Local energy policies should be based not only on the reduction of GHG Emissions, but also on developing short supply, distributed generation, and on dropping the energy demand through the increase of energy efficiency and more responsible consumptions. For this reason, the CoM approach can be further developed for being a cornerstone of local energy policy: including targets about using the local potentials, in terms of energy sources, and also in terms of increasing the energy efficiency. Moreover, a wider Climate Change policy should take into account also the net change in carbon stocks and greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change as stipulated by Kyoto Protocol (UNFCCC, 2014c).

CONCLUSIONS

“We live in an intricate and changing environment with interrelated feedback between ecosystems, society, economy and the environment”(EFI, 2014b), and make the Science-Policy interface effectively works is still an open challenge. Science works by models, and the policy making works with complex needs and interests: scientific method cannot replace decision making, but the scientific support is needed to set up useful policies.

The research activity faced different aspects related to local decision-making support, with the general aim of providing effective tools to support local policy in developing bioenergy supply chains. The challenge of local policies and plans related to resource usage and productive chains is to respond to regional or supra-regional guidelines, to address site specific needs from local communities and stakeholders, and to set up detailed objectives and actions, taking into account the actual material availability, and possible development scenarios.

The Chapter 1 focuses on the need of a multidisciplinary approach for ensuring sustainable processes and plans. It describes the relationships between energy and forestry sectors, and the need of holistic methods to plan a sustainable use of the resources. Particularly, the importance of evaluating environmental, social and economic aspects at local scale is highlighted.

The methods – proposed in Chapters 2, 3 and 4 – contribute to quantitatively evaluate of environmental aspects – considering also social and economic dimensions – and to define achievable policy targets.

The definition of a method to calculate the Carrying Capacity (CC) of a forestry system, and its application to evaluate the raw material availability with a focus for energy generation are described in Chapter 2. The final result is a tool that is capable to give added value to existing local forestry plans' data. The uncertainty of the results is high, but it depends mainly on the data quality, therefore the assessment can stimulate the local authorities to produce more standardized data for managing natural mixed forests, not only in terms of their physical format, but also in terms of defining common criteria for the forest management of similar areas. In addition to the fragmentation of planning authorities, the forest property fragmentation does not help in having detailed data on local forests for assessing the raw material availability; for this reason the involvement of forest owners is needed to effectively develop a local bioenergy chain.

The analyses of a local bioenergy supply chain and its possible development scenarios though a Sustainability Impact Assessment (SIA) method is described in the Chapter 3. The method supports rural development policies, considering different aspects: in this specific case rural development, energy issues and the environmental compatibility of developing a production chain. This approach allows the scientific analysis of trade-offs in rural development issues and can lead to innovative solutions for reaching policy goals.

A method to account for GHG emissions at municipal level and its application to several municipalities of Lombardy Region are described in the Chapter 4. The objective of the study was to define the baseline of the GHG emissions and to provide to local authorities a tool to monitor their action for reducing the emissions, and to recalculate the emissions over the time. The focus of this study is on evaluating the final consumption of energy and goods.

The three methods and their respective tools are complementary. First, each focuses on a specific stage of a supply chain:

- The CC assessment evaluates the effective raw material availability. Ensuring the sustainability of the material exploitation is a prerequisite to develop a sustainable energy supply.
- The SIA approach evaluates the impacts of the supply chain, and its development scenarios. It can drive the optimization of the supply under the light of its economic profitability, social implications, and environmental compatibility.
- The GHG accounting tool is based on final consumptions of energy and goods. It considers the final consumptions in the light of their climate change impacts, so it can support local energy policy for climate change mitigation.

Then, the weaknesses of the proposed approaches are due to the availability and quality of data: uncertain results are given by uncertain data and assumptions. Datasets are related to different sectors: existing data have been produced for other purposes, and the data collection resulted a time demanding stage. However, once data are collected, local policy makers and planners can rely on valuable databases on local biomass potential, forestry sector, and energy demand, which can be updated and adapted to specific needs.

The importance of setting credible baselines has been confirmed by each of the studies developed in the present Thesis: forecasted scenarios or actions must be based on a careful assessment of the actual conditions. Local decision-makers need to monitor the effects of their action over the time and defined scenarios may go through changes. For these reasons, it is important to define flexible methods and tools that allow both ex-ante and ex-post analyses. Besides, tools must be useful over the time: provided tools should be capable to adapt to new and more accurate datasets.

The methods and tools developed are based on the use of already existing data sets. In this way, the assessments can be replicated in similar context and there is no need of specific measuring to get input data for the evaluations. However, the datasets can be not homogenous – since different data sources are used – or inconsistent and partial.

About the Carrying Capacity evaluation, the methodology is effective as long as the forest management guidelines are opportunely defined to ensure the multi-functionality of forests. The biomass availability evaluation lacks of the time dimension: the available data do not allow knowing accumulations of biomass in the forests. Regarding the proposed Sustainability Impact Assessment, the flexibility given by the adopted framework allows considering several aspects. In order to set up a time efficient data collection, it is important to clearly define the objective of the assessment, consequently defining the indicators, and so the needed data and parameters to calculate the indicators. For the proposed GHG accounting method, the role of local authority is crucial: the baseline definition requires a strong collaboration from the municipality and the defined tool is intended to be used by municipality's officers.

The presented research can be further developed framing a more consistent linkage between the different methods, since these are referred to several aspects of the local planning of resources and energy supply. The Carrying Capacity assessment provides geo-referred data on the available raw material considering different forest managements and different level of the exploitation of the biomass. The analysis of the whole supply can benefit from the use of the geographical dimension, not only in terms of accounting for the available raw material, but also considering other data that are normally stored in GIS, such as distances between several facilities, and the distribution of energy (or raw material) demand. The integration of the geographical dimension with the supply chain analysis has promising future development. The results in terms of energy generation from woody biomass can be compared to the energy consumption needed to locally account the GHG emissions: the development of local forest-wood-energy supply chains can be assessed under the light of improving the local performance in terms of climate change mitigation.

Finally, a key element to further develop local decision support tools is to better structure the participatory process: local experts and stakeholders should be engaged in the baseline(s) assessment, scenarios definition, policy implementation, and monitoring process.

ANNEX I – RESULTS OF CARRYING CAPACITY ASSESSMENT

Results of Carrying Capacity Assessment are detailed in Table 16 at municipal level: on the basis of the Municipality layer (for OCC and TP), and on forestry type (for OCC and for CP).

Table 16 – OCC and TP values by Municipality

Municipality - CMLI	OCC (kg)	TP (kg) - 2008	TP (kg) - 2011
ARGEGNO	977971.808	727177.4467	739988.6945
BLESSAGNO	882895.306	-321923.7551	571175.2032
BRIENNO	455190.849	301112.6789	364152.6789
CARATE URIO	20699.0252	-169840.7799	-193390.2851
CASASCO D'INTELVI	336356.219	-160515.025	-308009.6423
CASTIGLIONE D'INTELVI	567170.908	46536.72651	-286619.6721
CERANO D'INTELVI	145525.28	-754299.7761	-327907.7756
CERNOBBIO	730323.089	260818.4709	396723.2794
CLAINO CON OSTENO	2405147.73	1439238.185	1771999.174
COLONNO	386664.083	265331.2664	245515.7444
DIZZASCO	290718.911	-6944.871242	170086.4661
LAGLIO	910121.194	684896.9556	704018.3808
LAINO	1735647.28	154037.8243	633487.4339
LANZO D'INTELVI	1636483.15	481506.5182	-1006560.298
LENNO	1342226.05	891780.8408	745656.7175
MEZZEGRA	148096.522	12077.2177	-352128.3164
MOLTRASIO	2147112.14	1188089.711	1277542.639
OSSUCCIO	554595.373	247356.2981	335208.6485

