Energy from biomass: a contribution to GHG limitation and sustainability of the local impact aspect

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Abstract

The promotion of renewable energy is mainly driven by the perspective of its production, in order to satisfy the local energy requirements and to reduce the greenhouse gas emissions. However, the final choice about the real acceptability of a biomass plant must take into account different aspects; from one side the benefits in terms of limitation of contribution to global warming and use of local resources for energy production; from the other side, the rather important effects on local air quality. In fact, it is important to evaluate the territorial aspects, the eventual need to import in order to satisfy the local energy requirement and, above all, consideration of environmental positive aspects is important, as concerns GHG limitation and the right destination of residual or waste materials that can be used in energy production. Thus, in order to evaluate advantages and limits, the useful tools consist of the classification of all the biomass that is available, the construction of energy and environmental balance, the definition of consumptions and emissions and the evaluation of air quality effects derived from meteorological and orographic conditions. These are the right instruments that can be utilized in order to evaluate the interactions of biomass plants with the global environment. These tools and instruments have been applied for two Italian case studies. The main conclusions are that the utilization of biomass for energetic purposes can lead to positive solutions towards the limitation of consequences as concerns climate change without unacceptable negative effects on a local scale, if careful localization is considered. The specific considered cases can be also indicative of a general methodology, useful for fundamental procedures of compatible energy planning.
Keywords: biomass, local compatibility, GHG, air quality, district heating.

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1 Introduction

The objective of European Union Directive 2009/98/EC is to obtain 20% of energy from alternative sources – for example, wind power, solar, biomass and so on – by 2020. 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, after the evaluation of the potential for energetic production, it is necessary to evaluate the significance of this result from an environmental points of view, in some cases conflicting with each other: on one side it is fundamental to consider the consequence of the performed choices in terms of 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.

This evaluation procedure has been adopted for the examination of two particular situations, by considering the energetic and biomass exploitation aspects of Piedmont Region and of Basilicata Region; the two cases were particularly interesting as they representative of different aspects in connection with geographical situation, household presence, industrial development, land use, presence of environmental constraints.

The specific considered cases can be also indicative of a general methodology, useful for fundamental procedures of compatible energy planning.

2 State of the art in Basilicata and in Piedmont regions

The current uses of biomasses can be estimated on the basis of research carried out in the Basilicata Region and in the Piedmont Region; two regions of Italy, the first in the South of Italy and the second in the North. The research is based on the authorized plants by authorities and on the plants in operation.

By analyzing the graph for the Basilicata region, we can observe that among the plants in operation, many use vegetable oil as fuel. It is assumed that this oil is imported, since there are currently no plants in Basilicata producing such oil.

Among the plants in operation is the Melfi incinerator, which is authorized to treat 65,000 tonnes of waste (municipal and industrial) each year, producing in cogeneration, 3.6 MW of electrical power transferred to the national network and 16.5 MW of thermal power. However, it is not possible to define precisely the contribution of local Lucanian waste.

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.

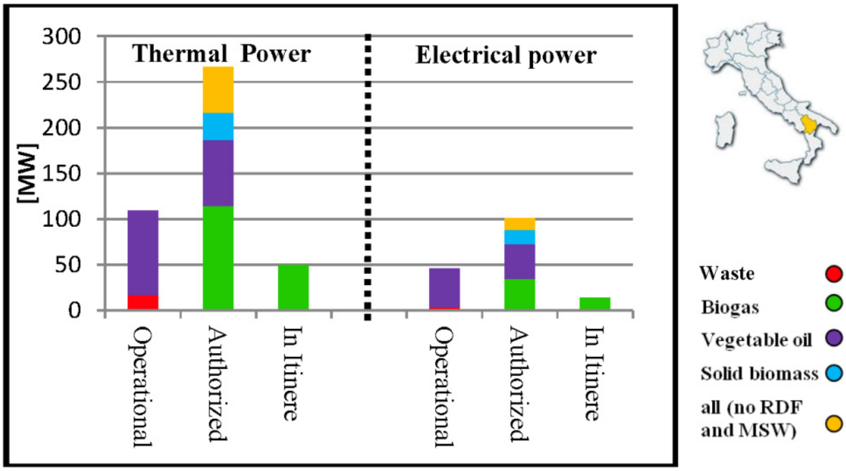

Figure 1: Electric and thermal power produced by the operational and authorized plant in Basilicata.

