Waste Biomass Valor (2012) 3:197–206
DOI 10.1007/s12649-011-9099-x

ORIGINAL PAPER

Biomass Thermal Treatment: Energy Recovery, Environmental Compatibility and Determination of External Costs

Deborah Panepinto · Giuseppe Genon

Received: 30 May 2011 / Accepted: 14 November 2011 / Published online: 22 November 2011
© Springer Science+Business Media B.V. 2011

Abstract Climate change is the primary worldwide issue of the twenty-first century, as it threatens not only natural ecosystems but many national economies as well. Since the major contributor to climate change is the emission of greenhouse gases, switching to renewable and clean sources of energy production would result in the most immediate benefit. And one of the main energy sources in this category is biomass. In this work some preliminary evaluations are reported concerning the environmental effects, as well as the related external costs, from both local and global points of view, of a proposed biomass plant to be constructed in Piedmont (northern Italy). The obtained results indicate that, from the local point of view, the environmental effectiveness of the plant is related to the percentage of the thermal energy that can be transferred from the district heating network to the local domestic boilers (with subsequent replacement of the related emissions). From a global point of view, and in particular concerning greenhouse gases (GHG), the carbon dioxide produced from biomass combustion would be balanced by the quantity that is absorbed by the plants during their lifetimes. Hence by operating a biomass plant capable of producing 20 thermal MW, we can remove carbon dioxide emissions equal to about 38.368 ton/year, and avoid external costs of 728.992 €/year, if at least 30% of the produced heat can be transferred to the district heating network.

D. Panepinto (✉) · G. Genon
DITAG, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy
e-mail: deborah.panepinto@polito.it

G. Genon
e-mail: giuseppe.genon@polito.it

Keywords Biomass plant · Greenhouse gas · Energy recovery · District heating · Environmental compatibility · External costs

Introduction

Climate change is the primary worldwide issue of the twenty-first century, as it threatens not only natural ecosystems but many national economies as well. Since the major contributor to climate change is the emission of greenhouse gases, switching to renewable and clean sources of energy production would result in the most immediate benefit. And one of the main energy sources in this category is biomass [1, 2].

Currently, fossil fuels such as coal, oil and natural gas are used for generating a very large proportion of the electricity in the world today. The combustion of these fuels gives rise to carbon dioxide (CO_2), which is a “greenhouse” gas discharged to the atmosphere. Hence there is keen interest in eliminating, as much as possible, the CO_2 emissions from sources such as fossil fuels. In comparison, the carbon dioxide generated in the combustion of biofuels is not considered to make any net contribution to the CO_2 content of the atmosphere, since CO_2 is absorbed by the photosynthesis of living biomass [3]. Biomass, therefore, is widely considered to be a major potential fuel and renewable resource for the future [4–9]. Energy from biomass based on short rotation forestry and from other energy crops can contribute significantly to the objectives of the Kyoto Agreement in reducing greenhouse gases emissions and consequently the problems related to climate change [10, 11].

In this context, in the present work, we studied the proposed construction of a biomass plant for electricity generation, in a small city in Piedmont (northern Italy), with the goal of cogenerating electricity to be sent into the local district heating network, which draws on both electricity and thermal energy. The catchment area of interest was the small municipal area where the plant is to be located.

In order to verify the environmental acceptability (compatibility) of the biomass plant, we performed an evaluation of the modification of emissive fluxes at both local and global levels. We considered the new emissive flux that would result from biomass plant activation, considering the type of fuel used and the system employed for environmental impact containment. We also evaluated the avoided emission flux, resulting from shutting down the domestic boilers, and the electricity generated and introduced into the electricity network. The calculation was based on known emission factors for different plant design solutions, and considered the thermal power of the current systems for comparison, using the tool of mass and energy balances. Finally, we performed an external cost analysis in order to establish the effective advantage or disadvantage of the proposed biomass plant.

Materials and Methods

Theory: Principal Forms of Energy Conversion of Biomass

The potential chemical energy contained in biomass can be utilized in the following applications:

(a) For thermal energy production with a combustion process (this is the main and traditional use);
(b) For the subsequent generation of electrical energy using ORC (Organic Rankine Cycle) or steam turbine systems that exploit the thermal energy from a combustion process;
(c) For electricity production, by using alternative internal combustion engines or gas turbines fed with gaseous fuel obtained from biomass conversion processes;
(d) For liquid biofuels synthesis;
(e) For the synthesis of chemical products derived from biomass.

