The environmental compatibility of biomass plants: a methodological approach

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Abstract

The European Union has an ambitious goal to reach a 20% share of energy from renewable sources in the overall energy mix and so with a policy that is dictated by these objectives, the use of renewable energy in Italy and many other European countries is strongly encouraged by substantial economic subsidies.

For these reasons, in Italy the use of biomass energy plants (in this context, we consider these as; the use of residues from forest maintenance, the conversion of available land for energy crops plantation, the rational destination of the solid and liquid manures of livestock and the energy recovery of food waste and waste from agro-industrial activities) are becoming increasingly popular, but it is necessary to evaluate if the use of this type of energy has an environmental and economic convenience. With reference to specific territory situations and by considering the realistic identification of the needs for electric and thermal energy it is necessary to evaluate how much of this energy requirement can be satisfied with energy from biomass and to define the environmental compatibility of biomass plants. These considerations have been applied in a specific area in Italy, Piedmont region (located in North Italy). We considered the possibility to improve the satisfaction of local energy balance and also the deriving aspects of environmental compatibility, with an example of a methodological approach. By using the available biomass in the Piedmont region, we use the tool of energy balance in order to define the potential production of energy and then with the tool of environmental balance, consideration about the agricultural processes, transport of biomass and localization of plants, we try to define the environmental impact deriving from the use of solid and gas biomasses.
Keywords: biomass, local compatibility, GHG, air quality, district heating, land utilization.

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1 Introduction

The European Union with the Directive 2009/28/EC establishes a common framework for the use of energy from renewable sources in order to reduce greenhouse gas emission and the need to import fossil fuel. While renewable energy plants (based on biogas produced by the anaerobic digestion of manure, and by burning energy crops such as vegetable oil, wood and solid biomass) are strongly encouraged under the European legislation, their effect on air quality raises serious concerns. In the present work, we use the tool of energy balance, environmental balance, consideration about agricultural processes, transport and localization, in order to define the positive and negative aspects deriving by use of biomasses. This procedure has been adopted for the examination of particular situations: Piedmont Region. We defined the value of the energetic result that can be obtained from the existing or potential sources of biomass, and the positive weight of the choice for the fulfillment of the required objectives of GHG limitation, with negative aspects of effect on local air quality. The specific considered case can be also indicative of a general methodology, useful for fundamental procedures of compatible energy planning. In fact, it is important to consider the consequence of the performed choices in terms of the emission of greenhouse gases, on the other hand it is required to evaluate the effect of the energetic production on the air quality in the area where the activity is located; these are two aspects that conflict with each other.

2 Biomasses in the Piedmont region

In order to evaluate the current uses of biomasses in Piedmont region and so the state of the art of biomass plant, a research based on the authorized plants by authorities and on the plants in operation has been carried out. The information about the number of biomass plants existing in the region are divided for Province and are represented in the following graph. From a detailed analysis of figure 1, we can note that the Turin province has the major production of electric power by authorized and in operation plants. In the Piedmont region, the total electric power of the biomass plants in operation and authorized is, respectively, of 170.17 MW and of 216.37 MW. In figure 2 we can find the electric power produced by different kind of biomasses.

3 Materials

3.1 Scenarios of study

In order to define the energy production by biomass in Piedmont region and the environmental compatibility deriving by its use, we try to define the different kinds of local biomass available for energy purpose. First of all, we have hypothesized different scenarios of study. The following three cases were considered:

- **Minimum scenario**: use of the currently available quantities of biomass,
- **Potential scenario**: use of potential quantities of biomass, estimated by considering the development of currently unused areas, within the limitations of the current infrastructure of the territory,
- **High scenario** based on the maximum theoretical quantitative of biomass estimable on the regional land.

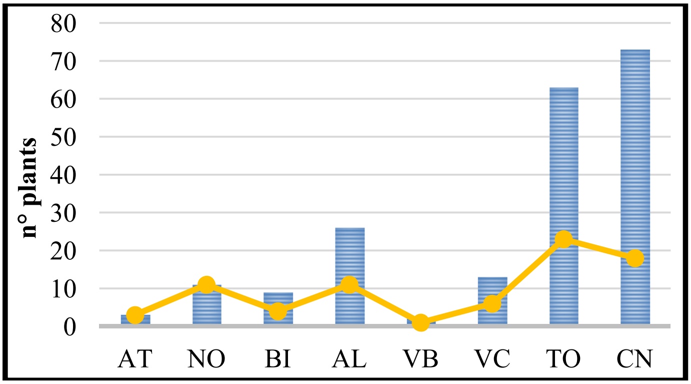

Figure 1: Number of authorized [ ] and in operation [ ] biomass plants, divided for Province of Piedmont region.