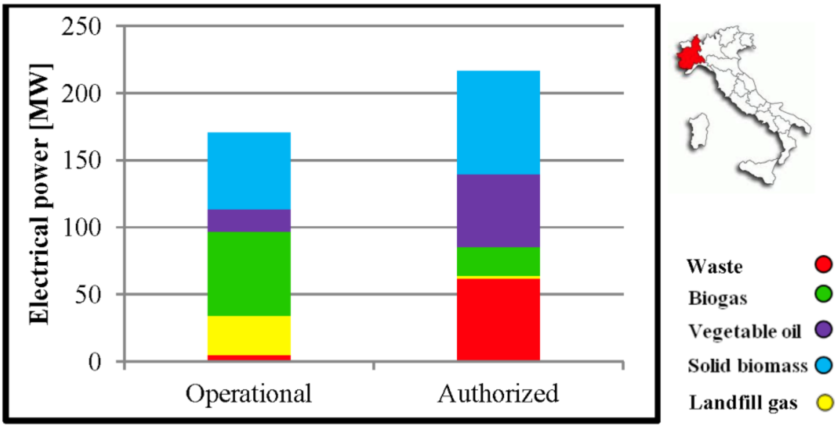

Figure 2: Electric power produced by the biomass plant in operation and authorized.

3 Materials and methods

3.1 Materials

In this section, we try to define the different kinds of local biomass that could be used for energy production in Basilicata and in Piedmont region, by considering different scenarios of use of biomass. In order to plan the available biomass in two region considered, we have hypothesized different scenario of study. In Basilicata [1], the following two 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.

On the contrary, for the Piedmont region, we have introduced, besides to the two scenarios a third scenario: the **high scenario** based on the maximum theoretical quantitative of biomass estimable on the regional land.

We will examine the agricultural, forestry and zootechnical sectors. It is important to note that the vegetables oil are not considered, because they are imported and so they are not important in order to valorize the local biomass.
The following data, derived by ENEA 2009 [2] and ISTAT 2010 [3], are used for energetic purposes.

Table 1: Summary of potential biomass in Piedmont.

	Piedmont			**Basilicata**	
Species	**Minimum** [kton/y]	**Potential** [kton/y]	**High** [kton/y]	**Minimum** [kton/y]	**Potential** [kton/y]
Forestry biomass	181.52	181.52	2.141.6	65.28	65.28
Agricultural biomass	136.3	186.68	664.6	513.64	513.64
Energetic culture	-	-	-	-	649.72
Sawmill wood waste	137.3	137.3	137.3	-	-

In order to evaluate the contribution of the zootechnical sector from [3], it is necessary to obtain counts of all the types of animals whose waste would be usable.

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

Regions	**Livestock type**	**Number of animals**
Basilicata	Cattle	86,384
	Swine	84,838
Piedmont	Cattle	872,096
	Swine	1,211,185

To define the theoretical potential energy production from zootechnical biogas 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, it is possible to obtain the expected production volume of manure and wastewater, and, from that data, based on the dry matter and the volatile solids content of the materials, we can calculate the expected biogas production.

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

	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/100kg 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 [Nm^3/tVS]	400	500	355	700

The methane percentage in the biogas as 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%.

3.2 Methods

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

- energy balance;
- environmental balance;

And this methodology is based on many assumptions.