In the field of biomass conversion to energy [point (a), (b) and (c)] we can identify two different possibilities connected primarily to the molecular structure and the water content of the biomass:

- Thermo-chemical processes (in particular direct combustion, gasification and pyrolysis): these processes are convenient for biomass with carbon–to-nitrogen ratio (C/N) higher than 30 and with a moisture content lower than 30%, or at least with moisture that can be easily reduced to 30% by drying. In this category we find all the vegetable biomasses;
- Biochemical processes (in particular anaerobic digestion): these processes are suitable for biomass with carbon-to-nitrogen ratio (C/N) lower than 30 or with moisture higher than 30%. In this category we find the aquatic cultures, some agricultural by-products, and municipal and industrial effluents. The transformation in energy/fuel is due to enzymatic action, normally in anaerobic conditions (i.e. by the production of biogas).

The thermo-chemical, more diffused processes for the conversion of vegetable biomass to energy are direct combustion and gasification/pyrolysis. In this work, in order to better represent actual situations in Italy, we selected direct combustion (Fig. 1).

Energy and Environmental Balances

In order to evaluate the local environmental benefits, it is necessary to compare the air quality around the assumed CHP (Combined Heat and Power) location before and after installation of the proposed new DH (District Heating) system. Therefore it is necessary to estimate the contribution of the existing boilers to the current emission concentrations in the local air.

Since the electricity to be discharged into the network will substitute for part of the centralized electricity production, the related environmental impacts, expressed in terms of primary energy consumption and atmospheric emissions, will be avoided. The quantification of this impact derives from the considered comparison term. At the same time the thermal energy supplied by the DH system allows the substitution for both the operation of the

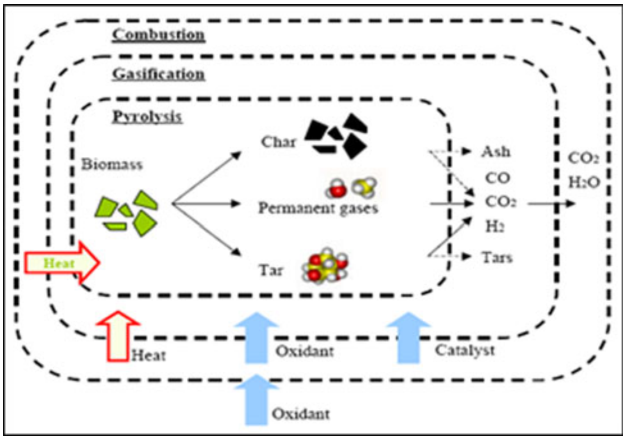

Fig. 1 Thermal processes scheme: direct combustion, gasification and pyrolysis

existing boilers and the related impacts of primary energy consumption and atmospheric emissions. In this case the avoided impacts essentially correspond to those of the substituted processes. In the draft of the environmental balance the two components of the avoided impacts (heat and emissions) constitute a compensation for the environmental load introduced by the DH system.

In addition to the energy and environmental balances, in order to evaluate the gravity of the impact produced by the plant (especially its local impact), it is necessary to consider the results of the dispersion models. With this approach it is possible to calculate the real air-quality modifications: the concentrations (annual mean values and maximum hourly values) that would be introduced by the future plant, and the ones that can be avoided (from eliminated existing domestic boilers). These can be compared with concentration maps [12] (Fig. 2).

In general, starting with a qualitative approach, it is possible to consider that a single plant, compared to many individual boilers, presents many advantages, among them minor pollution reduction and major energy efficiency increases: a large plant will have higher thermal efficiency and better smoke control than several small plants. From the quantitative point of view, the actual amount of heat supplied by district heating can substitute for the larger amount of heat generated by the operation of many boilers, and the relative impacts of avoided primary energy consumption and atmospheric emissions can also be directly measured. In the drafting of an environmental balance the two avoided impacts represent a compensation for the load that would be introduced by the combustion plant.

External Cost Methodology

Externalities are related to social welfare and to the economy. The methodology is, first, to measure the damages to society that are not paid for by its main actors; second, to translate these damages into a monetary value; and third, to explore how these external costs could be charged to the producers and consumers. Indeed, as the market takes into account the private costs, policy makers should try to take into account the external costs.