PELLIO INTELVI	618432.073	-711494.3412	-284505.4988
PIGRA	155514.982	36811.98586	-112122.1729
PONNA	582796.713	-1360322.63	-214566.5039
RAMPONIO VERNA	812235.524	-514851.5806	105068.4409
SALA COMACINA	534867.083	365493.6666	408134.8419
SAN FEDELE INTELVI	1028622.32	417617.8585	549293.8689
SCHIGNANO	2418524.11	507699.2903	1480251.935
TREMEZZO	785335.426	508268.3406	427389.0897
Total	22609273.2	4535658.522	7839883.071
Municipality - CMTL	OCC (kg)	TP (kg) - 2008	TP (kg) - 2011
ALBAVILLA	257544.76	-681244.1942	-418186.4613
ALBESE CON CASSANO	1830050.74	960040.5921	1109001.847
ASSO	783496.40	28397.11724	452089.8255
BARNI	1046839.47	-813568.4262	-2179811.822
BELLAGIO	3070161.29	814689.032	1829536.603
BRUNATE	5662.25	-60430.19833	-68265.38531
CAGLIO	1314651.43	913001.1439	894224.9199
CANZO	1281114.85	-637428.119	600696.6726
CASLINO D'ERBA	658299.67	277839.7378	353186.0865
CASTELMARTE	186400.38	-173119.695	-16283.05481
CIVENNA	520653.56	-490517.1533	416522.8467
ERBA	1062050.75	536360.601	660187.1672
EUPILIO	109645.60	-121083.5213	-159520.4296
FAGGETO LARIO	3376266.86	1972053.49	2380391.372
LASNIGO	520562.27	-309150.1873	259082.6032
LEZZENO	1327914.50	755131.6003	871830.2298
LONGONE AL SEGRINO	4117.50	-236306.0012	-74579.01637
MAGREGLIO	380269.01	157495.2094	-27325.38814
NESSO	1990622.21	533057.7691	1370931.598
POGNANA LARIO	289794.74	229435.7924	231835.7924
PONTE LAMBRO	12660.85	-297871.3225	-90975.9283
PROSERPIO	161251.58	-437158.7359	-39351.13292

PUSIANO	177738.50	104590.8037	108119.1539
REZZAGO	663433.98	117547.1823	430363.9421
SORMANO	1683779.79	757023.8334	1240362.24
TAVERNERIO	540373.29	-363701.3691	49962.36755
TORNO	612206.92	258565.5331	459985.7494
VALBRONA	2387874.16	640379.3292	1261532.766
VELESO	709928.06	249542.4445	512982.2417
ZELBIO	341369.70	117655.7609	-47829.88968
Total	27306735.06	4801228.05	12370697.52

Forestry Tipe - CMLI	**OCC (mc)**	**CP (kg) ± 15%**	**CP (MJ) ± 3%**
Maple (Ash and Lime)	4273.74	1055518.88	12245175.76
Birch	229.79	138943.64	1666143.61
Chestnut	2088.93	855709.85	10384332.02
Beech	13460.23	2939391.74	34160563.93
Ornus	5524.87	2293379.25	26511464.14
Total	25577.55	7282943.36	84967679.47
Forestry Tipe - CMTL	OCC (mc)	CP (kg) ± 15%	CP (MJ) ± 3%
Maple (Ash and Lime)	14442.81	3470875.20	39838039.87
Birch	1937.11	1171288.90	14045518.89
Chestnut	5150.91	2110018.84	25605801.22
Beech	7821.55	1708038.69	19850217.27
Reforestation of coniferous trees	701.59	212424.98	2455632.73
Robinia	564.06	157556.97	1821358.57
Ornus	4419.34	1587630.38	18353007.19
Spruce	1738.04	0.00	0.00
Beech Spruce	265.54	47680.44	552655.50
Scots Pine	92.99	0.00	0.00
Total	37133.9	10465514.39	122522231.2

ANNEX II – FURTHER DEVELOPMENTS OF THE DSS FOR BIOMASS AVAILABILITY ASSESSMENT

The method – and the tool – to calculate the biomass availability at local scale has been further developed, on the basis of the site specific data of the Como Province and the local experts opinion.

First, different data have been collected in order to get detailed information about:

- Forest type;
- Forest management;
- Forestry road system.

Data on wood accumulation are not available. In order to calculate the biomass availability, average data have been considered, with the support of local expert opinion.

The different information come from heterogeneous datasets, for this reason a fishnet with squared cells with side of 50 meters has been defined to simplify the GIS. The needed information are stored at the cell level through the utilization of numerical key codes. For example, the code that identifies the forestry type is K_T and it can vary from 1 to 99, and the code that identifies the forest management is K_G and it can be 100 for coppice or 200 for high forests, the sum of the two codes gives K_U that is an unique key to identify forest type and forest management of every cell.

A table, that assigns different information to each K_U, is linked to the fishnet. Specifically, the values of wood productivity can be calculated on the basis of K_U, according to literature data.

After calculating the average annual production of biomass, it is possible to add restrictions and information on the basis of different aspects, as accessibility, protection, and property of forests, risk, and technical restriction for specific uses as chipping.

For the specific case the accessibility is defined as the possibility of setting up a forestry harvesting site on the basis of distance from roads and slope classes of the area. Therefore, it is calculated jointly considering road characteristic and slopes. The capacity to perform the extraction at a certain distance depends on the type of road, which affects the ability to transit vehicles with a medium-large or small size. Trucks of medium to large size can usually carry cable crane, and small vehicles generally can carry forestry winch. That causes different maximum distances from the road border for harvesting activities. Also in this case, it is possible to define key codes: K_ROAD represents different road categories, and K_SLOPE represents different slope classes. From the combination of K_ROAD and K_SLOPE results K_ACC, that represents the accessibility category. That provides information on the maximum distance from the road and on which kind of harvesting system is more suitable. On the basis of the distance from the road, it is possible to create buffers in order to define the accessible areas with a higher detail than the one provided by PIFs data.

Regarding the protective and naturalistic functions of forests two level of protection can be identified: total protection and partial protection. The total protection areas consist in areas excluded by the calculation, as areas with high naturalistic interest and biodiversity hot-spots. The partial protection regards the areas where the harvesting activities are restricted due to special features.

The constraint "risk" considers the occurrence of particular types of environmental adversity such as landslides, avalanches, debris flows, and surface fires. It has been hypothesized the creation of a scoring system, that is based on the number of risk factors that are present on each cell with the intention of creating a map of risk, characterized by a growing degree of dangerousness, useful to local decision-makers to identify the level of risk that is present in that area, thus not arbitrarily define a reduction coefficient to the harvesting, but simply pointing the user to the presence and types of possible risk factors.

Finally, the data about the ownership is crucial to plan the harvesting activities. This information is generally available for a GIS.

ANNEX III – SIA - PRODUCTS DEFINITION

In ToSIA, products of the chain must be defined in terms of description, location and physical properties. As the value chain handles different units and ToSIA itself calculates based on Carbon flow, for each product conversion factors are needed: volume, mass, energy, economic value and carbon content. This is a key element in ToSIA, because the software works on material flow, specifically on carbon flow: indicators of every process are related to the quantity of carbon that flow "through" the process (e.g. tC – tons of Carbon), but the process unit is not necessarily "tons of carbon", for example, for energy generation processes it is kWh.

For the designed topology, products have been grouped into six categories with the same features as shown in Table 17.

The volumetric mass has been calculated considering the tree species of the area, to get the mass-volume conversion. The volumetric mass depends on the humidity of the wood and the swelling factor (Hellrigl, 2006), as described in Chapter 2.

Table 17 – Products categories and Conversion factors. Elaboration from (Francescato et al., 2012). PU is the Product Unit

Category and description	PU	Water content	$\frac{m^3}{PU}$	$\frac{t}{PU}$	$\frac{t_C}{PU}$	$\frac{kWh}{PU}$
"Wood in forests". Products from forests that can be harvested	m3	40%	1	0.893	0.35	2488.5
"Forestry Activities Products". Products from harvesting to the gate of transformation processes	t	40%	1.12	1	0.39	2787.2
"Logs". Products defined as logs in the supply chain	t	30%	2.562	1	0.43	3369.4
"Chips from Forestry Site". Products from the roadside chipping	m3	30%	1	0.26	0.11	876.65
"Chips from Terminal". Products from the chipping in terminal	m3	20%	1	0.223	0.11	880.23
"Energy". Products of the combustion process	kWh	-	8 E-4	3 E-4	1 E-4	1

ANNEX IV – SIA – DATA SOURCES AND ASSUMPTIONS FOR INDICATORS' VALUES

In order to calculate the Local Gross Value Added (LGVA), the prices of energy are assumed equal to prices of Natural Gas, for heat, and electricity for a final consumer. Research studies for similar areas (Magagnotti, 2012; Spinelli, Magagnotti, & Nati, 2009; Spinelli & Magagnotti, 2011) have been analyzed to get information about chipping process, and forestry activity costs. On this, it is important to report that the price of chips from terminal is higher, because the fuel quality is higher too. Also Production Costs for chips from terminal are higher, and transportation costs are lower (Francescato et al., 2012).