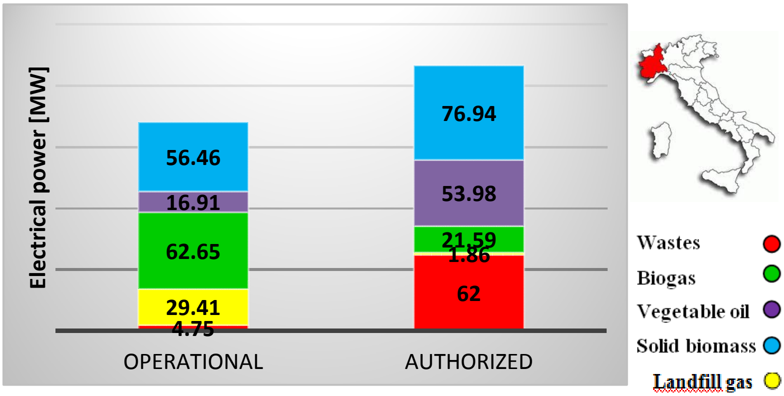

Figure 2: Electric power produced by the biomass plant in operation and authorized.

3.2 Inventory of available biomass

To define the potential biomass for energy supply, we will examine the agricultural, forestry and zootechnical sectors. It is important to note that the vegetable oils are not considered, because they are imported and so they are not indispensable in order to valorise the local biomasses.

The following data, derived by ENEA 2009 [1] and ISTAT 2010 [2], are used for energetic purpose.

Table 1: Summary of potential biomass in Piedmont.

Species	Minimum [kton/y]	Potential [kton/y]	High [kton/y]
Forestry biomass	181.52	181.52	2,141.6
Agricultural biomass	136.3	186.68	664.6
Sawmill wood wastes	137.3	137.3	137.3

Special attention is given to zootecnical sector; because a lot of evaluation is done in order to define the contribution of this sector to energy supply. Firstly, for this estimation, it is necessary to obtain counts of all the types of animals whose waste would be usable.

Table 2: Number of animals contributing to waste generation [3].

Livestock type	Number of animals
Cattle	872,096
Swine	1,211,185

Secondly, we considered only the sewage derived from the swine and cattle categories, because of their low percentage of dry substance [4]. From the number of swine and cattle, by using specific coefficients [5], it is possible to obtain the expected production volume of manure and wastewater, and, from that data, based on the dry matter (DM) and the volatile solids content (VS) of the materials, we can calculate the expected biogas production.

Table 3: Number of animals contributing waste [2].

	Solid cattle manure	Liquid cattle manure	Solid swine manure	Liquid swine manure
Mean weight [kg]	400	400	100	100
Liquid dejection [l/100 kg bodyweight *d]	7.28	7.28	11	11
Solid dejection [kg/100 kg bodyweight *d]	0.914	0.914	0.44	0.44
dm [w/w]	0.25	0.82	0.82	0.8
VS/dm	0.75	0.82	0.82	0.8
Biogas [Nm3/tVS]	400	500	355	700

Then, in the high scenario we have considered the co-digestion for the biogas production. The data used for the calculation of the quantity of energy crops, obtained by the literature, are reported in the following table.

Table 4: Coefficients for biogas production evaluation.

	Quantity [t/y]	dm [w/w]	VS/dm	Biogas [Nm3/tVS]
Corn silage	32,600	0.34	0.96	740
Triticale silage	16,300	0.32	0.95	650
Sorghum silage	16,300	0.27	0.95	650

The methane percentage in the biogas is a function of the type of substance and of the process condition. The variability is 50% (minimum) – 80% (maximum); in this specific case we considered a methane percentage of 55%. Then, the methane produced is the following:

Table 5: Methane produced by biogas.

Minimum [Nm^3/d]	**Potential [Nm^3/d]**	**High [Nm^3/d]**
14,011	70,059	280,237

We have considered different percentage of use of produced biogas; in fact, on the minimum scenario 5%, potential 25% and in the high scenario all the biogas available.

4 Methodological approach

4.1 Methodology

In order to determine the potential energy from local biomass and the resulting environmental impacts, we used the following tools:

- energy balance,
- environmental balance.

4.1.1 Energy balance

Firstly, by using the tool of energy balance, we can know if the use of local biomass could satisfy the local energy requirements and if it is possible to export it. Using the currently available biomass estimated in 3.2 – Inventory of available biomass and the minimum biomass heating, we calculated the available power.
Because the energy balance was computed for cogenerative configurations, we used the commercial value, which translates into 25% of electrical efficiency and 50% of thermal efficiency. By considering the production process for biogas, we determined that 50% of the heat produced would be used internally to heat the digesters [6].