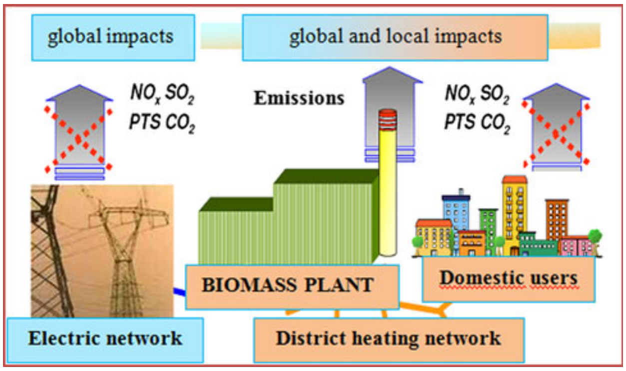

Fig. 2 Environmental balance

The impact pathway approach (IPA) is used to quantify environmental impacts as defined above and as illustrated in Fig. 3, the principal steps of the methodology [13].

In the following figure the external costs relative to the main pollutant are indicated, as they can be defined on the basis of the principal forms of impact; although the results have been established for another situation (the French condition) [13], because of the similarity of the phenomena they can be transferred to our case (Fig. 4).

For the parameter carbon dioxide the external cost is equal to about 19 €/ton [13]; this parameter is quite general, and it was obtained from the market value.

Results and Discussion

Biomass Plant and Catchment Area Data

In the following tables we report the main features (the technical and energy aspects) of the studied biomass plant. Table 1.

From the point of view of energy recovery the system chosen was ORC (Organic Rankine Cycle) Turboden 10 CHP, which uses diathermal oil as a working fluid. An example of this system is shown in Fig. 5. In this figure we can see the thermodynamic cycle and the components of ORC plants. With the chosen ORC system the temperature of the input diathermal oil was 300°C and the temperature of the output diathermal oil was 240°C. The temperatures of the incoming and outgoing hot water were 60 and 80°C, respectively.

From the biomass Lower Heating Value (10 MJ/kg), on the basis of thermal power (20 MW) and plant operation time (availability: 8.000 h/year equal to 288 × 10^5 s/year), it is possible to calculate the biomass feed rate with the following equation:

$$\text{Biomass feed rate [ton/year]} = \frac{\text{Thermal Power} \times \text{Availability}}{\text{LHV}} \qquad (1)$$

The value obtained from Eq. (1) is equal to about 57.300 ton/year.

In the following table we report the main energy plant features.

The catchment area constituted the municipal area where the biomass plant will be located. Then, using the data that have been found and calculated in the comprehensive table, the results are reported in the following:

By analyzing and processing the data reported in Tables 2 and 3, and in particular the indicators of "thermal