In order to calculate the Employment indicator a key parameter is the productivity of the different processes, in order to calculate the number of workers involved per ton of product. (Mielesi, 2012; Spinelli et al., 2009; Spinelli & Magagnotti, 2011) are data sources for forest harvesting activities. Data from (Magagnotti, 2012) have been considered to estimate values for fuel production processes. Data provided by the local enterprise Cip Calor Srl and local experts' opinion have been used to estimate the number of persons involved in the energy generation and in forestry planning processes. In the case of forestry planning it has been assumed 0.25 ha/day as needed average time to design a forestry site. Then, 7 working hours per day, and 1800 working hours per year have been assumed, so the final value for forest planning process is 0.01555 person/ha.

In order to estimate the Energy Use, local data – from BOMO Project and provided by the local enterprise Cip Calor Srl – and literature data – from (Francescato et al., 2012; Magagnotti, 2012) – have been considered. For combustion processes, the Energy Use has been assumed equal to zero. In reality, in these processes a use of energy can occur, but since they are intended for energy production, the Energy Use has been ignored.

In order to estimate the Emissions, data from (Schäffeler & Keller, 2008) have been used to quantify the emissions from forestry activities. Data from (EEA, 2009) have been used to estimate emissions of combustion plants. Conversion factors from (European Commission, 2010b; US EIA, 2011) have been used to estimate GHG Emissions from fuel consumption and burning processes.

REFERENCES

Alanne, K., & Saari, A. (2006). Distributed energy generation and sustainable development. Renewable and Sustainable Energy Reviews, 10(6), 539–558. doi:10.1016/j.rser.2004.11.004

Alfonso, D., Perpiñá, C., Pérez-Navarro, A., Peñalvo, E., Vargas, C., & Cárdenas, R. (2009). Methodology for optimization of distributed biomass resources evaluation, management and final energy use. Biomass and Bioenergy, 33(8), 1070–1079. doi:10.1016/j.biombioe.2009.04.002

Alpine Convention. (1994). Protocol on the implementation of the Alpine Convention relating to spatial planning and sustainable development. Chambéry, France.

APAT. (2007). Rapporto Rifiuti. Retrieved from http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-2007

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., … Pimentel, D. (1995). Economic growth, carrying capacity, and the environment. Science, 268(5210), 520–1. doi:10.1126/science.268.5210.520

Arvai, J., Bridge, G., Dolsak, N., Franzese, R., Koontz, T., Luginbuhl, A., … Thompson, A. (2006). Adaptive Management of the Global Climate Problem: Bridging the Gap Between Climate Research and Climate Policy. Climatic Change, 78(1), 217–225. doi:10.1007/s10584-006-9094-6

Awerbuch, S. (2006). Portfolio-Based Electricity Generation Planning: Policy Implications For Renewables And Energy Security. Mitigation and Adaptation Strategies for Global Change, 11(3), 693–710. doi:10.1007/s11027-006-4754-4

Baskent, E. Z., & Keles, S. (2005). Spatial forest planning: A review. Ecological Modelling, 188(2-4), 145–173. doi:10.1016/j.ecolmodel.2005.01.059

Bastianoni, S., Caro, D., Borghesi, S., & Pulselli, F. M. (2014). The Effect of a Consumption-Based Accounting Method in National GHG Inventories: A Trilateral Trade System Application. Frontiers in Energy Research, 2(January), 1–8. doi:10.3389/fenrg.2014.00004

Bell, S., & Morse, S. (2008). Sustainability indicators: measuring the immeasurable? (2nd ed.). London: Earthscan.

Berg, S. (2008). EFORWOOD Deliverable PD0.0.16: Manual for data collection for Regional and European cases – UPDATE 3 September 2008 (p. 110). Skogforsk. Retrieved from http://www.efi.int/files/attachments/publications/eforwood/efi_tr_36.pdf

Beursekens, L. W. M., Hekkenberg, M., & Vethman, P. (2011). Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States. Retrieved from http://www.ecn.nl/docs/library/report/2010/e10069.pdf

Blennow, K., Persson, E., Lindner, M., Faias, S. P., & Hanewinkel, M. (2014). Forest owner motivations and attitudes towards supplying biomass for energy in Europe. Biomass and Bioenergy, 67, 223–230. doi:10.1016/j.biombioe.2014.05.002

Boccardi, A. A., Perina, N., Ghidorzi, S., De Simone, D., Brolis, M., & Maffeis, G. (2012). Un approccio integrato per i Bilanci Energetico-Ambientali Regionali: il caso della Regione Lombardia (pp. 1–14). Milano, Italy. Retrieved from http://sirena.finlombarda.it/sirena/download/Metodologia_Bilancio.pdf

Boccardi, A., & Maffeis, G. (2011). BIOPOLE Technical Guide and User Guide. Retrieved from http://www.bioenergis.eu

Bongen, A. (2003). Using agricultural land for carbon sequestration. Consortium for Agricultural Soils Mitigation of Greenhouse Gases.

Bradshaw, G., & Borchers, J. (2000). Uncertainty as information:narrowing the Science-Policy gap. Conservation Ecology, 4(1). Retrieved from http://www.ecologyandsociety.org/vol4/iss1/art7/

Brun, F. (1998). L’evoluzione della politica forestale comunitaria. In Università degli Studi di Torino (Ed.), Turismo e ambiente. Pineta di Ischia, Un progetto Euromediterraneo per lo sviluppo (pp. 1–13). Ischia, Italy: Dipartimento di Economia e Ingegneria Agraria Forestale e Ambientale.

Brun, F. (2002). Multifunctionality of mountain forests and economic evaluation. Forest Policy and Economics, 4(2), 101–112. doi:10.1016/S1389-9341(02)00010-2

Carlsson, D., & Rönnqvist, M. (2005). Supply chain management in forestry—case studies at Södra Cell AB. European Journal of Operational Research, 163(3), 589–616. doi:10.1016/j.ejor.2004.02.001

Caserini, S., Fraccaroli, A., Monguzzi, A. M., Moretti, M., Giudici, A., Angelino, E., … Stresa, V. (2003). A detailed Emission Inventory for air quality planning at local scale: the Lombardy (Italy) experience. In 13th International Emission Inventory Conference “Working for Clean Air in Clearwater.” US EPA. Retrieved from http://www.epa.gov/ttnchie1/conference/ei13/poster/caserini.pdf

Cash, D., Clark, W., Alcock, F., Dickinson, N., Eckley, N., & Jäger, J. (2002). Salience, credibility, legitimacy and boundaries: linking research, assessment and decision making. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=372280

Castaneda, F. (2000). Criteria and indicators for sustainable forest management: international processes, current status and the way ahead. Unasylva (English Ed.), 51, 34–40. Retrieved from http://www.cabdirect.org/abstracts/20003028689.html

Castellani, V., & Sala, S. (2010). Energy from biomass: how to evaluate sustainability of technologies at local scale. In SEEP2010 Conference Proceedings. Bari, Italy. Retrieved from http://boa.unimib.it/handle/10281/24236?mode=full

Castro, L. M., Pio, C. a., Harrison, R. M., & Smith, D. J. T. (1999). Carbonaceous aerosol in urban and rural European atmospheres: estimation of secondary organic carbon concentrations. Atmospheric Environment, 33(17), 2771–2781. doi:10.1016/S1352-2310(98)00331-8

Cerutti, A. K., Iancu, A., Janssens-maenhout, G., Melica, G., Paina, F., & Bertoldi, P. (2013). The Covenant of Mayors in Figures 5-Years Assessment. (JRC, Ed.). Luxembourg: Publications Office of the European Union. doi:10.2788/1062

Cespi, D., Passarini, F., Ciacci, L., Vassura, I., Castellani, V., Collina, E., … Morselli, L. (2013). Heating systems LCA: comparison of biomass-based appliances. The International Journal of Life Cycle Assessment. doi:10.1007/s11367-013-0611-3

Chang, Y.-C., & Lee, C.-Y. (2003). Logistic scheduling: analysis of two-stage problems. Journal of Systems Science and System Engineering, 12(4), 385–407.