3.2.1 Assumption

The authors of this paper assume that the reader has a basic knowledge of biomass and bioenergy production, so that the general information on these aspects is not provided here. The basis of a balance calculation includes a number of assumptions regarding:

- ➢ the domestic boilers present in the Basilicata area are fed by 75% of wood and 25% of gas; on the contrary in the Piedmont region we have:

Table 4: Percentage of biofuels used in Piedmont [3].

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

- 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 hypothesized a percentage of 30%, 50% and 70%.

Then, on a local scale, during the environmental balance, we assumed that:

- for anaerobic digestion, we could disregard the emissions of CH_4 and N_2O;
- the CO_2 produced during the combustion phase is balanced by its absorption during the growing phase of the biomass itself (we did not include the cultivation, harvesting and transport of biomass, meaning that Life Cycle Assessment—LCA—was not used in this study) [4].

3.2.2 Energy balance

In the first case (using the currently available biomass estimated in 3.1.1 – Inventory of potential biomass for energy supply), we used the tool of energy balance in order to quantify the energy that could be produced by biomass: the volume of biomass that can be used to compute the expected energy generation, based on the minimum biomass-heating values (table 5).

Table 5: Minimum biomass heating values.

Forestry biomass	14.4 MJ/kg	**Biomass from livestock**	34.5 MJ/Nm^3
Agricultural biomass	14.28 MJ/kg	**Energetic culture**	17.2 MJ/kg

Because the energy balance was computed for cogenerative configurations, we used the commercial value, which translates to 25% electrical efficiency and 50% thermal efficiency, using the currently available power. (Considering the production process for biogas, we determined that 50% of the heat produced would be used internally to heat the digesters [5].)

3.2.3 Environmental balance

Next, in order to evaluate the local 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:

$$\text{Local/global emissions (added/eliminated)} \\ = \text{biomass plant emissions} - \text{substituted emissions}$$

The "added emissions" are the emissions from the biomass plants that will enter into operation; on the contrary, the "eliminated emissions" are that generate by the utilities that turn off when the biomass plant will operate. As eliminated emission, on global scale, we consider also that produced by centralized electricity, that are substituted by biomass plant (the biomass plant generated electricity that is transferred to the national electric grid).

For these calculations, the parameters considered are:

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

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) [6, 7].

4 Results and discussion

4.1 Energy balance

Having defined the biomass potentially usable in the two regions, 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 Table 6.

In the table below, we have the local Energy requirements of both regions and the percentage of energy satisfied requirements for different scenarios. More specifically, in the Basilicata with the use of all available biomass we can satisfy around the 73% of the local energy requirements (952 ktep); and in the potential there is a quantitative of energy higher than the actual requirement with the possibility to export it. On the contrary, in the Piedmont region, the local energy requirements (12.452 ktep) is higher than Basilicata and so it is not possible to satisfy the whole energy requirements.

Table 6: Available [A], Thermal [T] and electrical power [E] [MW] obtainable under the considered scenario.

	Basilicata			**Piedmont**		
	A	**T**	**E**	**A**	**T**	**E**
Minimum	359.14	175.46	122.83	233.57	115.44	82.03
Potential	661.94	326.86	228.1	622.38	319.12	229.03
High				1.603.26	775.18	567.15

4.2 Environmental balance

After the energy balance, we have applied the environmental balance for scenarios hypothesized for the two regions. The results for the two regions and scenarios considered are reported in the following graphs, considering the cogenerative configuration with a different hypothesis of percentage to connection to the DH.

The legend utilized for the graphs is the following: NO_x ■ SO_x ■ Dust ■.