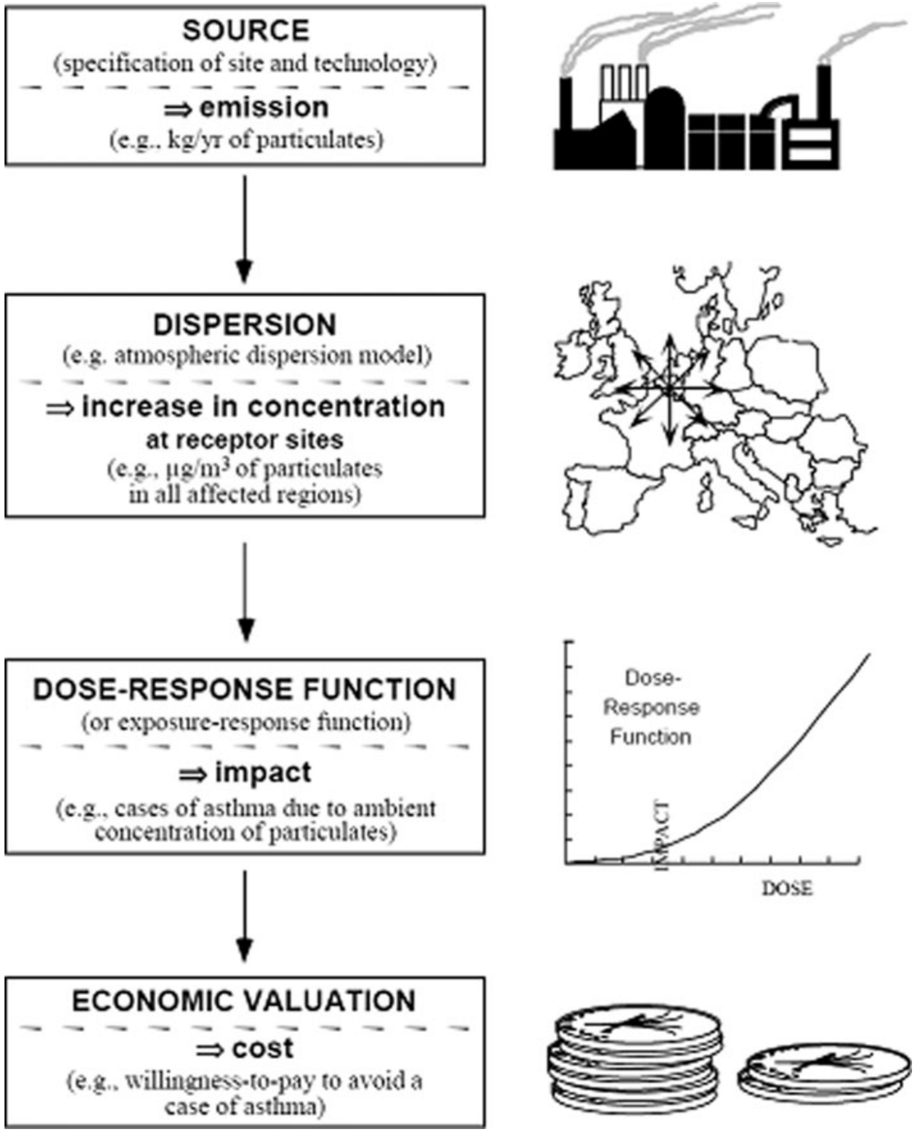

Fig. 3 The principal steps of an impact pathway analysis, using air pollution as an example

production" (Table 2) and "thermal energy requirements" (Table 3) it is possible to ascertain that the produced thermal energy will satisfy all the municipal area thermal energy requirements with a fraction left over, equal about to 30% of the produced energy. For this fraction it will be necessary to find other destinations, such as: industrial production facilities, heating for public and private buildings, and so on. By analyzing the need for thermal energy in the area proposed for the biomass plant, we can see that there are other facilities, some public and some commercial. The public facilities include offices, a nursery school and other schools. The commercial facilities include four restaurants and some shops.

In the following table we can see the required thermal energy for the different types of facilities. Table 4.

Our analysis showed that of the domestic boilers that could be replaced with heat from the biomass plant, 72% currently use oil and 28% use natural gas (average use for domestic boilers declared in the Piedmont Region).

Initial Considerations

In the proposed work we want to examine, in terms of environmental balance, the effects on air quality that the introduction of the biomass plant would provide at both local and global levels. The bases of the environmental balance are provided by the following equation:

$$\begin{aligned}&\text{Local/global emissions (added/eliminated)}\\&= \text{biomass plant emissions} - \text{substituted emissions} \qquad (2)\end{aligned}$$

From the point of view of the "biomass plant emissions" we refer to the data reported in Table 5 below. These data represent the emission factors that can

