

The potential of biomass supply for energetic utilization in a small Italian region: Basilicata

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Abstract The European Union Directive 2009/28/EC (European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC, Directive 2009/28/EC) establishes a common framework for the use of energy from renewable sources in order to reduce both greenhouse gas emissions and reliance on fossil fuels from foreign markets; more specifically the EU has the ambitious goal of reaching a 20 % share of energy from renewable sources in the overall energy mix by 2020. These objectives could drive policies that offer substantial economic subsidies for the use of renewable energy, both in Italy and in many other European countries. For all these reasons, biomass (one of the major sources of renewable energy) plants are getting a lot of attention in Italy, but it is necessary to determine whether using of this type of energy is environmentally beneficial and economically feasible. In this study, we evaluate the energy and so the environmental aspects by considering both current and potential biomass supplies available for energy utilization in a small region in the South of Italy: Basilicata, as well as the consequences of this energy conversion at both the local and the global scale.

Keywords Biomass · Energy · GHG generation · Environmental balance · Local pollutants · Environmental impact

Introduction

The objective of European Union Directive 2009/28/EC (Directive 2009/28/EC) is to obtain 20 % of energy from alternative sources (renewable energies), for example, wind power, solar, biomass, etc., 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, especially the high levels of CO₂ emissions from biogas plants, raises serious concerns. It is therefore necessary to define these plants' overall environmental sustainability, taking into account global parameters as well as environmental impacts at the regional and local scales.

The region of Basilicata in Italy contains large quantities of raw material that can be exploited for biomass energy. Nevertheless, before making large investments in biomass plants in this region, it is critical to assess their potential environmental impacts. The aim of this work is to determine the environmental sustainability of the biomass plants already existing in this region, and of future plants that may be proposed there. Two scenarios are studied: the minimum scenario and the potential scenario. Both of these scenarios will be considered from both global and local points of view. Globally, there is a potential benefit from reduced CO₂ production, if the emissions from the fluxes generated from biomass production, transport, and utilization are lower than those avoided from the displaced fossil fuel

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sources. At the local scale, there are potential impacts of dust, NO_x, and SO_x on air quality. At both scales, the costs of implementing the best available technologies must be considered, because any benefits accrued must be measured against high start-up investment costs for installing environmentally suitable technologies (anyway this point will not be debated in this paper). The analysis performed in this study considers both the positive effects of renewable energy use and GHG reduction, and concerns about effects on local air quality.

Current state of the art

In the literature are many references concerning bioenergy production and related environmental sustainability, in particular the individuation and utilization of indicators or methodologies corresponding to life cycle assessment (LCA) (Bare 2010; Brandão et al. 2011; Gasola et al. 2009; Gnansounou et al. 2009; Hanegraaf et al. 1998; Renó et al. 2011; Sawangkeaw et al. 2012) have made important contributions. For this study, the significant results are those concerning both the original definition of the evaluation scheme and the description of many situations relevant to our study. As far as biogas production and utilization is concerned, in (Poschl et al. 2010), the energy efficiency of several different biogas systems was evaluated and specific energy balances were defined; the study provides bases for assessments of environmental compatibility, including management of spent digestate. It has been observed (Borjesson and Berglund 2007) that biogas systems lead to environmental improvements, arising from changed land use and the improved handling of organic waste products, even if the real benefits have to be evaluated in comparison with fossil fuels; conversely, a numerical impact factor can be computed, based on the utilized raw material, the energy service that is provided, and the replaced reference system. The use of LCA has been suggested by Jury et al. (2010) to evaluate the contribution to climate change of biomethane production by mono-fermentation of cultivated crops; the results demonstrated an unequivocally lower contribution than from natural gas importation. The effects on ecosystem quality and human health damages were also evaluated. In order to acquire the necessary energy-production information, experiments using co-digestion of energy crops and cow or pig manure have been conducted on several different scales. For example, (Lehtomaki et al. 2007; Panichnumsin et al. 2010) determined the influence of operating parameters on methane yield and post-methanation potential. A standard methodology has been outlined (Schlamadinger et al. 1997), for comparing the greenhouse gas balances of bioenergy systems with those of fossil energy systems: a

careful definition of system boundaries, and many operating issues, have been dealt with in detail, with the final aim of optimization, with a focus on the effect on greenhouse gas emissions. In order to establish a reliable approach to the impact assessment of the biomass cultivation phase, different LCA models have been developed (Buratti and Fantozzi 2010), and data from experimental fields used for testing. The aspect of GHG balances of bioenergy systems for producing electricity and heat, and for the use of bio-fuels for transportation, has been examined in comparison with fossil reference systems in Cherubini (2010) using a standard LCA.

The literature contains many studies relating to this field. From the indicated references it is possible to establish that the environmental balances for energy crops exploitation are well-defined and many examples are at our disposal for useful comparisons. In any case a specific definition of the local context and the existing operating conditions must be carefully examined, in order to arrive at valid conclusions for a proposed application (Panepinto et al. 2013).

Current situation in Basilicata

The current uses of biomass can be estimated on the basis of research carried out in the Basilicata Region. The research is based on the authorized plants and on the plants under evaluation by the authorities, considering both small and large plants. The map below illustrates the distribution of current biomass plants in the region and two tables show the current situation in terms of thermal and electrical power produced by different kinds of biomass (Fig. 1).

The two tables below show the current situation (Tables 1, 2)

By analyzing the graphs (Fig. 2), 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 wastes (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 wastes.