Cherubini, F., Peters, G. P., Berntsen, T., Strømman, A. H., & Hertwich, E. (2011). CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy, 3(5), 413–426. doi:10.1111/j.1757-1707.2011.01102.x

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: the emerging research program. Proceedings of the National Academy of Sciences of the United States of America, 100(14), 8059–61. doi:10.1073/pnas.1231333100

COBAT. (2004). Rapporto Ambientale 2003. Rome, Italy. Retrieved from www.cobat.it

Corintea. (2003). Modello per lo studio di fattibilità e per la gestione di un distretto energetico basato sull'impiego di cippato.

Costanza, R. (2009). Science and Ecological Economics: Integrating of the Study of Humans and the Rest of Nature. Bulletin of Science, Technology & Society, 29(5), 358–373. doi:10.1177/0270467609342864

Daily, G. (1997). Nature's services: societal dependence on natural ecosystems. Island Press.

De Lucia, E. H., Drake, J. E., Thomas, R. B., & Gonzales-Melers, M. (2007). Forest carbon use efficiency: is respiration a constant fraction of gross primary production? Global Change Biology, 13, 1–11.

Den Herder, M., Kolström, M., Lindner, M., Suominen, T., Tuomasjukka, D., & Pekkanen, M. (2012). Sustainability impact assessment on the production and use of different wood and fossil fuels used for energy production in North Karelia, Finland. Energies. doi:10.3390/en50x000x

Devuyst, D., Hens, L., & De Lannoy, W. (2001). How green is the city?: sustainability assessment and the management of urban environments. Columbia University Press.

EEA. (2009). EMEP / EEA air pollutant emission inventory guidebook — 2009 (pp. 8055–8064). Copenhagen, Denmark.

EEA. (2013a). EU Emissions Trading System (ETS) data viewer. Retrieved December 23, 2013, from http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer

EEA. (2013b). European Union CO2 emissions: different accounting perspectives. Luxembourg: Publications Office of the European Union.

EEA. (2013c). Trends and projections in Europe 2013. Luxembourg: Publications Office of the European Union.

EFI. (2012). ThinkForest: A European high-level forum on the future of forests A European high-level forum on the future of forests. Retrieved January 15, 2014, from http://www.thinkforest.efi.int/portal/

EFI. (2014a). Current trends for forest biomass for energy in the EU. News Release. Retrieved June 05, 2014, from http://www.alphagalileo.org/ViewItem.aspx?ItemId=142465&CultureCode=en

EFI. (2014b). What Science can tell us. What Science can tell us. Retrieved May 27, 2014, from http://www.efi.int/portal/virtual_library/publications/what_science_can_tell_us/

EFORWOOD. (2010). EFORWOOD Project. Uppsala, Sweden.

EFORWOOD Consortium. (2010). Final Report from the EU Integrated Project EFORWOOD. ToSIA - A Tool for Sustainability Impact Assessment of the Forest-Wood Chain (p. 68). Uppsala, Sweden, Sweden: Skogforsk. Retrieved from http://www.innovawood.com/LinkClick.aspx?fileticket=%2FQ0Hklu9SPk%3D&tabid=284

Emmerich, W. (2003). Carbon dioxide fluxes in a semi-arid environment with high carbonate soils. Agriculture and Forest Meteorology, 116(1), 91–102.

Energy & Strategy Group. (2011). Biomass Energy Report. Retrieved from http://www.energystrategy.it

Eräjää, S., & Abrahams, A. (2014). New studies reveal severe flaws in EU biomass policies. EEB News. Retrieved May 23, 2014, from http://www.eeb.org/EEB/index.cfm/news-events/news/new-studies-reveal-severe-flaws-in-eu-biomass-policies/

ETATEC. (2007). Studio di pre-fattibilità Impianto “Grande Stufa” - Comune di Villa Guardia (Como) (pp. 1–96).

Europe’s Energy Portal. (2012). Fuel Prices, Rates for Power and Natural Gas. Retrieved January 15, 2012, from www.energy.eu

European Commission. The future of rural society (1988). Luxembourg, European Union.

European Commission. (2001a). Critical Review of Existing Studies and Life Cycle Analysis on the Regeneration and Incineration of Waste Oils. Retrieved from http://ec.europa.eu/environment/waste/studies/oil/waste_oil.htm

European Commission. (2001b). Waste management options and climate change. Luxembourg: European Communities.

European Commission. Communication from the Commission on Impact Assessment (2002). Bruxelles, Belge, European Union.

European Commission. Biomass action plan. , COM(2005) Communication from the Commission (2005). Bruxelles, Belge, European Union.

European Commission. 20 20 by 2020: Europe’s Climate Change Opportunity. , speech to the European Parliament, January (2008). Bruxelles, Belge, European Union. Retrieved from http://demo.r744.com/web/assets/link/speech_barroso_jan2008.pdf

European Commission. An EU energy security and solidarity action plan (2008). Bruxelles, Belge, European Union.

European Commission. Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage (2010). Bruxelles, Belge, European Union.

European Commission. (2010b). How to develop a Sustainable Energy Action Plan (SEAP) - Guidebook. (E. Union, Ed.) (p. 120). Luxembourg: Publications Office of the European Union. Retrieved from http://www.eumayors.eu/IMG/pdf/seap_guidelines_en.pdf

European Commission. A Roadmap for moving to a competitive low carbon economy in 2050 (2011). Bruxelles, Belge, European Union.

European Commission. (2011b). Europe 2020 targets. Retrieved July 20, 2012, from http://ec.europa.eu/europe2020/pdf/targets_en.pdf

European Commission. Innovating for Sustainable Growth: A Bioeconomy for Europe (2012). Bruxelles, Belge, European Union.

European Commission. A new EU Forest Strategy: for forests and the forest-based sector (2013). Bruxelles, Belge, European Union.

European Commission. (2013b). Europe 2020. Retrieved January 14, 2014, from http://ec.europa.eu/europe2020/index_en.htm

European Commission. (2014a). 2030 Framework for climate and energy. Bruxelles, Belge. Retrieved from ec.europa.eu/energy/2030_en.htm

European Commission. A policy framework for climate and energy in the period from 2020 to 2030 (2014). Bruxelles, Belge, European Union. Retrieved from http://ec.europa.eu/clima/policies/2030/docs/swd_2014_xxx_en.pdf

European Union. Consolidated version of the Treaty establishing the European Community (2002). Retrieved from http://eur-lex.europa.eu/en/treaties/dat/12002E/pdf/12002E_EN.pdf

FAO. (2006). Expert Consultation on Global Forest Resources Assessment (FRA): Towards FRA 2010. Kotka, Finland - Rome, Italy. Retrieved from http://www.fao.org/forestry/11187-0bff440555e4a92a0e3fd6ac8a488952a.pdf

FAO. (2010). Global Forest Resources Assessment 2010 - Main report. Rome, Italy: FAO Forestry Paper.

