PRENOVA PROIZVODNE TOVARNE V ENERGETSKI OBRAT NA LESNO BIOMASO

REDEVELOPMENT OF A MANUFACTURING FACTORY IN AN ENERGY GENERATION PLANT WITH WOOD BIOMASS

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UDK: 528:502.174.3
Klasifikacija prispevka po COBISS.SI: 1.03
Prispelo: 14. 11. 2022
Sprejeto: 13. 3. 2023

DOI: 10.15292/geodetski-vestnik.2023.01.58-69
OTHER SCIENTIFIC ARTICLES
Received: 14. 11. 2022
Accepted: 13. 3. 2023

SI | EN

IZVLEČEK

Proizvodno podjetje, ki zaradi gospodarske krize uporablja zastarele procese in tehnologije, ocenjuje možnosti za preusmeritev v energetiko. V prispevku je predstavljena skrbna analiza lokalnih virov na goratem območju Karnija (Italija) na podlagi ugotavljanja razpoložljive lesne biomase z instrumenti geografskega informacijskega sistema (GIS). Biomaso je mogoče izkoriščati v obratih za proizvodnjo energije in pomeni dobro možnost z visoko stopnjo dobička, izkorišča tudi prednosti tehnologije daljinskega ogrevanja. Pri presojanju tehnične izvedljivosti je bila za oceno energetskih potreb uporabljena tudi numerična regionalna kartografija, medtem ko na ekonomsko izvedljivost močno vplivajo lokalni predpisi o javnih spodbudah, vzpostavljenih za doseganje okoljskih ciljev, določenih z mednarodnimi pogodbami. Po drugi strani pa je okoljska trajnost takšnih elektrarn pogosto pozitivna, tudi če je povezana z lokalnim kontekstom. Posledično zmanjšanje emisij CO_2 je pomembno, če je lokacija kotlovnice pravilno določena, da se optimizira dobavna veriga od gozda do obrata.

ABSTRACT

A manufacturing company, which uses obsolete processes and technologies, due to the economic crisis, is evaluating a possible conversion to the energy sector. The paper presents a careful analysis of local resources in the mountain area of Carnia (Italy), identifying the available wood biomass, using Geographic Information System (GIS) instruments. The biomass can be exploited in energy generation plants and represents, a good option with a high margin of profit and takes advantage of the district heating technology. The technical feasibility also used numeric regional cartography to assess the energy needs, while the economic feasibility is highly influenced by local regulations on public incentives, established to reach the environmental goals set by the international treaties. On the other hand, the environmental sustainability of these plants is often positive, even if related to the local context. The consequent reduction of CO_2 emissions is relevant, as long as the location of the boiler room is correctly identified in order to optimize the supply chain from the forests to the plant.

KLJUČNE BESEDE

daljinsko ogrevanje, soproizvodnja, lesna biomasa, trajnost, GIS

KEY WORDS

district heating, cogeneration, wood biomass, sustainability, GIS

1 INTRODUCTION

The financial crisis that began in 2007, which involved quite all the industrialized Countries, the reduction of the Italian Gross National Product and the Industrial Production in the period 2013-2015, further aggravated by the pandemic crisis, mainly involved the "marginal areas", which already had an "inability to attract people, business activities, and capital investments" (Battino and Lampreu, 2019). The analysed area responds to these definitions, both for its peripheral position and for economic development, not yet including a high-profit and large-scale tourism sector. The Green Deal and the European Cohesion Policy, especially in the energy sector and in the exploitation of renewable sources, which are part of the goal of the Europe 2020 strategy (Chodkowska-Miszczuk, et al., 2016) offer alternative investment opportunities to retrain the companies affected by the crisis or to develop new ones.