Inventory data: potential of biomass in Basilicata

In this section, we try to define the different kinds of local biomass that can be used for energy production in Basilicata. In particular we will examine the agricultural, forestry and zootechnical sectors. This will be followed by some

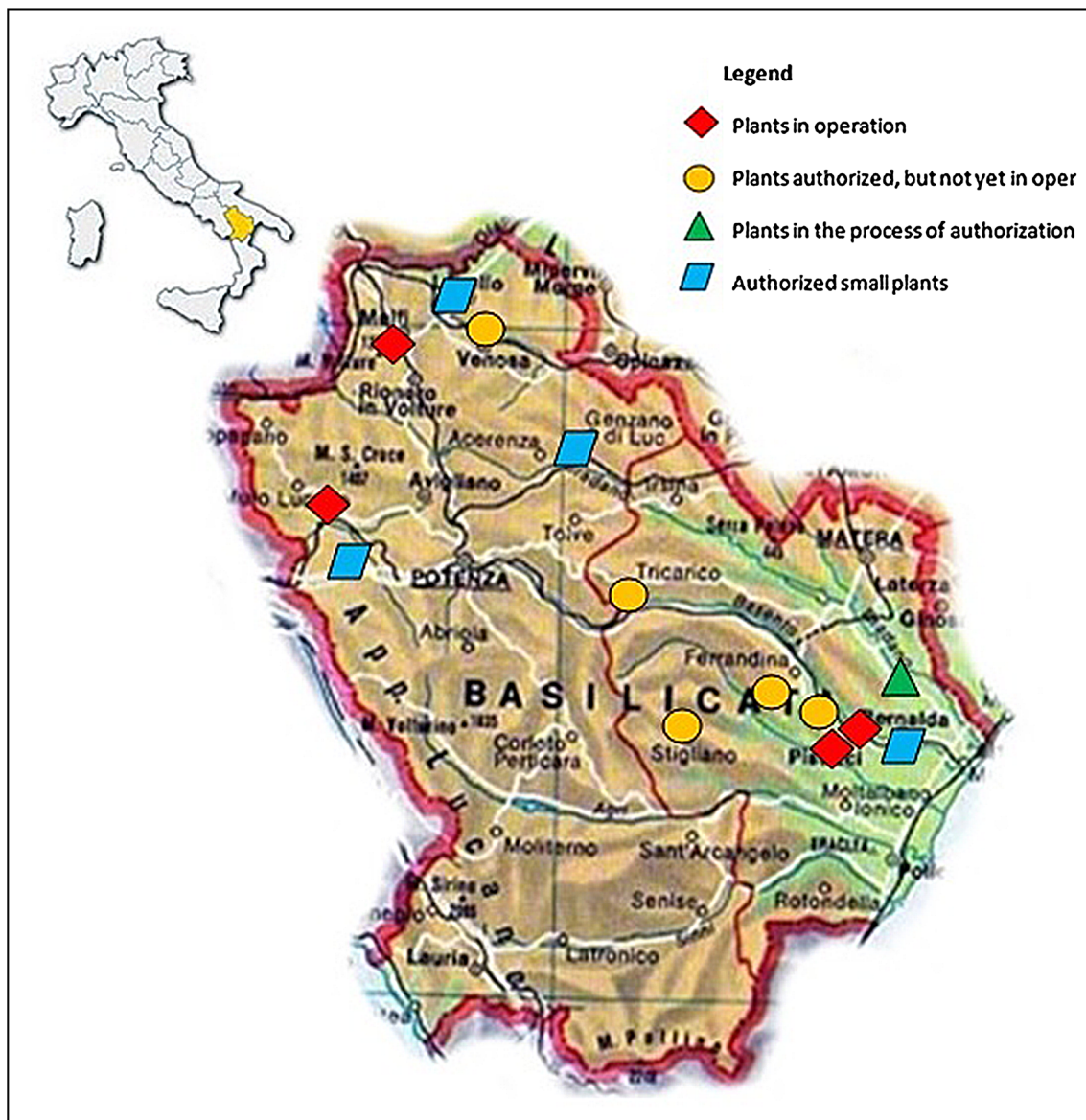


Fig. 1 Distribution of thermal and electric power produced from the biomass plants

Table 1 Thermal and electric power produced from the authorized small plants

	Thermal power (MW)	Electric power (MW)
Biogas	2.14	1.85
Combustion	2.78	0.5
Not indicated	–	0.1

considerations about non-cultivated areas and biofuel crops.

Forestry biomass

The Basilicata territory is 35.6 % forest, with a total forest area (not including private property) of 231.030 ha (ENEA

2010) and a clear predominance of mesophile and thermophile oak trees (51.8 %). By applying a set of sustainability assumptions to the amount of biomass currently harvested in the region, we calculated the volume of woody biomass that can be sustainably harvested in Basilicata to be about 65.28 kton/year (ENEA 2009).

Agricultural biomass

Agricultural land covers 58 % (ENEA 2010) of the Basilicata region, about 300,000 ha, and contains the following types of crops (ISTAT 2010) (Table 3).

The types of agricultural biomass in this area that can be used in energy production include the following (ENEA 2009) (Table 4).

Table 2 Thermal and electric power produced from large plants

	P_t (MW)	P_e (MW)
Plants in operation		
▲ Vegetable oil ^a	92.5	42.58
Plants authorized, but not yet in operation		
▲ Vegetable	29.62	15
▲ Straw and chips	114	35
▲ All vegetable (but no RDF and MSW)	49.77	13
▲ Vegetable oil	72.8	38.15
Plants in the process of authorization		
▲ Straw and chips	49.5	14

^a We assumed that this is imported because in Basilicata there are no plants producing oil

Biomass from livestock waste

To evaluate the contribution of the zootechnical sector from (ISTAT 2010), it is necessary to obtain counts of all the types of animals whose waste would be usable (Table 5).