4.1.2 Environmental balance

Secondly, in order to evaluate the environmental benefits deriving from biomass use, it is necessary to estimate both the atmospheric emissions of the existing boilers, and the expected emissions after the installation of the biomass plants. The environmental balance can be computed according to the following formula:

Local/global emissions (added/eliminated) =
biomass plant emissions - substituted emissions

The environmental balance is divided between two scales, one on a local scale and the other one on a global scale. More specifically, at the local level we considered the emissions avoided for the thermal energy produced by the plant and used for the district heating [7]. While, on global scale we considered two different components: the value of avoided emissions for the thermal energy and the value of avoided emissions for the electrical energy produced by plant. For the environmental balances we have taken in account emission factors for the various analyzed pollutants, for the different types of biomass used (liquid or solid), and for the various steps in the process. An emission factor is defined as the weight of pollutant issued by a source referred to the entity of energy production (MJ, kWh) [8, 9].

For these calculations, the parameters considered were:

- ❑ On the local scale: dust, nitrogen oxide, and sulphur oxide;
- ❑ On the global scale: dust, nitrogen oxide, sulphur oxide and carbon dioxide.

However, in an environmental balance, the assumption that the amount of CO_2 absorbed during plant growth was equivalent to the greenhouse gas emissions released during energy conversion is an excessive hypothesis. In fact, it should be noted that, for a detailed analysis of the environmental effects in terms of CO_2, we have to consider the emissions of the other gases such as CH_4 emissions and N_2O produced during pre and post storage of biomass to produce biogas and the indirect emissions deriving by agricultural processes, as harvesting and transport. In this way, we take into account the environmental effects at the level of combustion of biomass and the whole process: by harvesting to collecting of biomasses until to arrive to transport and use of biomasses. The assessment is only referred to CO_2.

For reason of space, the author of this paper assume that the reader has a basic knowledge of a supply chain of biomass and bioenergy production and specific information about the emission factor used in the agricultural process. For the emission factors used to estimate the emission of CO_2, it is possible to refer to [6, 10, 11]. Regarding the transport of biomasses, it is considered the transport with truck up to a distance of 50 km. The emission factor of the means of transport derived by European model COPERT 3 is about 413.5 g_{CO2}/km, with a capacity of 9 t of transportable biomass.

4.2 Hypothesis of the study

The basis of a balance calculation includes the following assumption: the domestic boilers present in the Piedmont region are fed by:

Table 6: Percentage [%] of biofuels used in Piedmont [3].

Furnace oil	Methane	Wood	GPL	Diesel	Coke
0.7	77	12	4	6	0.5

Then, in our study we considered the biomass plants with a cogeneration assessment, this means that all the electricity produced by the biomass plant is transferred to the network; on the contrary, about thermal energy, since we do not know the effective percentage of users connected to the DH, we have evaluated different hypotheses, expressed as percentages of users connected to the network. In particular we have hypothised a percentage of 30%, 50% and 70%.

5 Results and discussion

5.1 Energy balance

Once defined the biomass potentially usable, we can multiply this amount by the lower heating value, so as to obtain the potentially producible energy. From the analysis of different scenarios (minimum, potential and high), the transferred energy produced is shown in the following table:

Table 7: Available [A], Thermal [T] and electrical power [E] [MW] obtainable under the considered scenario.

	A	T	E
Minimum	233.57	115.44	82.03
Potential	622.38	319.12	229.03
High	1.603.26	775.18	567.15

By analysing figure 3 and table 7 above, the energy value obtained for three different scenarios: minimum, potential and high, are important in order to reach the objective of Union European. In fact, with an Italian Decree, Burden Sharing, the Piedmont region has the ambitious objective to obtain 15% of its energy from alternative sources by 2020. The biomasses, solid and gaseous, can help to reach these objectives.

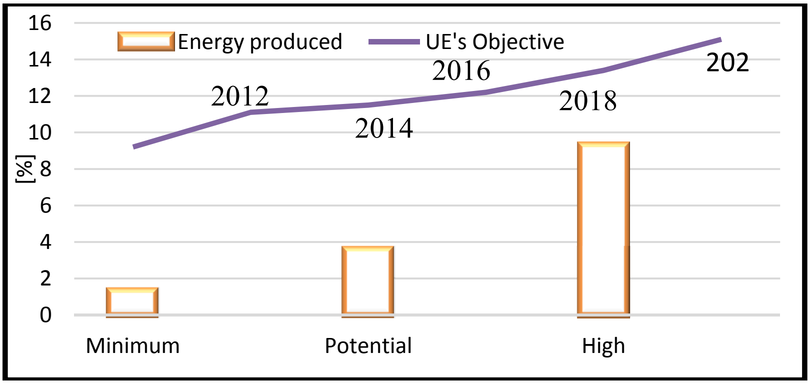

Figure 3: Energy produced by biomass in three scenarios and objective of UE in 2020.