For the redevelopment of industrial activity, the availability of close renewable sources can present a good investment opportunity and the greater attention to the environmental and sustainability aspects has produced numerous regulations, protocols and agreements to reduce pollutant emissions and the anthropic contribution to climate change. Every single country has specific results to reach, accordingly with the Kyoto Protocol and the Climate and Energy Protocol 20 20 20. Furthermore, in December 2019, "The European Green Deal" was announced; it represents a roadmap for making the EU's economy sustainable fixing different goals including the clean energy production and pollution strong reduction to reach zero net emission of greenhouse gasses by 2050. This policy is then supported by the National Recovery and Resilience Plan (#NextGenerationItalia), where in "Mission 2: Green Revolution and ecological transition", investments will be made in Green Communities for the sustainable and resilient development of rural and mountain areas, which they intend to exploit, in a balanced way, the main resources at their disposal. This can be achieved by supporting the development, financing and implementing the sustainable development plans from an energetic, environmental, economic and social point of view, with particular reference to the production of energy from local renewable sources (e.g. biomass and cogeneration).

The sustainable exploitation of biomasses for energy production depends on several factors: on one hand, it involves a reduction of GHG emissions, but on the other hand, it can cause a significant increase of particulates (PM10) and NOx (Jeswani et al, 2020). Furthermore, to evaluate the environmental improvement the different existing plants must be considered together with the currently used fuel: the exploitation of carbonized biomass for a "virtual district heating network" can substitute traditional fuel with economic, environmental, and social benefits (Drobnik et al, 2019). The exploitation of different types of biomasses not only implies a different rate of pollutant emissions, but also different supporting activities, like collection and transport, which must be evaluated to assess the environmental sustainability (Fan et al, 2021). Focusing on wood biomasses, several authors highlight the role of the exploitation of residues of forest industry: it reduces the land requirements to produce fuelwood (Syrbe et al, 2022), the GHG emissions (Giuntoli et al, 2021), and has a great impact on the overall availability of wood biomass (del Giudice et al, 2022). The exploitation of wood biomasses represents not only a via to the reduction of fossil fuel consumption but also a good option from the economic point of view for developing countries, which can upgrade their rural activities (Ribeiro et al, 2021). To achieve such results the integration with a district heating system shows good performance in combination with a short supply chain, as shown in a case study in northern Italy (Nikodinoska et al, 2018), but to guarantee the sustainability in a long term period is necessary a well-designed forest management system (Lee and Ha, 2022).

Decision Support Systems (DSS) based on GIS (Geographic Information Systems) can be used to identify the availability of renewable resources and the best plants location for their exploitation. Efficient analysis on transport networks must include road's capacity and their slope, while the optimization process involves several variables (e.g. plant capacity to minimize overall costs (Höhn, et al., 2014), management of the forests for their maintenance through the years (Sánchez-García, et al., 2015), choice of where to localize certain operations, like chipping, which can be performed on-site or near the final plant (Akhtari, et al., 2014) and (Tommasi, et al., 2018).

The exploitation of forest biomass is better suited to a district heating plant, both for economic and environmental aspects (Fagarazzi, et al., 2014), although other configurations are also possible (e.g. cogeneration).

This paper analyses the case study of a redevelopment and conversion project of a production hall into an energy generation system connected to a district heating plant. After acquiring the useful data, the technical, economic feasibility and environmental sustainability are presented. To calculate the required thermal power, the GIS methodology was applied to analyse the metric data of the building units using the numeric regional technical map, which provides the hearable volumes, implemented through the AutoCAD MAP 3D software. The impact of the change in public investment incentives was also highlighted.

2 MATERIALS AND METHODS

The existing plant is located in the peripheral industrial area of Villa Santina (Udine) in an area mainly covered by beech forests (overall extension of Carnia is about 1,200 km2 and its population is close to 40,000 inhabitants), but with limited forestry exploitation. Villa Santina was widely devastated by the 1976 earthquake and the reconstruction had to respect high standards about its anti-seismic performance, but not thermal ones. The plant encountered the economic and production crisis and any redevelopments for a new manufacturing activity had not revealed a positive margin, while the conversion to the energy sector seemed to be a good opportunity.