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. 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 (the volatile solid content shows the quantitative of organic substance content in the biomass and potentially transformable in biogas) of the materials, we can calculate the expected biogas production (Table 6).

Table 3 Types of crops produced in Basilicata (ISTAT 2010)

Crops	ha
Grains	240,126.76
Pulses	8,294.10
Vegetable growers	8,288.62
Forage crops	26,633.00
Grapevine	8,736.8
Olive trees and fruit-bearing	28,749.76
Vegetable garden	1,533.9

Table 4 Available agricultural biomass and useable thermal potential

	Straw	Pruning	Olive residues and marc
Available agricultural biomass (kton/year)	452.10	49.96	11.58
Useable thermal potential (MW)	129.17	11.89	2.4

Table 5 Number of animals contributing waste (ISTAT 2010)

Livestock type	Number of animals
Cattle	86,384
Swine	84,838

From these calculations, the total biogas production was projected to be about 68.08 MNm³ per year, and the total methane production, about 37.45 MNm³/year and, so the potential electric power is about 16.38 MW.

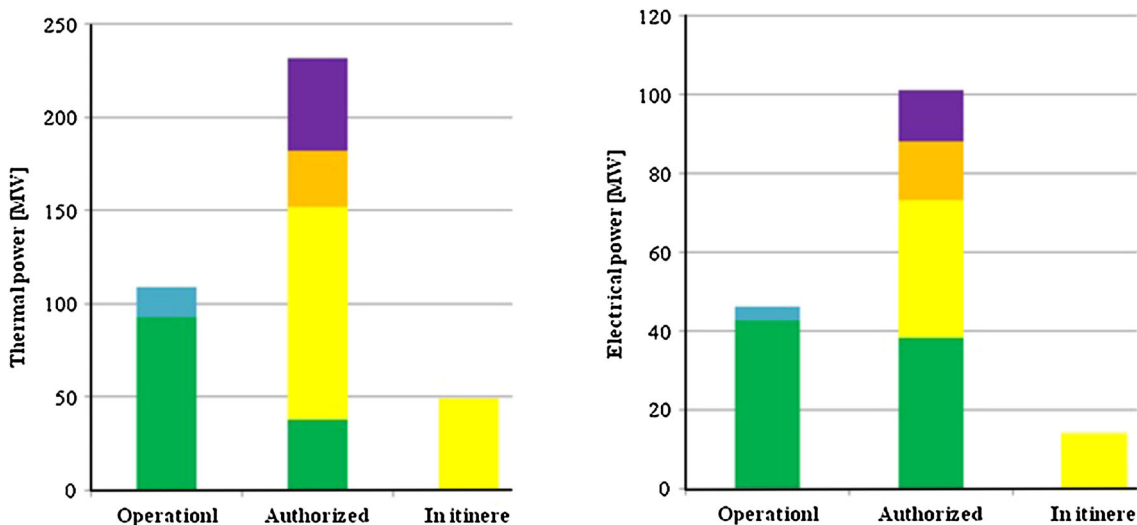


Fig. 2 Power generated by large plants; on the left thermal power, on the right electrical power

Table 6 Biogas production from anaerobic digestion of solid and liquid manure (ENEA 2010; Panepinto et al. 2013)

	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 × day)	7.28	7.28	11	11
Solid dejection (kg/100 kg bodyweight × day)	0.914	0.914	0.44	0.44
Manure (kg/day)	315,819.9	2,518,266.37	37,328	933,218
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
Biogas production (Nm ³ /day)	23,686.49	123,898.71	2,390.61	36,582.15

Table 7 Data used to calculate the quantity of biofuel crops produced in a year

Species	Dry substance (ton _{ds} /h)	Area for the biofuel crops (ha)	Dry substances produced (ton _{ss} /year)
Cane	25	7,383.24	184,581.00
Panico	28	7,383.24	206,730.72
Poplar tree	15	7,383.24	110,748.60
Miscanthus	20	7,383.24	147,664.8

Table 8 Biomass available for energy production in Basilicata

Straw (kton)	452.10
Pruning (kton)	49.96
Olive residues and marc (kton)	11.58
Forestry biomass (kton)	65.28
Biofuel crops (kton)	649.72

Energy crops

Currently there are no areas dedicated to biofuel crops in Basilicata, and the possibility of converting the existing production systems to these crops is very low, for both pedo-climatic and socio-economic reasons. However, in order to study the potential energy from biomass, it is necessary to include crops such as cereals (currently covering 546,671.03 ha), and also to postulate the cultivation of biofuel crops on all the available arable land not currently used for other purposes. The all available arable lands, actually, are not restricted areas and so, we can postulate their use for the cultivation of biofuel.

In this latter case, from (ISTAT 2010), in Basilicata we have about 29,532.96 ha of uncultivated arable land.

The biofuel crops used in this study were cane, miscanthus, panico, and poplar trees. We hypothesized the use of the uncultivated area for producing these crops. The data used for the calculation of the quantity of biofuel crops, obtained from the literature, are reported in the following table (Table 7).

Since it is very difficult, for various reasons (social, economic and so on), to change land utilization, we first

considered only the actual quantity of biomass present in the study area, and then, in a second scenario, the possibility of utilizing the uncultivated area for biofuel crop cultivation, without converting the existing production system.

Evaluation of total availability of biomass

After defining the land areas and volumes of available biomass, using the waste coefficient, it is possible to determine the volumes of dedicated biomass (expressed in terms of kton of dry substances) available for energy production (Table 8).

Methodology for environmental evaluation and energy estimation

Hypothesis of study

In order to determine whether the use of biomass in the region of Basilicata is environmentally feasible, it is necessary to perform an evaluation of environmental compatibility by using the concept of environmental balance. The purpose of such analysis is to determine the impacts of the existing plants on the region, and also to evaluate this aspect in connection with the energy possibilities in the Basilicata region, by exploiting the full potential of energy from biomass. 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.