5.2 Environmental balance

After the energy balance, we have applied the environmental balance for hypothised scenarios: minimum, potential and high scenario.

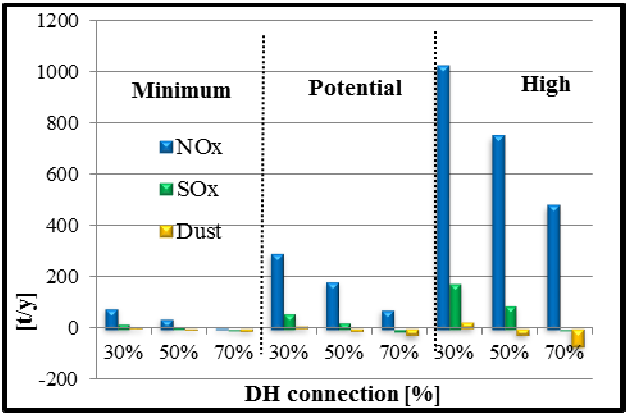

Figure 4: Environmental balance on local scale on the left.

The results are reported in the graphs (figure 4 and figure 5), considering the cogenerative configuration and with a different hypothesis of percentage to connection to the DH (30%, 50% and 70%). The pollutants studied are dust, NO_x and SO_x and the environmental balance is referred to global and local scale.

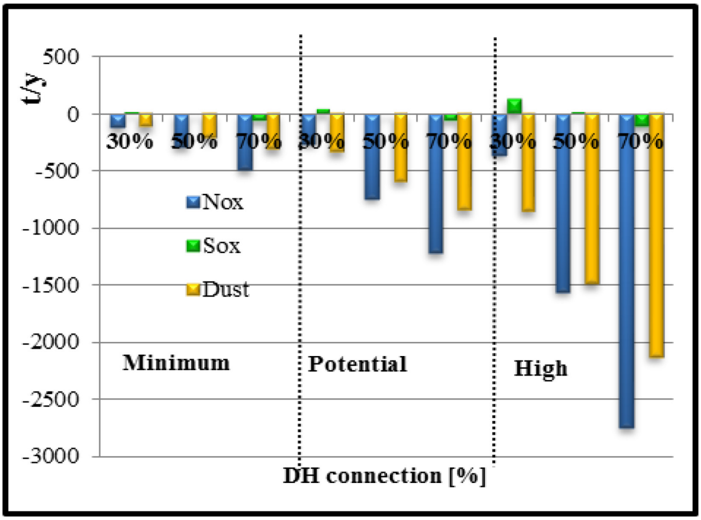

Figure 5: Environmental balance on global scale.

With a detailed analysis of figure above, we can note, in general, an improvement of pollutants emitted in the case of a high percentage of connection to DH. Entering in the single graph, we can observe on local scale an environmental benefit for the pollutant dust in the three scenarios and for all percentage of connection to DH. However, we achieved some environmental advantages for dust and sulphur oxide in case of 70% of connection to DH.

On a global scale, on the contrary, we must consider, additionally, the avoided impact, including not only the thermal energy produced and transferred, but also the electricity produced and transferred. In this case we still have a worsening of the air quality for the pollutant parameter sulphur oxide, but only with a low connection. Anyhow, for both scales, the advantages increase with an increased percentage of connection to the DH.

There are, then, some benefits with the addition of biomass plants, because a large quantity of carbon dioxide released into the atmosphere would be avoided. More specifically, the quantity of avoided CO_2 increases with an increasing of percentage of user connections to the DH. This environmental benefit increases even more, in the high scenario. Figure 6 shows the situation for the pollutant parameter carbon dioxide for the scenarios and depending by percentage of connection to the DH:

We need to note that the CO_2 considered here is the result of a stack balance; in a more detailed analysis, it would be more correct to consider additional sources of CO_2, such as, for example, the transportation and production of fuels. And so, considering the worst case of emissions of CO_2 (30% of connection to DH), we consider the agricultural processes and transport, too, for the two kind of biomass considered: solid and gaseous, in order to define the emission of CO_2. The results are represented in table 8.