At first, the research involved the collection of existing data about the currently installed heating plants, energy consumption, outdoor temperatures, and biomass availability; the next step was the estimation of the total power requirements, using the design power and historical temperatures data to perform the technical feasibility. The main source of climatic data is the public database of the Agenzia Regionale per la Protezione dell'Ambiente (ARPA); existing information about the already installed plants was obtained by the Municipality, while the "Comunità Montana della Carnia" provided a report about the woodland situation.

Wood biomass availability estimation uses the data collected in (Akhtari, et al., 2014), where an overall production of about 15,960 m3 of retractable biomass was calculated, corresponding to 13,800 tons/year, of which 12,463 tons/year was available since other existing plants already use a part of the wood. Considering a mean calorific value of wood of about 3.4 kWh/kg (hardwood), this quantity of biomass can feed a Combined Heat and Power plant (CHP) that generates about 999 kWe (electric power) (Tommasi, et al., 2018). The possibility of wood exploiting in the shed of the existing activity was confirmed after verifying its position: it was less than 70 km away from the wood sources and connected to them by a suitable road network, both for capacity and slope (Figure 1) (de Santoli, et al., 2015).

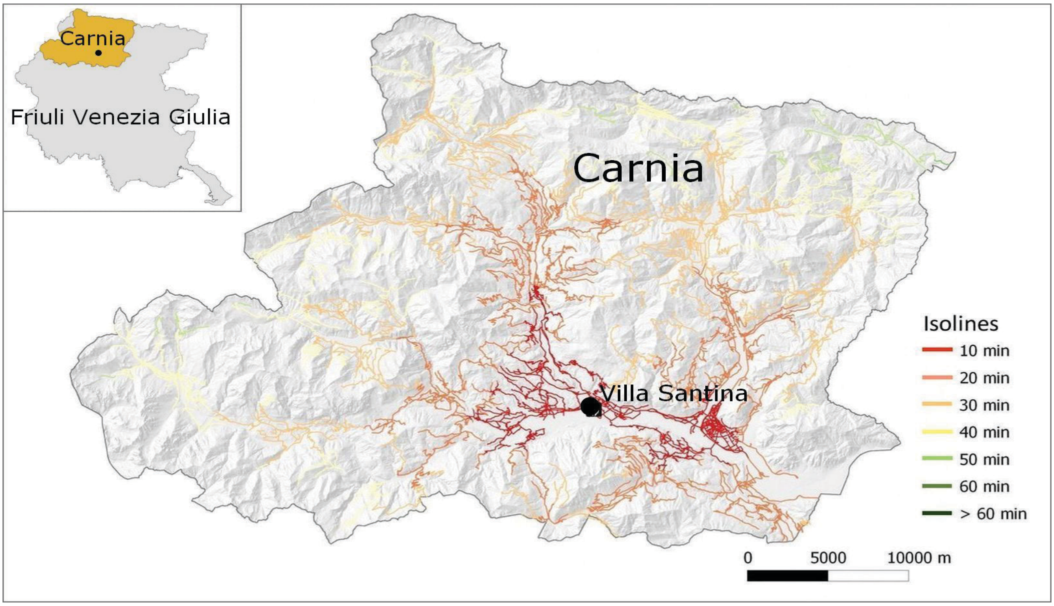

Figure 1: The road network of the Carnia region with the travel times.

Data about heating power demand were calculated considering three different scenarios:

1. district heating of the existing public buildings and the private ones characterized by an installed power greater than 116kW;
2. district heating of the existing public buildings and of all the private ones;
3. district heating of the existing public, private and industrial buildings.

In the first case, the Municipality had the necessary information; in the other cases the energy demand was estimated considering the total volume of the buildings, extracted from the regional digital cartography (Crlienko, 2015) and the statistical data about specific energy consumption. The elaboration of the existing data of a Municipality in the nearby and at the same altitude reveals a mean specific power of 30 kW/m3 for heating purpose, considering public, private and industrial buildings. The nominal power obtained from these data was corrected considering the user's contemporaneity coefficient and the oversizing of the existing plants, in order to obtain the design value.