Initial considerations

The domestic boilers present in the analyzed area are fed 75 % by methane and 25 % by wood (biomass). The basis of a balance calculation includes a number of assumptions

Table 9 Definition of the CO₂ emitted (by the biomass plant) and of the CO₂ adsorbed by the plants during their growth

CO ₂ emitted by the biomass combustion plant kg CO ₂ /ton biomass	Minimum CO ₂ plant adsorption	Mean CO ₂ plant adsorption	Maximum CO ₂ plant adsorption
1,835	598	1,347	2,096

Table 10 Minimum biomass heating values

Forestry biomass	Forestry products	14.4 MJ/kg
Agricultural biomass	Straw	17.28 MJ/kg
	Pruning	14.4 MJ/kg
	Olive residues and marc	12.96 MJ/kg
Biofuel crops	Cane	17 MJ/kg
	Panico	17.2 MJ/kg
	Poplar trees	14 MJ/kg

regarding electricity and thermal energy use, and we hypothesized two different configurations:

- electrical configuration,
- cogenerative configuration.

In the electrical configuration, all the electricity produced by the biomass plant is transferred to the network; for the cogenerative configuration, since we do not know the effective percentage of users connected to the district heating network, we have evaluated different hypotheses, expressed as percentages of users connected to the network; more specifically, we have considered between 10 and 100 % of user connection to the district heating network.

We underline, as reported in the paragraph above, that the two different configurations are applied to the two considered cases: minimum and potential scenario.

We then assumed that:

- for anaerobic digestion, we could disregard the emissions of CH₄ and N₂O;
- the CO₂ 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 LCA was not used in this study). In fact, on the basis of the specific literature (Blengini et al. 2011; Panepinto and Genon 2012) the combustion of biomass in biomass combustion plant is considered CO₂ neutral. In order to verify this affirmation we tried to draw up a comparison between the CO₂ emitted from the combustion plant and the CO₂ adsorbed from the plants during their growth. In order to establish this last term we draft (tipo “stesura”) a balance between the CO₂ adsorbed by the plants during their growth (IPCC 2007) and CO₂ released during their

respiration. By drawing this balance we can note that the CO₂ released from the plants during their respiration is an argument not very studied (Palliotti and Silvestroni 2007; Amthor 2000; Poorter et al. 1990). Anyway, it is possible assume that the CO₂ release is equal of about the 30–80 % of the adsorption (Palliotti and Silvestroni 2007). The range of change it is in connection of the periodicity season. So the results obtained are summarized in the following table (Table 9).

By analyzing the above reported table, we can see that in effect there are some year period where the biomass combustion plant can consider CO₂ neutral and there are other period where this affirmation it is incorrect.

Elaboration methodology

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

- energy balance;
- environmental balance.

Energy balance

In the first case (using the currently available biomass), we used energy balance 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 10).

In order to establish the biomass plant thermal power we used the following equation:

$$\text{Thermal power} = \text{Biomass quantitative} \times \text{lhv.} \quad (1)$$

lhv is lower heating value.

In order to obtain the electric or the electric and thermal energy effectively usable we applied to the thermal power previously determined the appropriate yield.

Because the energy balance was computed for two different configurations of biomass plants, there are two different efficiency values. For the electrical configuration, we used 18 % electrical efficiency; for the cogenerative configuration, we used the commercial value, which translates to 25 % electrical efficiency and 50 % thermal efficiency, for the scenario 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 (Blengini et al. 2011)].

Environmental balance

Next, in order to evaluate the local environmental benefits deriving from biomass use, it is necessary to estimate both

Table 11 Emission factors for heating and electricity (Provincia di Torino 2007; European Environmental Agency 2007; GSE 2012)

Emission factor for electricity				
Fuels	Dust mg/kWh	NO _x	SO _x	CO ₂ g/kWh
Electricity	600	943	29	675
Emission factors for heating				
Fuels	Dust mg/MJ	NO _x	SO _x	CO ₂ g/MJ
Natural gas	0	40	0	55.6
Biomass	60	150	10	–
Biomass plant (with flue gas depuration treatment)	4	30	10	–
Fuels	Dust g/kWh	NO _x	SO _x	CO ₂
Biogas	0	1.826	0.18	250–600

the atmospheric emissions of the existing boilers, and the expected emissions after the installation of the biomass plants. The environmental balance can then be computed according to the following formula:

$$\text{Local/global emissions(added/eliminated)} \\ = \text{biomass plant emissions} - \text{substituted emissions.} \quad (2)$$

Since the biomass-generated electricity that is transferred to the national electric grid replaces a portion of the centralized electricity production, it will prevent a portion of the environmental impacts associated with that centralized production. At the same time, the heat generated by the biomass plant with a district heating network can replace some of the thermal power of the utilities and thus its related impacts, such as primary energy consumption and atmospheric emissions. These are the “avoided impacts.” The “added impacts,” on the other hand, are the emissions from the biomass plants that will be brought online.

In the environmental analysis it is necessary to evaluate all the contributions (both added and avoided) on both local and global “scales.” The environmental balance is analyzed on local and global scales by considering, first, the difference between the added impact for the new power plant and the avoided impact of substituting existing thermal power; and then, the elimination of the impact of centralized electricity production. More specifically, at the local level we considered the emissions avoided for the thermal energy produced by the plant and used for district heating; while at the global level, 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 the plant.

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.