FCBA. (2005). Transport Tool. Retrieved October 10, 2012, from http://www.fcba.fr/eforwood/index.html

Fiorese, G., & Guariso, G. (2010). A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Environmental Modelling & Software, 25(6), 702–711. doi:10.1016/j.envsoft.2009.11.008

Fondazione Idra. (2011). Patto dei Sindaci - Covenant of Mayors. Retrieved January 21, 2014, from http://www.fondazioneidra.it/Pattodeisindaci/

Foote, K., & Lynch, M. (1995). Geographic Information Systems as an integrating technology: context, concepts, and definitions. Retrieved January 15, 2014, from http://www.colorado.edu/geography/gcraft/notes/intro/intro.html

Forsberg, G. (2000). Biomass energy transport Analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy, 19(1), 17–30. doi:10.1016/S0961-9534(00)00020-9

Frame, B., & O’Connor, M. (2011). Integrating valuation and deliberation: the purposes of sustainability assessment. Environmental Science & Policy, 14(1), 1–10. doi:10.1016/j.envsci.2010.10.009

Francescato, V., Paniz, A., Negrin, M., Antonini, E., & Zuccoli Bergomi, L. (2012). Legna Cippato e Pellet. (AIEL, Ed.) (III.). Legnaro - Padova, Italy. Retrieved from www.biomasstradecentre2.eu

Francescato, V., & Zuccoli Bergomi, L. (2008). Wood fuels handbook (English ed., p. 83). Legnaro - Padova, Italy: AIEL. Retrieved from www.biomasstradecentres.eu

Frombo, F., Minciardi, R., Robba, M., & Sacile, R. (2009). A decision support system for planning biomass-based energy production. Energy, 34(3), 362–369. doi:10.1016/j.energy.2008.10.012

Gamborg, C., Millar, K., Shortall, O., & Sandøe, P. (2011). Bioenergy and Land Use: Framing the Ethical Debate. Journal of Agricultural and Environmental Ethics, 25(6), 909–925. doi:10.1007/s10806-011-9351-1

Garrod, B., Wornell, R., & Youell, R. (2006). Re-conceptualising rural resources as countryside capital: The case of rural tourism. Journal of Rural Studies, 22(1), 117–128. doi:10.1016/j.jrurstud.2005.08.001

Gasparatos, A., El-Haram, M., & Horner, M. (2008). A critical review of reductionist approaches for assessing the progress towards sustainability. Environmental Impact Assessment Review, 28(4-5), 286–311. doi:10.1016/j.eiar.2007.09.002

Genon, G., Torchio, M., Poggio, a, & Poggio, M. (2009). Energy and environmental assessment of small district heating systems: Global and local effects in two case-studies. Energy Conversion and Management, 50(3), 522–529. doi:10.1016/j.enconman.2008.11.010

Glavič, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. Journal of Cleaner Production, 15(18), 1875–1885. doi:10.1016/j.jclepro.2006.12.006

Gómez, A., Zubizarreta, J., Rodrigues, M., Dopazo, C., & Fueyo, N. (2010). An estimation of the energy potential of agro-industrial residues in Spain. Resources, Conservation and Recycling, 54(11), 972–984. doi:10.1016/j.resconrec.2010.02.004

Gough, A. D., Innes, J. L., & Allen, S. D. (2008). Development of common indicators of sustainable forest management. Ecological Indicators, 8(5), 425–430. doi:10.1016/j.ecolind.2007.03.001

Gough, C., Castells, N., & Funtowicz, S. (1998). Integrated Assessment: an emerging methodology for complex issues. Environmental Modeling and Assessment 3, 3, 19–29.

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2013). Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. Journal of Cleaner Production. doi:10.1016/j.jclepro.2013.06.046

Grumbine, R. E. (1994). What is Ecosystem Management? Conservation Biology, 8(1), 27–38.

GSE. (2008). Biomasse. Retrieved December 20, 2012, from http://www.gse.it/it/EnergiaFacile/guide/Energiaelettrica/Biomasse/Pages/default.aspx

GSE. Incentivazione della produzione di energia termica da impianti a fonti rinnovabili ed interventi di efficienza energetica di piccole dimensioni - Regole Applicative del DM 28.12.2012 (2013). Italy. Retrieved from http://www.gse.it/it/Conto Termico/

Guldin, R. W., Parrotta, J. A., & Hellström, E. (2005). Working Effectively at the Interface of Forest Science and Forest Policy. IUFRO Occasional Paper No. 17. Vienna, Austria. Retrieved from http://www.ibcperu.org/doc/isis/9115.pdf

Haartveit, E. Y., Kozak, R. A., & Maness, T. C. (2004). Supply Chain Management Mapping for the Forest Products Industry : Three Cases from Western Canada. Journal of Forest Products Business Research, 1(1), 1–30.

Hellrigl, B. (2006). Elementi di Xiloenergetica. (AIEL, Ed.). Padova, Italy: AIEL.

Helm, D. (2002). Energy policy: security of supply, sustainability and competition. Energy Policy, 30(3), 173–184. doi:10.1016/S0301-4215(01)00141-0

Hickey, G. M., & Innes, J. L. (2005). Scientific review and gap analysis of sustainable forest management criteria and indicators initiatives (p. 64). Retrieved from http://www.forrex.org/sites/default/files/forrex_series/FS17.pdf

Hilborn, R., Walters, C. J., & Ludwig, D. (1995). Sustainable exploitation of renewable resources. Annual Review of Ecology and Systematics, 26, 45–67.

Holling, C. S. (1978). Adaptive environmental assessment and management. (I. I. for A. S. Analysis, Ed.). International Institute for Applied Systems Analysis.

IINAS, EFI, & JR. (2014). Forest biomass for energy in the EU : current trends, carbon balance and sustainable potential. Darmstadt, Madrid, Joensuu, Graz. Retrieved from http://www.eeb.org/EEB/?LinkServID=FE1EAF33-5056-B741-DBEF3F46BC26A1E1

IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories. (T. I. P. on C. C. (IPCC), Ed.) (Vol. 2, pp. 1–2). Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC.

ISTAT. (2012). Agricolture and Livestock. Retrieved August 08, 2012, from http://agri.istat.it/sag_is_pdwout/jsp/NewDownload.jsp

ISTAT. (2014). Lombardia - Regional Data. Retrieved March 11, 2014, from http://www.istat.it/it/lombardia

ITABIA. (2008). Goals of Bioenergy in Italy - Key Elements for 2020 Objectives (p. 87). Rome, Italy. Retrieved from http://www.itabia.it/rapporto 2008/itabia_ing/stampa/InfoUtStampa.pdf

Italian Ministry for Economic Development. (2010). Italian National Renewable Energy Action Plan. Rome, Italy.

Italian Ministry for Economic Development. (2012). DM 15.03.2012 - Burden Sharing. Rome, Italy.

Italian Ministry of Agricolture. (2012). Piano della filiera legno 2012-14. Rome, Italy. Retrieved from http://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/5082

Italian Ministry of Environment. (2012). Inventari e proiezioni nazionali delle emissioni. Retrieved March 05, 2013, from http://www.minambiente.it/pagina/inventari-e-proiezioni-nazionali-delle-emissioni

Italian Termotechnical Committee. (2011). Guidelines for the development of supporting tools for bio-energy initiatives. Retrieved from http://www.makeitbe.eu

Jankowski, N., Schmidl, C., Marr, I. L., Bauer, H., & Puxbaum, H. (2008). Comparison of methods for the quantification of carbonate carbon in atmospheric PM10 aerosol samples. Atmospheric Environment, 42(34), 8055–8064. doi:10.1016/j.atmosenv.2008.06.012

Janse, G., & Konijnendijk, C. C. (2007). Communication between science, policy and citizens in public participation in urban forestry—Experiences from the Neighbourwoods project. Urban Forestry & Urban Greening, 6(1), 23–40. doi:10.1016/j.ufug.2006.09.005

Jumppanen, J., Kurttila, M., Pukkala, T., & Uuttera, J. (2003). Spatial harvest scheduling approach for areas involving multiple ownership. Forest Policy and Economics, 5(1), 27–38. doi:10.1016/S1389-9341(02)00044-8

Kajikawa, Y. (2008). Research core and framework of sustainability science. Sustainability Science, 3(2), 215–239. doi:10.1007/s11625-008-0053-1

Kasprzyk, J. R., Nataraj, S., Reed, P. M., & Lempert, R. J. (2013). Many objective robust decision making for complex environmental systems undergoing change. Environmental Modelling & Software, 42, 55–71. doi:10.1016/j.envsoft.2012.12.007

Kates, R. W., Clark, W. C., Corell, R., Hall, M., Jaeger, C. C., Lowe, I., … Svedin, U. (2001). Sustainability Science. Retrieved from http://papers.ssrn.com/paper.taf?abstract_id=257359

Keegan, D., Kretschmer, B., Elbersen, B., & Panoutsou, C. (2013). Cascading use : a systematic approach to biomass beyond the energy sector. Biofuels, Bioproducts and Biorefining, 7(2), 193–206. doi:10.1002/bbb

Keen, P. (1980). Decision Support Systems: a research perspective. Retrieved from http://dspace.mit.edu/handle/1721.1/47172

Kersten, G. E., Mikolajuk, Z., & Gar-On Yeh, A. (2000). Decision support systems for sustainable development: a resource book of methods and applications. (Springer, Ed.) (p. 423). Springer.