In the following graphs we can see the results of the environmental balance on a local scale:

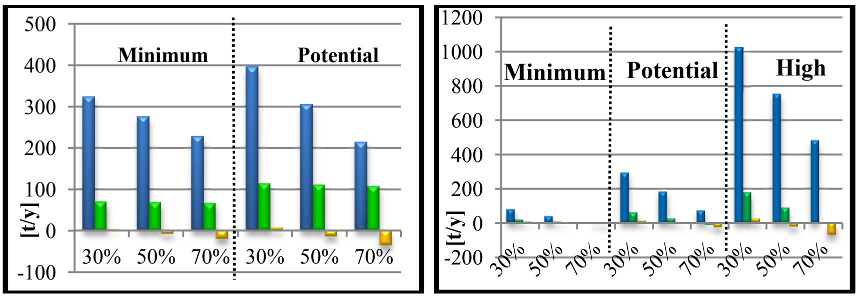

Figure 3: Environmental balance on the local scale for Basilicata region (on the left) and for the Piedmont region (on the right).

By analyzing the graphs above, for both regions on the local scale, we can see an increase in emitted pollutants, but an environmental benefit in case of connection to the district heating network by 70%; we have some advantages in the case of pollutant dust.

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. In the following graphs (figure 4), we can see the result of environmental balance on global scale.

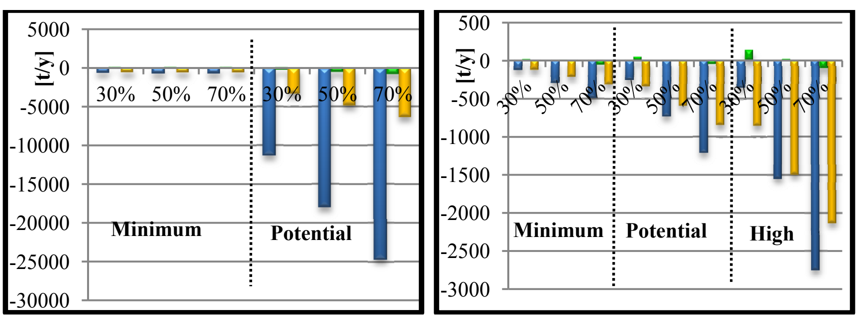

Figure 4: Environmental balance on the global scale for Basilicata region on the left and for Piedmont region on the right.

With a detailed analysis of the figures above, we can note, in general, that we achieved some environmental advantages for dust and sulphur oxide; in particular in case of 70% of connection to the DH, we have some advantages for nitrogen oxide, too. 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 of 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 potential scenario. Figure 5 shows the situation for the pollutant parameter carbon dioxide.

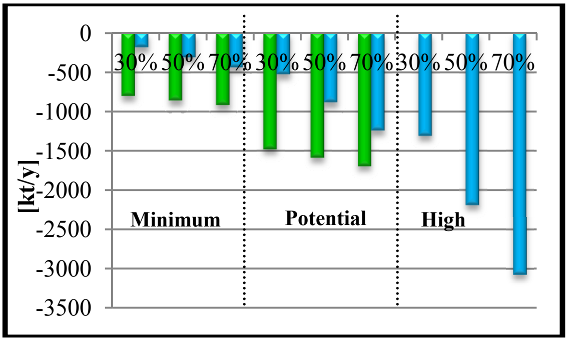

Figure 5: Environmental balance for the pollutant parameter CO_2 for Basilicata and Piedmont.

By analyzing Figure 5 we observe a general improvement of CO_2 emissions at the global level, for environmental balance. This improvement will be greater with a greater number of operating plants. In fact, considering the Basilicata region, the advantages are higher than Piedmont region because the biomass available is high. 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.

5 Considerations about the local air quality

It is essential bearing in the mind that the two regions are very different in terms of geographic and structural situation. In this sense, it is necessary to highlight that the local impact phenomena in the two regions will be different in connection with the different meteorological condition (wind calm, stability and thermal inversion phenomena, and so on) and for the population distribution. The air quality depends, not only on type and concentration of pollutants emission, but the meteorological and orography 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) to promote the accumulation of pollutants. The comparison has been done, just between the two regions, one in the north and one in the south, which present completely different the above cited conditions. At meteorological level, wind and atmospheric stability are the two aspects that the most affect the dispersion of a flue gas. From ARPA data elaboration, in Basilicata, compared to an average speed generally higher than 6–7 m/s, there are different areas characterized by higher speed to 7 m/s, with peaks between 8 and 9 m/s; instead, in the Piedmont region is obtained that the values of annual average wind intensity is 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 area of specific interest for the problems of air pollution. The table 8 shows the average annual frequencies of the categories of stability (potential), according to Pasquill for the meteorological stations located around the two regional capitals.