From the point of view of the “biomass plant emissions” we refer to the data reported in Table 11 concerning the emission factors that can be calculated for a biomass plant, taking into account the flue gas treatment. These are literature data. In order to obtain the value of the “biomass plant emissions” we multiply the emission factors reported in Table 11 by the MJ producible from the analyzed plant; in the term biomass plant we also considered the biogas plant and so for the calculation of this contribute we multiply the emission factors for biogas reported in Table 11 for the MJ produced. Finally the total biomass plant emissions is obtained by the sum of the biomass plant emission and the biogas plant.

For the “substituted emissions” we used the emission factors used in the domestic boilers: methane (natural gas) and wood (biomass), added to the emission factors for the production of the electricity.

Remembering that an emission factor is defined as the weight of pollutant issued by a source referred to the entity of energetic production (MJ, kWh), in Table 11 we reported the emission factors to generate thermal and electric energy.

In order to obtain the “substituted emissions” it is necessary to operate, as previously already indicated, a distinction: at local level this value corresponds to the emissions avoided for the thermal energy produced by the plant and transferred by a district heating. At global level this value is obtained by adding two different parts: the

Table 12 Thermal and electrical power obtainable under the minimum scenario

Crops	Primary power (MW)	Cogenerative configuration		Electrical configuration
		Electrical power (MW)	Thermal power (MW)	Electrical power (MW)
Biogas	40.97	16.38	11.47	3.68
Forestry waste	31.08	15.54	10.88	5.59
Agricultural waste	287.09	143.54	100.48	51.69

Table 13 Thermal power obtainable under the potential scenario

Crops	Primary power (MW)	Cogenerative configuration		Electrical configuration
		Electrical power (MW)	Thermal power (MW)	Electrical power (MW)
Biogas	40.97	16.38	11.47	3.68
Forestry waste	31.08	15.54	10.88	5.59
Agricultural waste	287.09	143.54	100.48	51.69
Biofuel crops	302.8	151.4	105.98	54.5

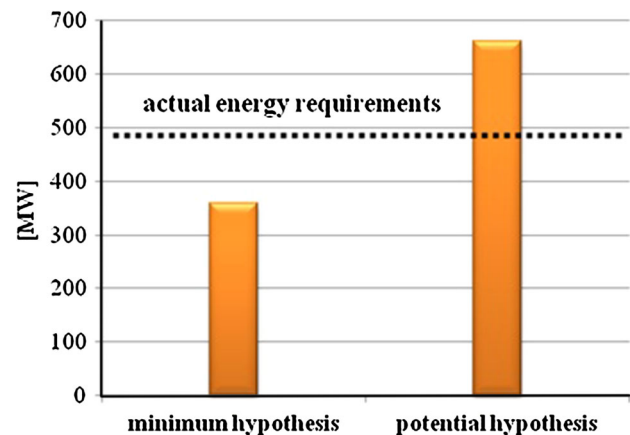
quote of emissions avoided for the thermal energy produced by the plant and transferred by a district heating and the quote of emissions avoided for the electric energy produced by the plant.

The quote of emissions avoided for the thermal energy produced, both at local level analysis and at global level analysis, is obtained by multiplying the emission factors reported in Table 11 by the thermal MJ produced by the plant and potentially transferred to the district heating. The quote of emission avoided for the electric energy produced, is obtained by multiplying the emission factors reported in Table 11 (concerning the electricity) by the electric kWh produced by the biomass plant (Panepinto and Genon 2012).

The following hypotheses have been used in the balance evaluations:

- at the global level, all the electricity produced by the biomass plant is transferred to the network,
- at the local level, not knowing the effective percentage of connection of the users (domestic boilers) to the district heating network, we evaluate different hypotheses expressed as percentages of connection to the network.

The electricity emission factor are computed consider the Italian electrical mix constituted by renewable source

**Fig. 3** Local energy satisfied with the use of biomass**Table 14** Environmental balance for the actual situation on both local and global scales

	NO ₂	SO ₂	Dust
Local scale (ton/year)			
Operational	-124.14	26.70	-48.49
Authorized	-114.70	72.85	-13.68
In itinere	-56.13	11.23	-16.46
Global scale (ton/year)			
Operational	-508.60	14.88	-293.11
Authorized	-915.93	48.21	-523.48
In itinere	-167.03	7.82	-87.02

for the 23.6 %, coal for the 20.1 %, natural gas for the 44.1 %, oil products for the 1.4 %, nuclear for the 4.4 %, other source for the 6.4 % (GSE 2012).

It should be noted that, for a detailed analysis of the environmental effects of the operation of a biogas plant in addition to the CO₂ that is produced during the combustion of biogas and the transport of biomass, we should also have considered the emissions of other gases such as CH₄ emissions produced during biomass pre- and post-storage and N₂O. However, since these emissions are negligible compared with the emissions of CO₂ during the combustion and transport processes, they were omitted from the study.

Results and discussion

In the environmental balance, we assumed that the amount of CO₂ absorbed during plant growth was equivalent to the greenhouse gas emissions released during energy conversion. Consequently, we need to re-emphasize that this study is not a LCA, but an environmental evaluation only during the process of biomass conversion to energy (i.e., the combustion of solid biomass and the anaerobic digestion of manure).