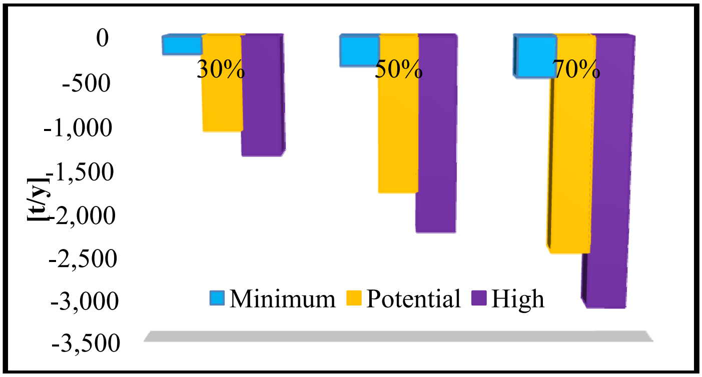

Figure 6: Environmental balance for the pollutant parameter CO_2 for Piedmont region.

Table 8: CO_2 emission [t/y] by environmental balance, agricultural processes and transport.

	Environmental balance	**Agricultural processes**	**Transport**	**Total**
Minimum	-193,76	28,898	1,66	-163,21
Potential	-1.046,76	424,89452	5,65	-616,22
High	-1.322,37	1335,32273	16,79046	29,75

In general, we can note that introducing some consideration about the emission of CO_2 deriving by agricultural processes and transport, we have some way environmental benefit in terms of CO_2: this only for the minimum and potential scenario. In the high scenario, we have an emission of CO_2 at about 30 t/y. This means that in order to have negative emission of CO2, a right use of biomass and a right choose of solid or gaseous biomasses is necessary. In fact, in the high scenario we have considered the all use of gaseous biomass; this could be a possible cause of a high emission of carbon dioxide.

6 Consideration about the localization of biomass plants

After consideration about some benefits deriving by the use of local biomass in terms of energetic production and environmental balance, some considerations are important about the local air quality, in order to make an exact localization of biomass plants. The air quality depends not only on type and concentration of pollutants emission, but on the meteorological and geomorphological condition of an area, too. In fact, at the same emissive conditions, it is the meteorology (wind and stability) and the topography (surface, roughness, influence of buildings and obstacles, urban area, coastal and marine areas, soils with articulated profile and characteristics) that is able to promote the accumulation of pollutants. At meteorological level, wind and atmospheric stability are the two aspects that the most affect the dispersion of a flue gas. For example, in the Piedmont region, the values of annual average wind intensity are about 2.19 m/s and only three sites in Piedmont highlight wind speeds higher than 4 m/s. In addition, the conditions of atmospheric stability are of specific interest for the problems of air pollution: the stability conditions are much more frequent, around 7.8 of frequency, with the light winds and these are the most favorable conditions to stagnation and accumulation of pollutants [12]. Moreover, a further condition that occurs frequently in Piedmont is the thermal inversion, a particular meteorological and atmospheric phenomenon in which the normal vertical thermal gradient, usually negative, is inverted. The thermal inversion at ground is more frequent and intense during the winter season, periods of high pressure and poor air circulation. The thermal inversion generates a highly stable layer to the convection, limiting in this way each vertical mixing of air. A further aspect to consider is the topography: the Piedmont Region, located in the Po Valley, bounded by Alps in the North and West, and from the Apennines to the South, is constituted by a sort of closed basin, where the pollutants emitted in the area, however, tend to stagnate. Finally, the last aspect to consider is the degree of exposure of the population: also this aspect is very different in different regions. In general, the topography and meteorological and receptors are site specific, but it is necessary to consider these data for a full environmental assessment and to understand the real environmental impact on the area considered and on the population. On the basis of these considerations, in order to decide to construct a biomass plant in a specific area, it is important to consider also the real air quality deriving from use of biomass.

7 Conclusions

The aim of this work was to determine the potential energy production capability, both electrical and thermal, for Piedmont Region, and the environmental impacts of such production.

As for energy production, it was found that the use of biomass could contribute to reach anyhow the objective of Europe 2020.

For the environmental impact analysis, we can see a real environmental improvement depending on the effective percentage of connection of users (domestic boilers) to the district heating (DH) network. These evaluations showed that, with higher percentages of user connection to the DH, there was a decrease only in dust on the local scale, but on the global scale, we achieved benefits for all the considered pollutants. As for GHG emissions, these kinds of energy production plants are always advantageous: the CO2 produced from biomass combustion is in fact balanced by the quantity that is absorbed by the plants during their growth phase. At the end, after the consideration of an energetic and environmental compatibility, it is important to define the meteorological and orographic aspects of the area where the plant would be located. These considerations would be a methodological approach to adopt in order to define the energetic and environmental aspects deriving by use of biomasses.

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