The potential of the GIS tools for processing and analysing large amounts of geographic data made it possible to create a specific database related to the volume of buildings in the municipality of Villa Santina (UD).

To obtain the information necessary to achieve the set objectives, the project was divided into phases, related to the data collection, organization, analysis and processing.

All the tools used to create "large" databases at company level can also be applied in the creation of a Personal geodatabase that can satisfy the requests for specific projects with fewer users.

The volume of the buildings was calculated using the data retrieved from the IRDAT catalog (Infrastruttura Regionale di Dati Ambientali e Territoriali per il Friuli Venezia Giulia - Catalog of Environmental and Territorial Data for Friuli Venezia Giulia Region) (Figure 2).

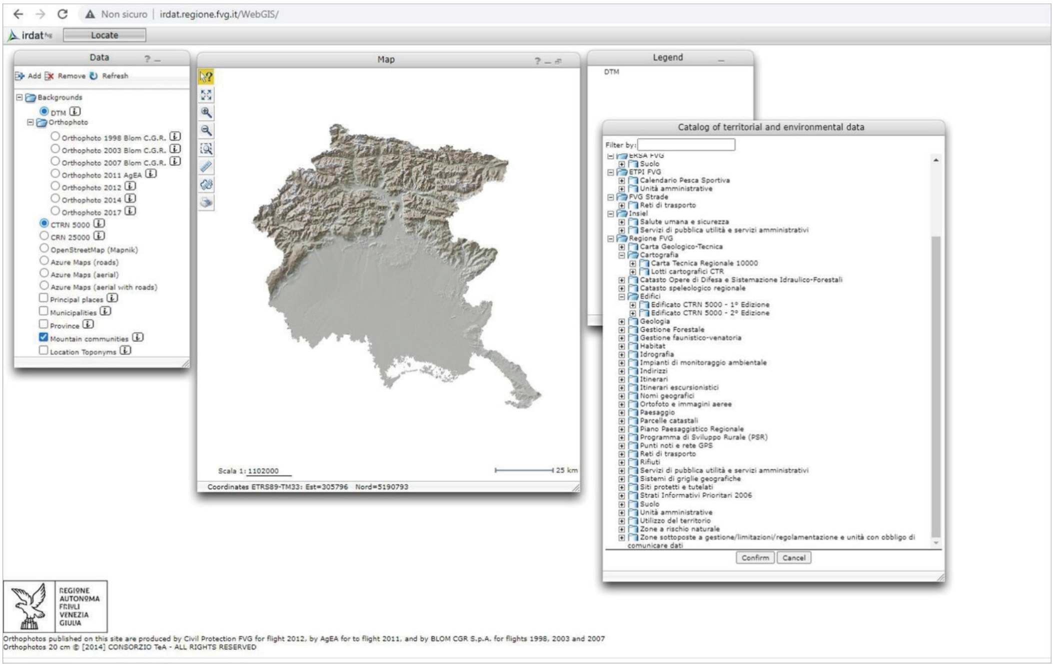

Figure 2: Web GIS IRDAT FVG for searching and downloading map data.

The theme used in this work is "Buildings".It is a structured database in Geomedia Access environment with the polygonal representation of the buildings extracted from the CTRN 5000 (Carta Tecnica Regionale Numerica - Numerical Regional Technical Map scale 1:5000) and the associated information related to the height and volumes of the buildings. The CTRN geographical reference is related to the IGM 1:50000 map.

The Catalog of Environmental and Territorial Data arises from the need to integrate, through a single IT platform, the access to the information assets of an environmental and territorial nature of the regional administration; futhermore it sets a broader objective: to provide a service on a regional scale, aimed at all subjects operating in the area (public administrations, research and training institutes, operators for public services), offering them the opportunity to publish online the reference information (metadata) related to the environmental and territorial databases of its competence.