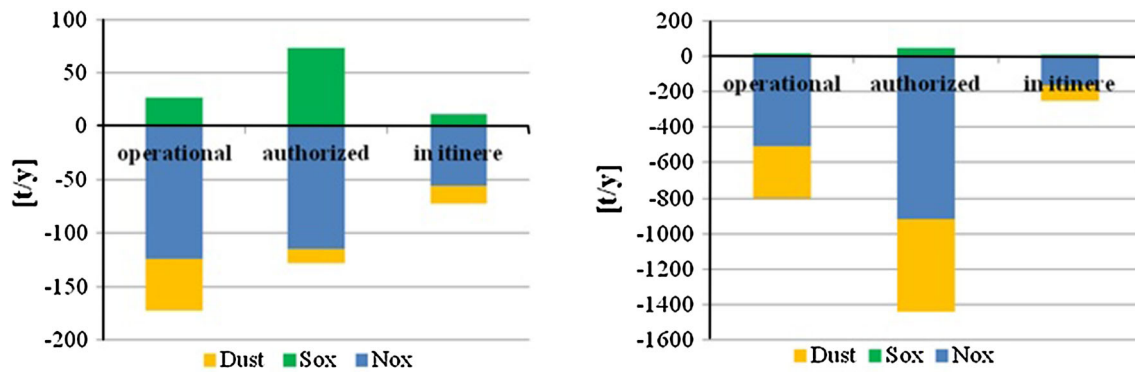


Fig. 4 Environmental balance refers to the actual situation, with local scale on the left, global scale on the right

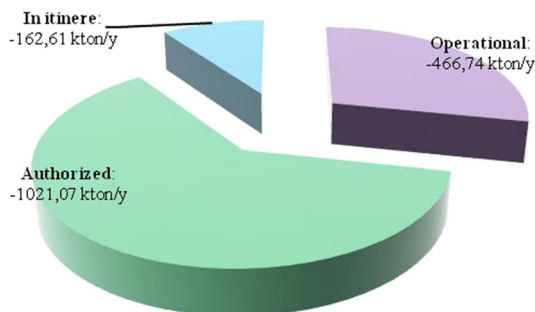


Fig. 5 Environmental balance for the actual situation, for the parameter CO₂

Energy balance

The energy value of biomass was obtained for two different scenarios: minimum and potential, and for two different configurations: electrical and cogenerative.

For the minimum scenario, only the actual production system was considered, taking into account agricultural waste, forestry waste, and zootechnical products. The obtained results are reported in the following table (Table 12).

For the potential scenario, we hypothesized the conversion of unused land to crops for energy production. The obtained results are reported in the following table (Table 13).

The European Union has the ambitious of reaching a 20 % share of energy from renewable sources in the overall energy mix by 2020. In Italy there is a decree called Burden Sharing, whose goal is to distribute the responsibility for reaching the Italian national objective among the various regions.

According to the decree, Basilicata is required to obtain 33.1 % of its energy from alternative sources by 2020. Biomass qualifies as such an alternative source, and considering the local energy requirements (492.73 MW), we can determine the percentage of local energy that could be satisfied with biomass, under both of the two scenarios. Looking at Fig. 3, we see that we can satisfy around 72 % of local energy requirements under the first scenario: using all the available biomass. Under the potential scenario, the

quantity of energy produced would be even higher than the local requirements, and the excess could be exported.

Environmental balance

The environmental balance was initially applied to the actual situation (considering currently operating plants, authorized plants, and plants in the process of being authorized) in order to evaluate the actual impacts on the region. In the following table, we report the local-level results for the three different stages of plants considered: Table 14 and Fig. 4

The above graph shows the emissions from the three groups of plants, for the considered pollutants. On the local scale, we can immediately observe that we have a positive environmental impact for the parameters nitrogen oxide and dust, but we have a worsening of the air quality for the pollutant parameter sulphur oxide. On a global scale, 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.

Figure 5 shows the situation for the pollutant parameter carbon dioxide.

By analyzing the figure above we observe a general improvement of CO₂ emissions at the global level, for environmental balance. This improvement will be greater with a greater number of operating plants. Today, by considering only the plants in operation, it is possible to avoid the emissions of about 460 kton/year of carbon dioxide. We need to note that the CO₂ considered here is the result of a stack balance; in a more detailed analysis, it would be more correct to consider additional sources of CO₂, such as, for example, the transportation and production of fuels.

As mentioned above, we applied the environmental balance to two scenarios: minimum and potential. In these scenarios we used the potential biomass classification above reported, and the results for both scenarios are reported for the two configurations: electrical and

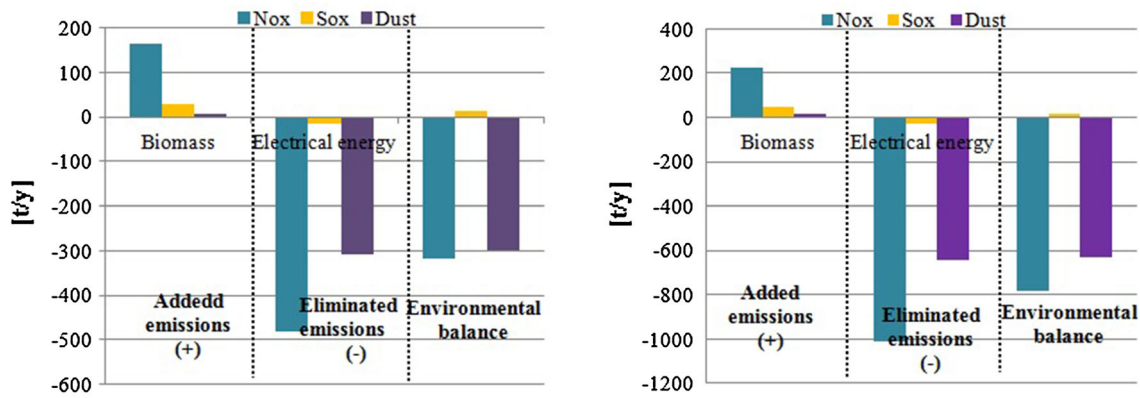


Fig. 6 Environmental balance on the global scale in the electrical scenario: on the *left* minimum scenario, on the *right* potential scenario

Table 15 Environmental balance for the pollutant CO₂ in the electrical configuration scenario

Minimum scenario	345.65 kton/year
Potential scenario	724.21 kton/year

cogenerative. In the following tables and graphs we report the results of the performed calculations.