From Table 7 we note, as in the Piedmont region are much more frequent the stability conditions, with the light winds and these are the most favorable conditions to stagnation and accumulation of pollutants. 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 are more frequent and intense during the winter season, periods of high pressure and poor air circulation. The thermal inversion generates an 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 Appennines to the South, is constituted a sort of closed basin, where the pollutants emitted in the area, however, tend to stagnate; the Basilicata region, on the contrary, is not a closed basin in which the pollutants stagnate. On the basis of these considerations, to know the real air quality deriving from use of biomass, we can use the atmospheric dispersions models of pollutants (see the max as example), which consider the orographic and meteorological data of the specific zone. The maps realization is a result of the simulation of the atmospheric dispersion of pollutant emitted with the use of biomass and the model simulation is conducted with the model ISCST3 (Industrial Source Complex version 3) as Short Term (ISCST3). The consequences in the two regions of the introduced pollutant fluxes could be very different. Finally, the last aspect to consider is the degree of exposure of the population also this aspect is very different in two 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.

Table 7: Frequency of the stability category by Pasquill for the two regional capitals [8].

Grade of stability	High instability A	Medium instability B	Low instability C	Neutrality D	Low stability E	High stability F	Extremely high stability G
Potenza	4.5	5.6	10.4	43.3	6.7	18.1	11.4
Torino	12.1	13.8	8.3	8.2	7.8	30.2	19.6

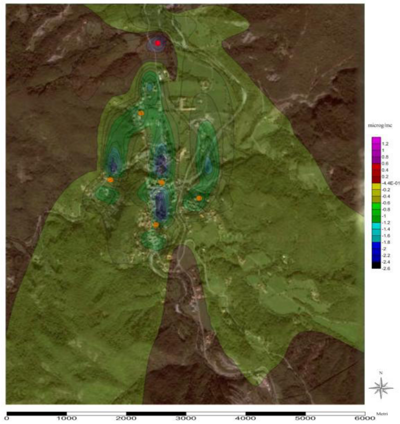

Figure 6: An example of air quality with a pollutant dispersion models.

6 Conclusions

The aim of this work was to determine the potential energy production capability, both electrical and thermal, of the available biomass of the Basilicata and Piedmont Region, and the environmental impacts of such production. This evaluation has been conducted using the tools of mass and energy balance, on both local and global scales. As for energy production, it was found that by using all the currently available biomass (the “minimum” scenario), we could satisfy about 72% of the local energy requirements for the Basilicata, on the contrary about Piedmont region, we can’t satisfied only the 24,9 % (high hypothesis), but use of biomass could contribute to reach anyhow the objective of Europe 2020. For the environmental impact analysis, the results are very similar: for both Basilicata and Piedmont, we can see a real environmental improvement depends 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 CO_2 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 an energetic and environmental compatibility, it is important to define the meteorological and orographic aspects: for the Piedmont region this aspect are disadvantageous for the installation of biomass plants. For some practical situations in different parts of Italy the proposed procedure demonstrates the importance of biomass full exploitation for satisfaction of energetic scenarios, the positive aspects as concerns GHG emissions, and the possibility of a limitation of the local environmental impact by a right use of cogeneration systems and full thermal power use, and also by considering a correct territorial localization of the plants. The utilization of biomass for energetic purposes can lead to positive solutions towards the limitation of consequences as concerns climate change without unacceptable negative effects on local scale, if a careful localization is considered, chiefly in the framework of electric and thermal distribution schemes.

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