Kilkenny, M. (1998). Transport Costs and Rural Development. Journal of Regional Science, 38(2), 293–312. doi:10.1111/1467-9787.00093

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: building a new discipline. Sustainability Science, 1(1), 1–6. doi:10.1007/s11625-006-0007-4

Koukkari, H., & Nors, M. (2009). Life Cycle Assessment of Products and Technologies. VTT - Technical Research Centre of Finland.

Kukkonen, J., Pohjola, M., Ssokhi, R., Luhana, L., Kitwiroon, N., Fragkou, L., … Havardslordal, L. (2005). Analysis and evaluation of selected local-scale PM air pollution episodes in four European cities: Helsinki, London, Milan and Oslo. Atmospheric Environment, 39(15), 2759–2773. doi:10.1016/j.atmosenv.2004.09.090

Kurttila, M. (2001). The spatial structure of forests in the optimization calculations of forest planning Ð a landscape ecological perspective. Forest Ecology and Management, 142, 129–142.

Kuvan, Y. (2005). The use of forests for the purpose of tourism: the case of Belek Tourism Center in Turkey. Journal of Environmental Management, 75, 263–274. doi:10.1016/j.jenvman.2005.01.003

Lafleur, M. C. C., & Fraanje, P. J. (1997). Towards sustainable use of the renewable resource wood in the Netherlands — a systematic approach. Resources, Conservation and Recycling, 20(1), 19–29. doi:10.1016/S0921-3449(97)01195-6

Lamarque, P., Quétier, F., & Lavorel, S. (2011). The diversity of the ecosystem services concept and its implications for their assessment and management. Comptes Rendus Biologies, 334(5-6), 441–9. doi:10.1016/j.crvi.2010.11.007

Larkin, P. (1977). An epitaph for the concept of maximum Sustained Yield. Transactions of the American Fisheries Society, 106(1), 1–11.

Larsen, H. N., & Hertwich, E. G. (2009). The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. Environmental Science & Policy, 12(7), 791–798. doi:10.1016/j.envsci.2009.07.010

Larsen, H. N., & Hertwich, E. G. (2010). Identifying important characteristics of municipal carbon footprints. Ecological Economics, 70(1), 60–66. doi:10.1016/j.ecolecon.2010.05.001

Laurent, A., Olsen, S. I., & Hauschild, M. Z. (2012). Limitations of carbon footprint as indicator of environmental sustainability. Environmental Science & Technology, 46(7), 4100–8. doi:10.1021/es204163f

Lindner, M., Suominen, T., Palosuo, T., Garcia-Gonzalo, J., Verweij, P., Zudin, S., & Päivinen, R. (2010). ToSIA—A tool for sustainability impact assessment of forest-wood-chains. Ecological Modelling, 221(18), 2197–2205. doi:10.1016/j.ecolmodel.2009.08.006

Lindner, M., Werhahn-Mees, W., Suominen, T., Vötter, D., Zudin, S., Pekkanen, M., … Pizzirani, S. (2012). Conducting sustainability impact assessments of forestry-wood chains: examples of ToSIA applications. European Journal of Forest Research, 131(1), 21–34. doi:10.1007/s10342-011-0483-7

Liu, Y., Gupta, H., Springer, E., & Wagener, T. (2008). Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. Environmental Modelling & Software, 23(7), 846–858. doi:10.1016/j.envsoft.2007.10.007

Lombardy Region. (2006). Rural Development Programme 2007-2013. Milano, Italy.

Lombardy Region. (2007). Dati di emissione INEMAR. Retrieved May 05, 2011, from http://www.inemar.eu/xwiki/bin/view/Inemar/WebHome

Lombardy Region. (2008). Energy Action Plan. Milano, Italy. Retrieved from http://sirena.finlombarda.it/sirena/download/Piano_Azione_Energia2008.pdf

Lombardy Region. (2009). Technologies Strategic Plan. Milano, Italy. Retrieved from http://sirena.finlombarda.it/sirena/download/Piano_Strategico_Tecnologie.pdf

Lombardy Region. (2010). Sustainable Lombardy Plan (pp. 0–87). Milano, Italy: Lombardy Region. Retrieved from http://sirena.finlombarda.it/sirena/download/PLS.pdf

Lombardy Region. (2014a). I tipi forestali della Lombardia. Retrieved April 30, 2014, from http://www.agricoltura.regione.lombardia.it/cs/Satellite?c=Redazionale_P&childpagename=DG_Agricoltura/Detail&cid=1213596968534&packedargs=NoSlotForSitePlan=true&menu-to-render=1213597715124&pagename=DG_AGRWrapper

Lombardy Region. (2014b). SIRENA - Regional Informative System for Environment and Energy. Retrieved March 11, 2014, from http://sirena.finlombarda.it/sirena/index.jsp

Lopes, J. a. P., Hatziargyriou, N., Mutale, J., Djapic, P., & Jenkins, N. (2007). Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. Electric Power Systems Research, 77(9), 1189–1203. doi:10.1016/j.epsr.2006.08.016

Magagnotti, N. (2012). Analisi dei cantieri di cippatura in merito ad aspetti operativi e di salvaguardia degli operatori. Università di Bologna.

Mann, S. (2011). Sustainable lens: a visual guide. (N. Studio, Ed.) (p. 206). Dunedin.

Mantau, U., Saal, U., Prins, K., Steierer, F., Lindner, M., Verkek, H., … Anttila, P. (2010). EUwood - Real potential for changes in growth and use of EU forests. Final report. (p. 160). Retrieved from http://ec.europa.eu/energy/renewables/studies/doc/bioenergy/euwood_final_report.pdf

Marra, M., Castellani, V., Mirabella, N., Sala, S., Negri, M., & Guercini, S. (2011). Technological Characteristics and Sustainability Assessment of Short Forestry-Wood Chain for Alpine Hardwood Furniture. In 3rd International Scientific Conference on Hardwood Processing (ISCHP32011) (pp. 147–155). Blacksburg, Virginia, USA.

Martire, S., Castellani, V., & Sala, S. (2011). Sustainability assessment of forest biomass supply chain at local scale: carrying capacity of the system for energy valorisation. Setac Europe XXI Annual Meeting. Retrieved from http://boa.unimib.it/handle/10281/23915

Matthies, M., Giupponi, C., & Ostendorf, B. (2007). Environmental decision support systems: Current issues, methods and tools. Environmental Modelling & Software, 22(2), 123–127. doi:10.1016/j.envsoft.2005.09.005

MCPFE. Declaration of the Second Ministerial Conference on the Protection of Forests in Europe (1993). Helsinki. Retrieved from http://www.foresteurope.org/docs/MC/MC_helsinki_gral_declaration.pdf

Mielesi, A. (2012). Situazione globale delle imprese boschive della Regione Lombardia. Università di Milano.

Montanari, R. (2004). Environmental efficiency analysis for enel thermo-power plants. Journal of Cleaner Production, 12(4), 403–414. doi:10.1016/S0959-6526(03)00015-5

Morrison-Saunders, A., & Pope, J. (2013). Conceptualising and managing trade-offs in sustainability assessment. Environmental Impact Assessment Review, 38, 54–63. doi:10.1016/j.eiar.2012.06.003

Murray, F. (2013). The changing winds of atmospheric environment policy. Environmental Science & Policy, 29, 115–123. doi:10.1016/j.envsci.2013.02.005

Myllyviita, T. (2013). Sustainability assessment of forest resources – tools for a problem-orientated approach. Dissertationes Forestales (Vol. 2013, p. 1). doi:10.14214/df.168

Myllyviita, T., Hujala, T., Kangas, A., & Leskinen, P. (2011). Decision Support in Assessing the Sustainable Use of Forests and Other Natural Resources - A Comparative Review. The Open Forest Science Journal, 4, 24–41.