The first results refer to the electrical configuration, where all the electricity produced by the biomass is transferred to the existing network. The environmental

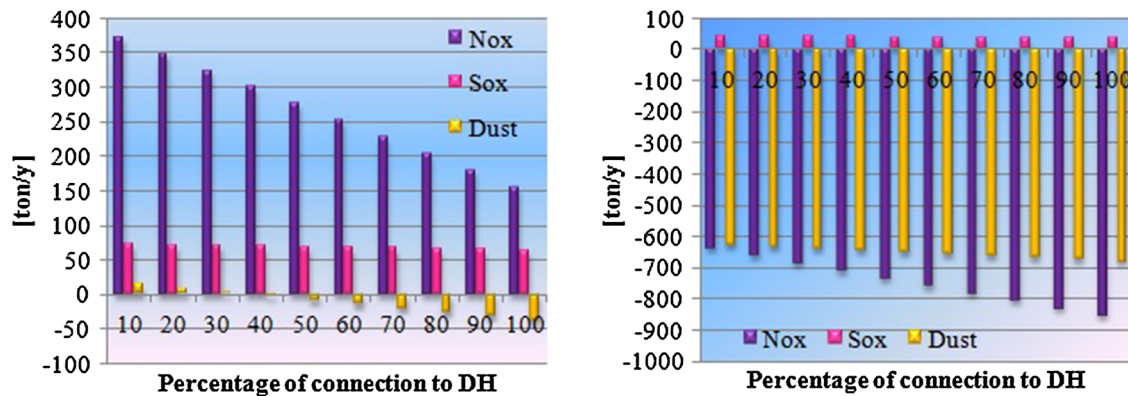


Fig. 7 Environmental balance for the minimum scenario, with local scale on the *left*, global scale on the *right*

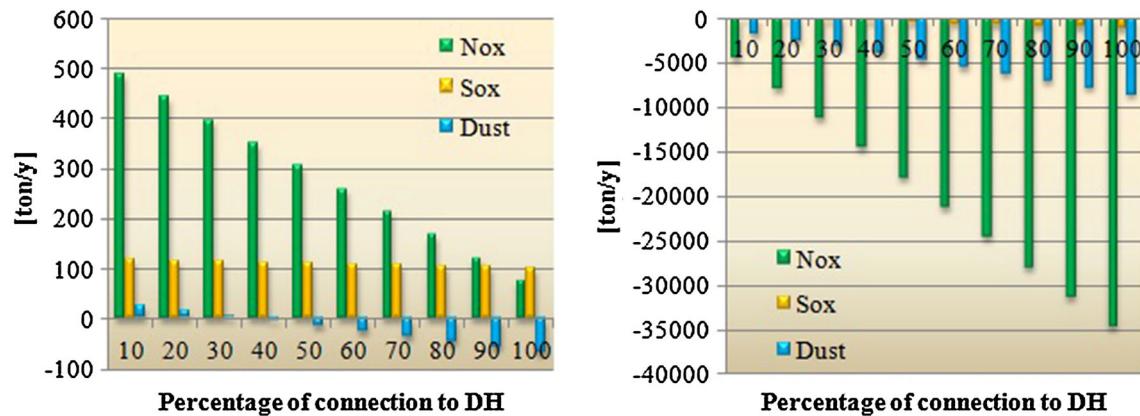


Fig. 8 Environmental balance for the potential scenario, with local scale on the *left* and global scale on the *right*

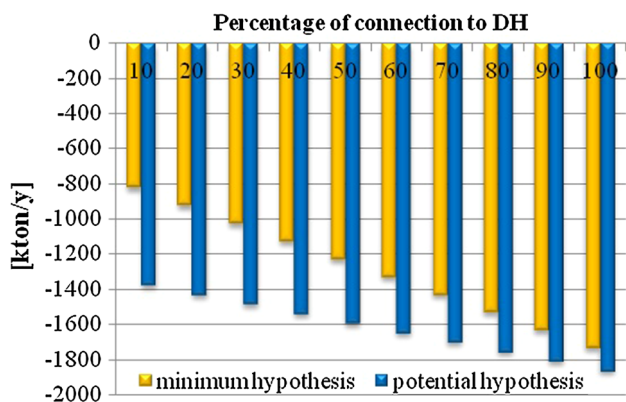


Fig. 9 Environmental balance for the potential and minimum scenarios, for the pollutant parameter CO₂

balance has been applied to both minimum and potential scenarios (Fig. 6).

By analyzing the results of the environmental balance we can see an improvement in the emissions for dust and nitrogen oxide, under both scenarios. On the other hand, we observe a worsening for the parameter sulphur oxide.

On the global scale, we also consider the pollutant parameter carbon dioxide (Table 15).

The second set of results elaborates the environmental balance in the cogenerative configuration scenario, where we have hypothesized different percentages of user connection to the district heating network, by keeping the electrical power at a fixed value and varying the thermal power percentage. The obtained results are reported in the following graphs, where we can see the results of the environmental balance on both local and global scales, in the minimum scenario (Fig. 7).

By analyzing the above figures we can see that on the local scale we have a worsening of the emissions for the pollutant parameters NO_x and SO_x, and that the quantity of pollutant emissions increases with the increasing of percentage of connection to the district heating network; on the global scale, on the other hand, in addition to the increased production of electrical energy, we have an improvement in the pollutant parameters dust and NO_x. And although there is a worsening of sulphur oxide emissions, that increase is due entirely to the increased percentage of connection. As for the pollutant parameter dust, we can observe a general improvement, at the environmental balance level, on both local and global scales.