The developed search engine allows the users to identify, among the existing themes, those of interest, and for specific categories of data and allows to view them using a geographical representation tool (WebGIS). It is also possible to use a service to download the data in the appropriate computer formats. Furthermore, the themes can be used through geographic web services in OpenGIS WFS (Web Feature Service) and WMS (Web Map Service) formats, making it possible, in the context of the most popular GIS software, to use the geographical resource without downloading but using a service accessible via the network.

The conversion of shapefiles into ArcMap and ArcCatalog is possible throw the "Conversion tools", selecting "To Geodatabase". In this group of tools the "Feature Class to Feature Class" method has been used (Figure 3).

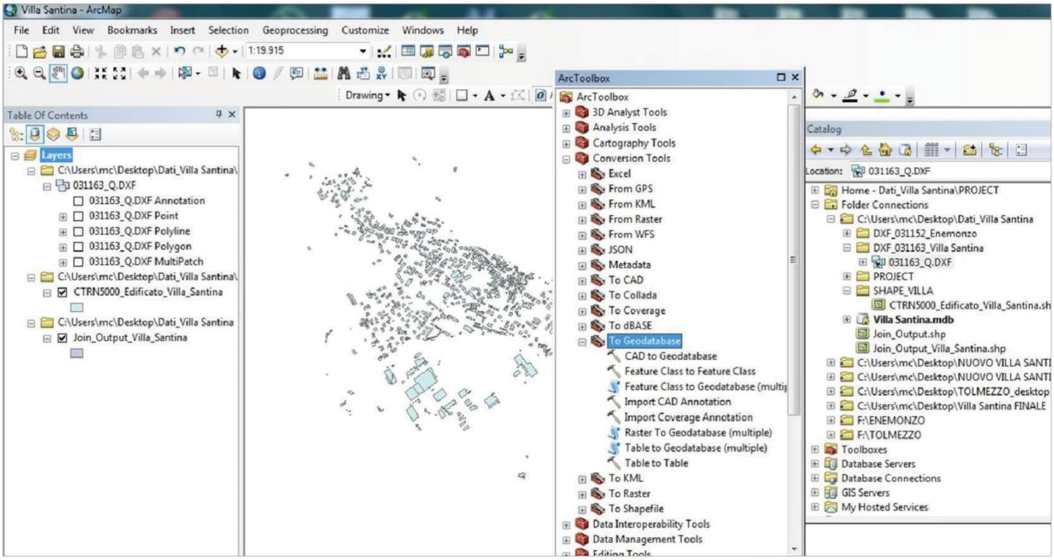

Figure 3: Web GIS IRDAT FVG for searching and downloading map data.

The metadata profile that describes the spatial data published through the Catalog is based on the ISO19115 standard, the result of the work of the ISO TC211 commission, which outlines the standard, widely used at European level, for the construction of territorial data repositories. It also uses the GEMET (Global Environmental Multilingual Thesaurus), produced as part of the European project EEA-ETC / CDS & T funded by the European Environment Agency: a dictionary of over 5000 terms created explicitly to promote research on environmental issues.

The project allows:

- the creation of a georeferenced Personal Geodatabase that contains the volumes of the buildings of Villa Santina;
- the management of AutoCad data formats - dxf (drawing exchange format) and GIS - shapefiles in order to produce a database that can also be exported to Microsoft Access.

The amount of information offered by the IRDAT FVG allows you to work with real data and study their practical applicability in different contexts. The created Geodatabase can provide an optimal basis for further developments and updates, extending the area involved in the analysis and/or including other neighboring municipalities.