Nasi, R., Wunder, S., & Campos A., J. J. (2002). Forest ecosystem services: can they pay our way out of deforestation? Higher Education. Costa Rica. Retrieved from http://www.mendeley.com/research/forest-ecosystem-services-can-they-pay-our-way-out-of-deforestation/

Nerman, A. (2000). A View of How the Internet Can Influence A View of How the Internet Can Influence the. Luleå University of Technology.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., & Olsson, L. (2007). Categorising tools for sustainability assessment. Ecological Economics, 60(3), 498–508. doi:10.1016/j.ecolecon.2006.07.023

NOAA. (2013). Carbon Dioxide at NOAA’s Mauna Loa Observatory reaches new milestone: Tops 400 ppm. ESRL News. Retrieved July 01, 2013, from http://www.esrl.noaa.gov/news/2013/CO2400.html

Noon, C. E., & Daly, M. J. (1996). GIS-based biomass resource assessment with BRAVO. Biomass and Bioenergy, 10, 101–109.

Nussbaum, R., Bass, S., Morrison, E., & Speechly, H. (1996). Sustainable Forest Management: An analysis of principles, criteria and standards. Towards a Sustainable Paper Cycle. Retrieved from http://pubs.iied.org/pubs/display.php?o=8065IIED

OECD. (2009). The Bioeconomy to 2030: designing a policy agenda (p. 322).

Oliveri, S. (2010). Un nuovo metodo per la stima del potenziale di biomasse forestali su scala regionale . Applicazione al territorio lombardo. In Atti 14a Conferenza Nazionale ASITA - 9-12 novembre 2010 (pp. 1397–1402). Brescia, Italy.

Päivinen, R., Lindner, M., Rosén, K., & Lexer, M. J. (2010). A concept for assessing sustainability impacts of forestry-wood chains. European Journal of Forest Research, 131(1), 7–19. doi:10.1007/s10342-010-0446-4

Palosuo, T., Suominen, T., Werhahn-Mees, W., Garcia-Gonzalo, J., & Lindner, M. (2010). Assigning results of the Tool for Sustainability Impact Assessment (ToSIA) to products of a forest-wood-chain. Ecological Modelling, 221(18), 2215–2225. doi:10.1016/j.ecolmodel.2010.03.020

Paris, M. (2013, January). Conflitto Stato-Regioni: una causa ogni tre giorni. Il Sole 24 ORE. Retrieved from http://www.ilsole24ore.com/art/notizie/2013-01-31/conflitto-statoregioni-causa-ogni-104556.shtml?uuid=AbD83sPH

Pastorello, C. (2008). Estimation of residential wood combustion in the Lombardy Region. Lombardy Region and JRC European Commission.

Pedroli, B., Elbersen, B., Frederiksen, P., Grandin, U., Heikkilä, R., Krogh, P. H., … Spijker, J. (2013). Is energy cropping in Europe compatible with biodiversity? – Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. Biomass and Bioenergy, 55, 73–86. doi:10.1016/j.biombioe.2012.09.054

Pennati, S., Castellani, V., & Sala, S. (2009). CO2 budget estimation and mapping at a local scale. Ecosytems and Sustainable Development VII, 12. doi:10.2495/ECO090031

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., & D'haeseleer, W. (2005). Distributed generation: definition, benefits and issues. Energy Policy, 33(6), 787–798. doi:10.1016/j.enpol.2003.10.004

Perlik, M., & Messerli, P. (2004). Urban Strategies and Regional Development in the Alps. Mountain Research and Development, 24(3), 215–219. doi:10.1659/0276-4741(2004)024[0215:USARDI]2.0.CO;2

Peter Hall, J. (2001). Criteria and indicators for sustainable forest management. Environmental Monitoring and Assessment, 67, 109–119. Retrieved from http://books.google.com/books?hl=en&lr=&id=dYL5Jx7vmdkC&oi=fnd&pg=PR9&dq=Criteria+and+indicators+of+sustainable+forest+management&ots=TJFyqvpqu_&sig=kOOjcZ3bCj7jxLUr1TOq-OGNH8o

Pettenella, D., & Andrighetto, N. (2011). Le biomasse legnose a fini energetici in italia: uno sleeping giant? Energy, 1–10.

Pezzoli, K. (1997). Sustainable development: a transdisciplinary overview of the literature. Journal of Environmental Planning and Management, 40(5), 549–574.

Piazzalunga, a., Belis, C., Bernardoni, V., Cazzuli, O., Fermo, P., Valli, G., & Vecchi, R. (2011). Estimates of wood burning contribution to PM by the macro-tracer method using tailored emission factors. Atmospheric Environment, 45(37), 6642–6649. doi:10.1016/j.atmosenv.2011.09.008

Pimentel, D., Mcnair, M., Buck, L., Pimentel, M., & Kamil, J. (1997). The Value of Forests to World Food Security. Human Ecology, 25(1), 91–120.

Pope, J., Annandale, D., & Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. Environmental Impact Assessment Review, 24(6), 595–616. doi:10.1016/j.eiar.2004.03.001

Power, D. J. (2007). A Brief History of Decision Support Systems. Retrieved March 30, 2014, from http://dssresources.com/history/dsshistory.html

Provincia di Como. (2011). Piano energetico della Provincia di Como - II Documento di aggiornamento. Como, Italy. Retrieved from http://www.provincia.como.it/temi/territorio/ambiente/aria-energia/energia/

Puettmann, K. J., Coates, K. D., & Messier, C. C. (2008). A critique of silviculture: managing for complexity. (Island Press, Ed.).

Pykalainen, J., Pukkala, T., & Kangas, J. (2001). Alternative priority models for forest planning on the landscape level involving multiple ownership. Forest Policy and Economics, (2), 293–306.

Ramaswami, A., Chavez, A., Ewing-Thiel, J., & Reeve, K. E. (2011). Two approaches to greenhouse gas emissions foot-printing at the city scale. Environmental Science & Technology, 45(10), 4205–6. doi:10.1021/es201166n

Rametsteiner, E., Pulzl, H., & Puustjarvi, E. (2006). D1.1.1 Draft FWC review of existing sustainability indicator concepts and sustainability indicator sets of relevance for the FWC, review of potential indicators for selection and their assessment. EFORWOOD Project Consortium.

Regione Liguria. (2011). Programma Marittimo - Progetto Biomass (pp. 1–57).

Remedio, E. M., & Domac, J. U. (2003). Socio-economic analysis of bioenergy systems: a focus on employment (p. 53). Retrieved from http://www.globalbioenergy.org/bioenergyinfo/sort-by-date/detail/en/c/10478/

Repo, A., Tuomi, M., & Liski, J. (2011). Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues. GCB Bioenergy, 3(2), 107–115. doi:10.1111/j.1757-1707.2010.01065.x

Reuters. (2014). Swiss government will draft law on immigration curbs by year-end. Reuters. Retrieved February 02, 2014, from http://www.reuters.com/article/2014/02/12/us-swiss-immigration-idUSBREA1B15L20140212

Riba, L., Piazzi, M., Tresso, G., & Bussone, M. (2012). La filiera bosco legno energia nelle valli Chisone e Germanasca (p. 148). Cuneo, Italy. Retrieved from http://www.uncem.piemonte.it/upload/162_10/UNCEM_STUDIO_FILIERA_LEGNO_VALLI_CHISONE_GERMANASCA_rid.pdf

Rotmans, J. (2006). Tools for Integrated Sustainability Assessment: A two-track approach. The Integrated Assessment Journal, 6(4), 35–57.

Sacchelli, S., Fagarazzi, C., & Bernetti, I. (2013). Economic evaluation of forest biomass production in central Italy: A scenario assessment based on spatial analysis tool. Biomass and Bioenergy, 53, 1–10. doi:10.1016/j.biombioe.2012.11.026

Sacramento-Rivero, J. C., Romero-Bquedanoa, G., & Blanco-Rosete, S. (2009). Criteria for the selection of sustainability indicators in Bio-refineries evaluation. In Easy Eco Conference "Stakeholder perspective in evaluating sustainable development." Budapest.