Finally, we analyzed the potential scenario (the conversion of the actual productive system to increased biofuel crop production). The environmental balance results are reported in the following graphs.

With a detailed analysis of Fig. 8, we can note that we achieved some environmental advantages, for dust, on the local scale, and for nitrogen oxide, dust and sulphur oxide,

on the global scale. 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 CO₂ increases with an increasing of percentage of user connections to the DH. This environmental benefit increases even more, in the potential scenario. The specific results for carbon dioxide are: Fig. 9.

On the contrary, the analysis of sensitivity about the ecological impact, after a lot of consideration and results as reported in the paragraph Result and discussion—Environmental balance, we can note in the following figure that we have an improvement of ecological impact in hypothesis of use of all potential biomass available in the region and using a cogenerative configuration (100 % of connection to district heating) (Fig. 10).

Further considerations

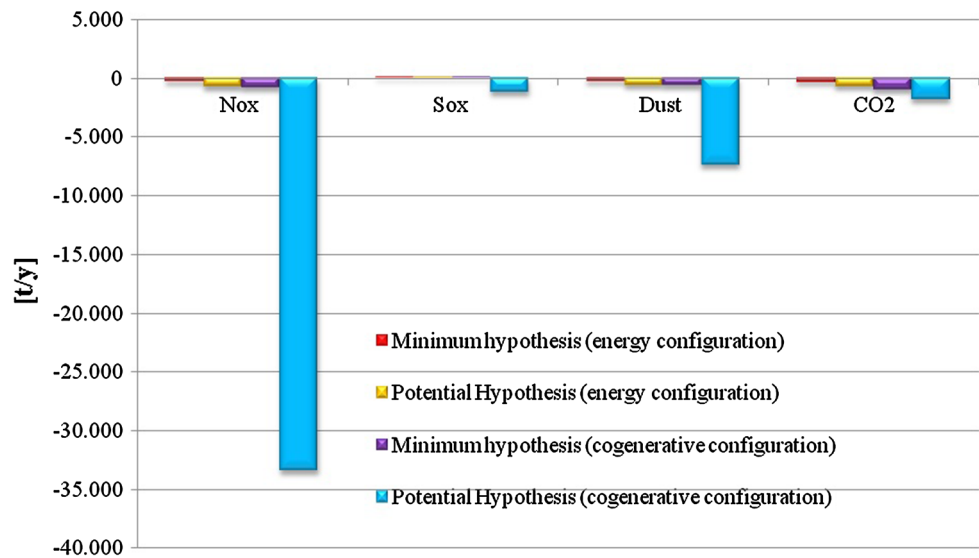
The assumption that the biogenic carbon cycle is neutral (the amount of CO₂ absorbed during plant growth is equivalent to greenhouse emissions released during energy conversion and end-life of residues) is often an oversimplification. For example, in the case of anaerobic digestion plants, we disregarded the emissions (as well as the unpleasant odors) of CH₄ and N₂O, even though these are environmental concerns. Based on reliable emission factors and international studies, it is possible to assess the ammonia and methane emissions. Since these gases contribute to the greenhouse effect with differing intensities, some corrective coefficients have been introduced in order to determine their equivalent CO₂ emissions. This is a measurement unit used to quantify the Global Warming Potential of GHG, and CO₂ is the gas used as a reference for quantifying the GWP of other gases (Table 16).

In this study, we estimated a contribution of CO₂-equivalent emissions of about 14,041.2 ton/year, but based on the environmental balance, we avoided about 112,210 ton/year of CO₂ and therefore the CO₂ balance is always negative, meaning that the use of manure to produce fuel has some benefit in terms of carbon dioxide. This is only an example to underline that LCA is a useful tool, in order to

Table 16 CO₂ equivalent of GHG

Greenhouse gases	CO ₂ equivalent (kg CO ₂ -eq/kg gas)
Carbon dioxide (CO ₂)	1
Methane (CH ₄)	25
Nitrous oxide (N ₂ O)	298

Fig. 10 Sensitivity analysis for the ecological impact



capture the complexity of the environmental evaluation and inter-dependencies existing in the bioenergy chain. In fact, in this way, considering the different processes (agricultural, energy conversion, end of life), it is possible to know all of the environmental impacts, so that an appropriate management of biomass and the use of best technologies to reduce pollutant emissions, could encourage the use of biomass for energy production.

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 Region, and the environmental impacts of such production, taking into consideration the thermo- and bio-chemical processes required. 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. But if we could increase the volume of biomass by cultivating currently unused arable land (the “potential” scenario), the amount of energy produced could be higher than local requirements, enabling export of the excess.

For the environmental impact analysis, the results are different for the two configurations: electrical and cogenerative. The electrical configuration refers to the actual situation in Basilicata, where all the electricity produced can be transferred to the network. In this configuration, for both scenarios (minimum and potential), we can see a real environmental improvement for the pollutant parameters dust and nitrogen oxide, but a worsening of emissions of

sulphur oxide. For the cogenerative configuration, results will depend on the effective percentage of connection of users (domestic boilers) to the district heating network. Hence we evaluated several different scenarios, expressed as percentages of connection to the network. These evaluations showed that, with higher percentages of user connection to the district heating network, 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. Hence, from this point of view, substituting biomass plants for conventional energy sources can be pronounced a definite environmental benefit.

Overall, this study supported three conclusions. First, using biogas as an energy fuel could eliminate negative local impacts of such gas. Secondly, policy makers could apply the methodology used here in future energy planning, in order to reach the objective of European Union Directive 2009/28/EC, of increasing the production of energy from renewable sources to 20 % by 2020. Finally, this evaluation could be used to assess the environmental impact of a single biomass plant on both local and global scales.

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