The heat energy requirement for the whole season was calculated on the base of the mean daily outdoor temperatures collected for the previous seasons and compared with the design internal temperatures (20°C). The sum of the differences of these values gives an estimate of the energy required for the heating, indicated in degree-days. Villa Santina has a value foreseen by the rules of 3.109 (climatic zone "F" where the thermal power plants can operate all year round). Focusing on the period between November and March, the mean number of degree-days for the previous seasons is equal to 2,354 with 5,200 operating hours of functioning plants. Comparing these data with the nominal design power of the plant, the heating energy requirement are:

1. alternative 1: nominal power 26 MW and project power 21.6 MW and heating energy 22,481 MWh;
2. alternative 2: nominal power 21.9 MW and project power 18.1 MW and heating energy 24,467 MWh;
3. alternative 3: nominal power 28.5 MW and project power 23.6 MW and heating energy 30,703 MWh.

Economic feasibility considered the installation of a CHP plant with three heat generators of 9 MW fed by biomass and calculated the cash flows.

In positive flows were included those linked to the special price of electric energy, equal to 185 €/MWh for the first twenty years, and, for the first ten years, also the White Certificates, equal to 106.39 € for each saved tons of oil equivalent (toe) compared to the existing configuration. Negative flows included plant and district piping costs with a bank loan equal to 60% of the total amount of the investment. The interest rate for the loan was set to 3.39%, while the discount rate used to calculate the Net Present Value (NPV) was 3%, equal to that of Italian 10-year treasury bonds (Persson and Werner, 2011). The estimate of the overall costs for the district heating plant is based on a preliminary project and actual market prices; the district heating network serves 341 buildings with a global piping with a length of nearly 13.5 km and a pre-unit cost around 400 €/m, a value near that reported in (Gudmundsson, et al., 2014). The biomass boiler unit cost is 0.36 M€/MW (included in the range reported in (De Toni, et al., 2011), while for the cogeneration unit is 4.8 M€/MW. The estimated annual electricity consumption of the pumps of the district heating is equal to 250,000 kWh, obtained on the basis of the foreseen operating hours of the plant, while the maintenance cost is calculated as a fraction of the investment value: equal to 0.5% for civil engineering works and 1.5% for the others works. The economic and environmental results for the three scenarios are:

1. alternative 1: initial investment 5.674 M€, NPV = -3.634 M€, Payback period: > 20 years, CO_2 saved 4,331 tons/year;
2. alternative 2: initial investment 6.013 M€, NPV = -0.176 M€, Payback period: > 20 years, CO_2 saved 4,818 tons/year;
3. alternative 3: initial investment 6.113 M€, NPV = -8.158 M€, Payback period: 10 years, CO_2 saved 5.873 tons/year.

The analysis focused on the third alternative, which showed the best VPN after 20 years. The NPV analyzes for the cogeneration plant consider two different starting conditions, relating to 2014 and 2019, because in the last year the Italian government deleted the special purchase price for the electric energy produced from wood biomass before. White Certificates' value also changed through the years: in February 2018, they reached their highest value (about 400 €/toe, used as a maximum favorable limit), while their mean value in 2019 was around 260 €/toe. In these new conditions, the foreseen intervention is no more advantageous due to the high cost of the electric power generation plant: indeed, the NPV after twenty years is negative.

The configuration consisting only with heat generator and district heating network was therefore analyzed. The economic analysis, based again on the NPV, reveals a possible good performance of this kind of intervention and considers two opportunities (Figure 4): the first one includes the incentive of White Certificates worth 260 €/toe (June 2019), while the second does not provides any incentive. The latter option represents the worst condition and considered to predict any future policy choices in this sector. The analysis reveals how, even without incentives, with a twenty years' time horizon, the proposed solution has a positive NPV.

The next step is to design the thermal plant, choosing the best size of the boilers. To install different boilers with a nominal power that is a fraction of the total one required, instead of using only one bigger, which is a normal practice, both to reach higher performances and to prevent any inefficiencies due to possible breakages. It is therefore necessary to evaluate the thermal energy demand profile, considering the historical temperature data of the last heating seasons. To estimate the heating thermal energy required in the last seasons, the real mean temperature values, which are stored every ten days for the whole season, were compared with the design one, which has to be maintained in the heated rooms (consumption energy in the years between 2006 and 2017), the average value of which is equal to 53,112 MWh.