Sala, S., & Castellani, V. (2010). Decision Support System for sustainable forest management based on Life Cycle Assessment. In S. Europe (Ed.), From simplified LCA to advanced LCA. Poznan, Poland. doi:10.1016/j.jenvman.2009.06.018.

Sala, S., Meli, M., & Ciapponi, K. (2009). Progetto CO2ntare. Milano, Italy. Retrieved from http://boa.unimib.it/handle/10281/24527#.UuJvqtL8K9I

Schäffeler, U., & Keller, M. (2008). Non-road fuel consumption and pollutant emissions. Study for the period from 1980 to 2020 (Environmen., p. 171). Bern: Federal Office for the Environment. Retrieved from www.environment-switzerland.ch/uw-0828-e

Schlamadinger, B., Spitzer, J., Kohlmaier, G. H., & Lüdeke, M. (1995). Carbon balance of bioenergy from logging residues. Biomass and Bioenergy, 8(4), 221–234.

Schmidl, C., Marr, I. L., Caseiro, A., Kotianová, P., Berner, A., Bauer, H., … Puxbaum, H. (2008). Chemical characterisation of fine particle emissions from wood stove combustion of common woods growing in mid-European Alpine regions. Atmospheric Environment, 42(1), 126–141. doi:10.1016/j.atmosenv.2007.09.028

Schultink, G. (2000). Critical environmental indicators: performance indices and assessment models for sustainable rural development planning. Ecological Modelling, 130, 47–58.

Servizio studi del Senato. (2011). Il contenzioso Stato-regioni sull'energia. Rome, Italy. Retrieved from http://www.senato.it/documenti/repository/dossier/studi/2011/Dossier_279.pdf

Spinelli, R., & Magagnotti, N. (2011). The effects of introducing modern technology on the financial, labour and energy performance of forest operations in the Italian Alps. Forest Policy and Economics, 13(7), 520–524. doi:10.1016/j.forpol.2011.06.009

Spinelli, R., Magagnotti, N., & Nati, C. (2009). Options for the Mechanized Processing of Hardwood Trees. International Journal of Forest Engineering, 20(1), 39–44.

Spurr, S. (1964). Forest ecology. (Wiley, Ed.) (p. 352). Wiley.

Stupak, I., Lattimore, B., Titus, B. D., & Tattersall Smith, C. (2010). Criteria and indicators for sustainable forest fuel production and harvesting: A review of current standards for sustainable forest management. Biomass and Bioenergy, 35(8), 3287–3308. doi:10.1016/j.biombioe.2010.11.032

Sucic, B. (2011). Integration of sustainability into overall energy policy. Kranj: Regional Development Agency of Gorenjska.

Sugumaran, R., & Degroote, J. (2010). Spatial Decision Support Systems: principles and practices. (CRC Press, Ed.) (p. 507).

Tansley, A. G. (1935). The Use and Abuse of Vegetational Concepts and Terms. Ecology, 16(3), 284–307.

Tedeschi, V., Federici, S., Zenone, T., Facciotto, G., Vergante, S., Matteucci, G., … Suefert, G. (2005). Greenhouses gases balance of two poplar stands in Italy: a comparison of a short rotation coppice and a standard rotation plantation. In XIV European Conference & Exhibition, Biomass for Energy, Industry and Climate Protection.

Tenerelli, P., & Carver, S. (2012). Multi-criteria, multi-objective and uncertainty analysis for agro-energy spatial modelling. Applied Geography, 32(2), 724–736. doi:10.1016/j.apgeog.2011.08.013

Toniolo, A. R. (1937). Studies of depopulation in the mountains of Italy. Geographical Review, 27(3), 473–477.

Torchio, M. F., Genon, G., Poggio, A., & Poggio, M. (2009). Merging of energy and environmental analyses for district heating systems. Energy, 34(3), 220–227. doi:10.1016/j.energy.2008.01.012

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity -€ " ecosystem service management. Ecology Letters, 8(8), 857–874. doi:10.1111/j.1461-0248.2005.00782.x

Tsoulfas, G. T., & Pappis, C. P. (2008). A model for supply chains environmental performance analysis and decision making. Journal of Cleaner Production, 16(15), 1647–1657. doi:10.1016/j.jclepro.2008.04.018

Turton, H., & Barreto, L. (2006). Long-term security of energy supply and climate change. Energy Policy, 34(15), 2232–2250. doi:10.1016/j.enpol.2005.03.016

UK Department of Energy and Climate Change. (2011). Estimated impacts of energy and climate change policies on energy prices and bills. London.

UNECE. (2011). Joint Wood Energy Enquiry - Forestry and Timber. Joint Wood Energy Enquiry 2011. Retrieved December 03, 2013, from http://www.unece.org/forests/jwee.html

UNFCCC. (2006). Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session, held at Montreal from 28 November to 10 December 2005. Addendum. Part two: Action taken by the Conference of the Parties serving as t (pp. 1–100). Geneva, Swiss. Retrieved from http://unfccc.int/documentation/documents/advanced_search/items/6911txt.php?priref=600003821&

UNFCCC. (2014a). Doha Amendment. Retrieved January 13, 2014, from http://unfccc.int/kyoto_protocol/doha_amendment/items/7362.php

UNFCCC. (2014b). Kyoto Protocol. Retrieved January 15, 2014, from http://unfccc.int/kyoto_protocol/items/2830.php

UNFCCC. (2014c). Reporting and accounting of LULUCF activities under the Kyoto Protocol. Retrieved June 03, 2014, from http://unfccc.int/methods/lulucf/items/4129.php

United Nations. (1987). Report of the World Commission on Environment and Development: Our Common Future.

US EIA. (2011). Voluntary Reporting of Greenhouse Gases Program - Electricity Factors. Retrieved December 12, 2012, from http://www.eia.gov/oiaf/1605/coefficients.html

US EPA. (2006). Solid Waste Management and Greenhouse Gases - Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM). Retrieved from http://epa.gov/epawaste/conserve/tools/warm/SWMGHGreport.html

Verheem, R. (2002). Recommendations for sustainability assessment in the Netherlands - EIA in the Netherlands: views from the Commission for EIA in 2002 (pp. 9–14). Utrecht, the Netherlands: Commission for EIA. Environmental Impact Assessment in the Netherlands.

Verkerk, P. J., Anttila, P., Eggers, J., Lindner, M., & Asikainen, A. (2011). The realisable potential supply of woody biomass from forests in the European Union. Forest Ecology and Management, 261(11), 2007–2015. doi:10.1016/j.foreco.2011.02.027

Viana, H., Cohen, W., & Lopes, D. (2010). Assessment of forest biomass for use as energy. GIS-based analysis of geographical availability and locations of wood-fired power plants in Portugal. Applied Energy, 87(8), 2551–2560. doi:10.1016/j.apenergy.2010.02.007

Vidal, N., Kozak, R., & Cohen, D. (2005). Chain of custody certification: an assessment of the North American solid wood sector. Forest Policy and Economics, 7(3), 345–355. doi:10.1016/S1389-9341(03)00071-6

Viglia, S., Nienartowicz, A., & Franzese, P. P. (2014). Integrating Environmental Accounting. Life Cycle and Ecosystem Services Assessment. Journal of Environmental Accounting and Management, 1(4), 307–319. doi:10.5890/JEAM.2013.11.001

Voivontas, D., Assimacopoulos, D., & Koukios, E. G. G. (2001). Aessessment of biomass potential for power production: a GIS based method. Biomass and Bioenergy, 20(2), 101–112. doi:10.1016/S0961-9534(00)00070-2

Weitz, K. a., Thorneloe, S. a., Nishtala, S. R., Yarkosky, S., & Zannes, M. (2002). The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States. Journal of the Air & Waste Management Association, 52(9), 1000–1011. doi:10.1080/10473289.2002.10470843

Wiedmann, T. (2009). A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecological Economics, 69(2), 211–222. doi:10.1016/j.ecolecon.2009.08.026

Zanchi, G., Pena, N., & Bird, N. (2012). Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel. GCB Bioenergy, 4(6), 761–772. doi:10.1111/j.1757-1707.2011.01149.x