The nominal thermal power required by the foreseen district heating network is equal to 23.6 MW and it was computed considering an outside design temperature equal to -12°C. The maximum, minimum and mean energy consumption for several years were estimated respectively. The subsequent phases of the research used 2016 data, focusing on the estimation of the best number of boilers to be installed and on their size. The duration curve was modified adding the contribution related to the production of sanitary hot water, which was estimated considering the overall number of involved citizens (2,200), a mean water consumption of 80 dm3/person and a temperature of 5°C and 48°C in the inlet and outlet respectively.

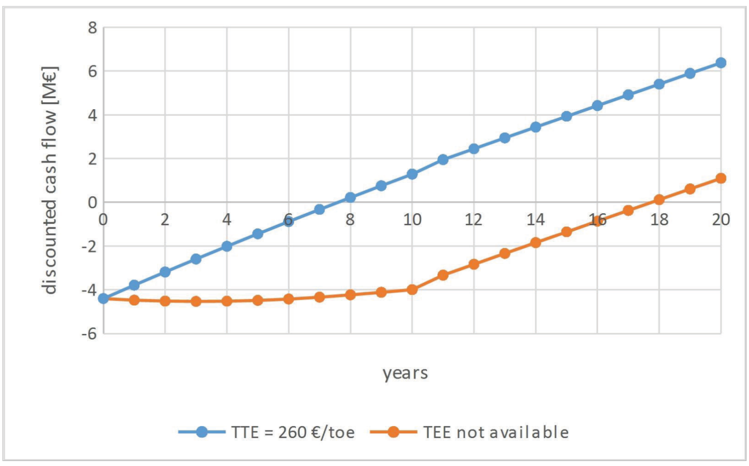

Figure 4: NPV for only district heating network - no cogeneration.

The linked thermal power demand is about 560 kW and Figure 5 shows the updated duration curve and three other curves related to three different hypothetical sizes of the wood fed boiler, equal to 6, 8, and 10 MW, foreseeing the exploitation of all the available wood biomass.

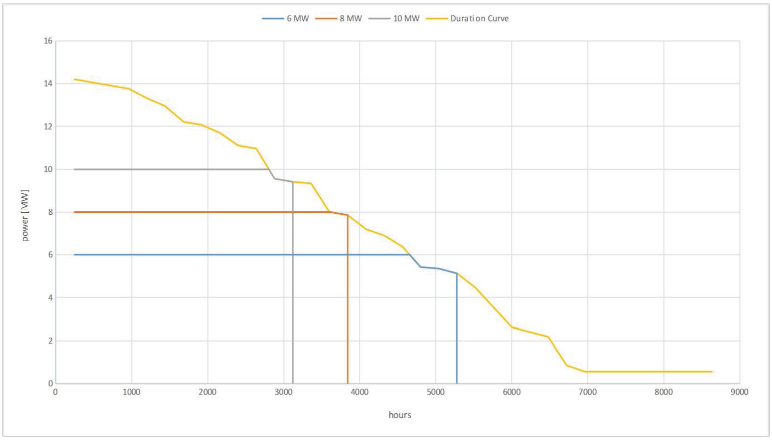

Figure 5: Duration Curve and heating generators.

The study reveals that in all three cases, the boilers run for almost 90% of the time at their nominal conditions, therefore with high efficiency. Daily fuel consumption of the 10 MW boiler is about 72 tons/day of chips, while the 6 MW boiler needs 43 tons/day. Furthermore, adopting the 6 MW boiler, the total required power can be reached installing three other equal-size boilers, fed with a different fuel, and this implies an optimal fractioning level. The design solution includes biomass generator power 6 MW, biomass consumption 43 tons/day and operating time 5,280 hours/year.

Environmental sustainability estimated the lower emission comparing the new plant with the existing ones: high and low powered. The research highlighted that the third alternative can reach positive results both for economic and environmental aspects.

To calculate the CO2 production the following equations were used (1), (2), the first for the new plant with district heating network (integration plant included (Mancarella and Chicco, 2009)) and the second for the current configuration with a lot of little plants fed by methane:

$$E_{CO_2, y} = F_{e, bio} \cdot e_{CO_2, bio} + F_{e, m, int} \cdot \mathrm{e}_{CO_2, m, int} + L_{av} \cdot n_{av} \cdot e_{CO_2 L} \tag{1}$$

$$E_{CO_2, y} = F_{e, m} \cdot e_{CO_2, m} \tag{2}$$

where

$F_{e, bio}$ = annual energy requirement supplied by the cogeneration plant fuelled by wood biomass (kWh_t);

$e_{CO_2, bio}$ = specific CO_2 emission from cogeneration plant fueled by wood biomass = 16 g/kWht (Mancarella and Chicco, 2009);

$F_{e, m, int}$ = annual energy requirement provided by the supplementary plant fueled with methane (kWh_t);

$e_{CO_2, m, int}$ = specific emission of CO_2 from an additional methane-fueled plant = 124 g/kWh$_t$ (Bottio, et al., 2009);

L_{av} = average transport length (to and from) = 70 km;

e_{CO_2L} = specific CO_2 emission from heavy vehicles with 3 axles for a maximum weight of 24 tons gross of the vehicle weight of 4.5 tons Euro III/1999/96/EC [www.arpa.emr.it] = 1.020 g/km;

n_{av} = average number of transports per year of woodchips = 316;

$F_{e, m}$ = annual energy demand required by buildings (kWh$_t$);

$e_{CO_2, m}$ = specific CO_2 emission from methane-powered boilers of buildings = 252 g/kWh$_t$ (Bottio, et al., 2009).

In the examined situation the values of energy consumptions was:

$F_{e, bio}$ = 34,367 MWh

$F_{e, m, int}$ = 23,280 MWh

The last step in the design process was the assessment of the reduction of CO_2 emissions. Besides the nearly 6,500 tons of CO_2 saving another aspect must be highlighted: the new district heating plant concentrates all the emissions in one single source-point, which is not located inside the Municipality's houses area, but far away, in the industrial area, from where they are diluted and spread away.

2 CONCLUSION

The instability of the public incentives due to political choices has a deep impact on the economic feasibility of the investment in the energy sector, particularly if renewable sources exploitation is involved. In Italy, the abolition of the special price for the electric energy produced in plants fed by biomass and the high costs related to that kind of plants have made the investment in a CHP plant unprofitable.

In the mountain regions, on the other hand, there is a high availability of wood biomass, often at low cost, and the existing heating plants have a low efficiency. In this context, the exploitation of district heating technologies, combined with heat generators fed by wood biomass, can make a good margin of profit (NPV after twenty years is negative) (Bozhikaliev, et al., 2019). For this purpose, the costs of chip wood provision must remain low and a careful analysis must be performed to verify the boiler room position in the territory and the location where to execute the chipping operations.

The positive impact on the environmental sustainability of this kind of plants is a constant, mainly due to the CO2 emissions saving and this added value must be considered independently from the economic feasibility. The exploitation of the district heating plant involves lower cost for the end-user and this can also discourage the utilization of household wood-burning stoves, which are commonly used in the considered area and represent an important source of other pollutants.

A second benefit of the exploitation of the available wood biomass is related to the management of the forests, currently increasingly abandoned; this good practice will have a positive impact on both the environmental and the economic aspects. Indeed, a correct management and cleaning of the woodlands involve firstly more safety condition against both landslides and fire; secondly, different positive effects in the tourism sector can be achieved.

Future steps of the research foresee on one hand an extensive analysis of the overall environmental impact of the wood exploitation, performing the Life Cycle Assessment and on the other hand the estimate of the economic impact that the new management of the woodlands can generate, for example on the local tourism development.

Aknowledgments

Thanks to informatics engineer Maja Crljenko, who made this work possible with the contribution of her degree thesis.

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