Fig. 4 External costs

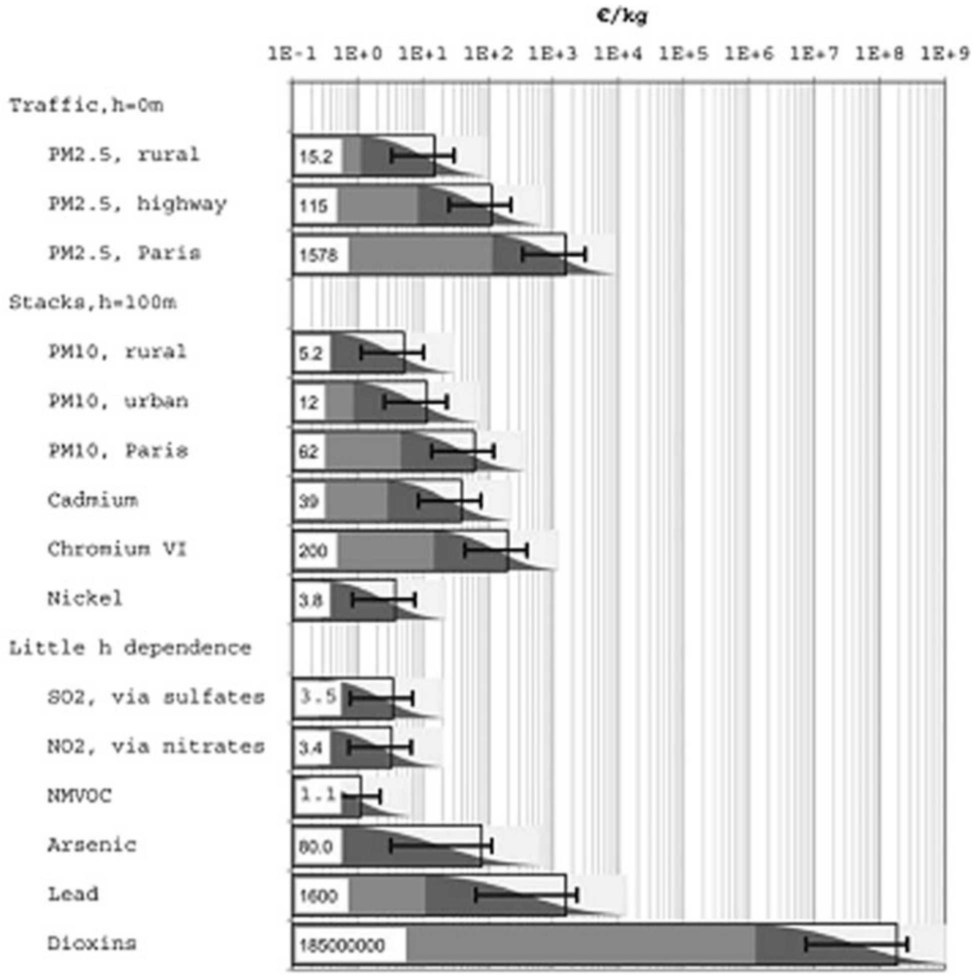

Table 1 Main features of the studied plant

Fuel	Biomass—different residual biomass stream (“clean” wood and waste wood)
Technology	Combustion on fluidized bed
Energy recovery	Organic rankine cycle (ORC)
Capacity	20 MW
Availability	8,000 h/year
η_e	20%
η_{tot}	80%
Treatment emissions	
Dust	ESP (Electrostatic precipitation)
NO_x	SCR (Selective catalytic reduction)
SO_x	Injection of CaOH

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 5 by the MJ produced from the analysed plant.

For the “substituted emissions” we used the emission factors for the domestic boilers and the natural gas and oil combustion, 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 Tables 6 and 7 we respectively report the emission factors to generate thermal and electric energy.

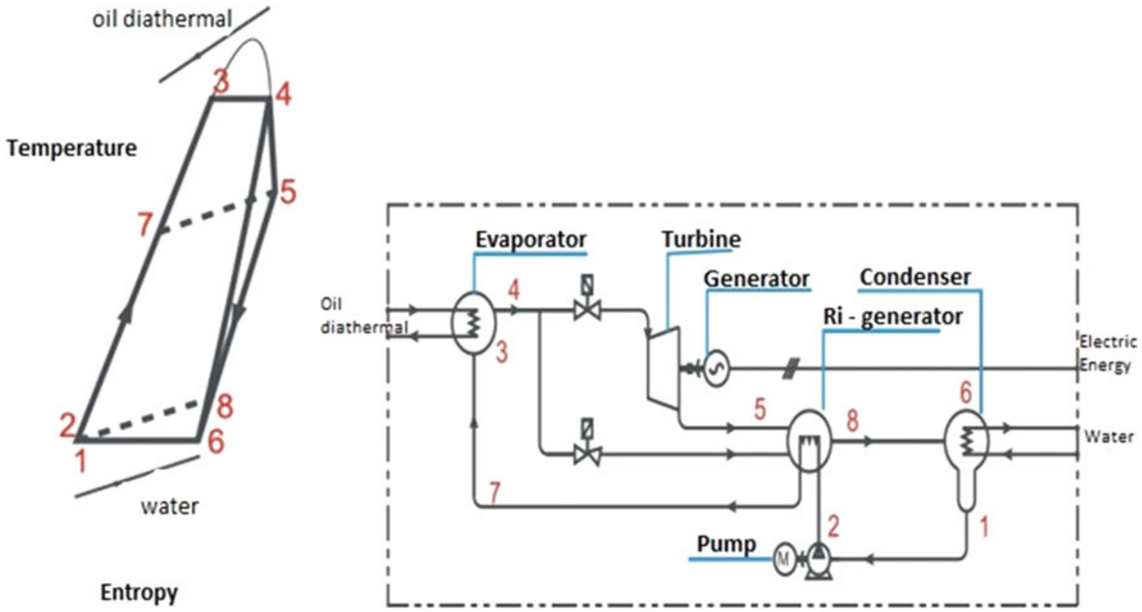

Fig. 5 Thermodynamic cycle and components of ORC plants

Table 2 Summary of the biomass plant energy data

Required biomass	57.300 ton/year
Plant capacity	20 MW
Electric production	4 MW
Thermal production	12 MW

Table 3 Data for the catchment area

Population	6.000
n° houses	4.000
Thermal energy requirement	67 GWh/year

Table 4 Required thermal energy for the different types of facilities

Utilities	Required thermal energy [MWh/year]
Residential utilities	67.200
Public utilities	3.100
Commercial utilities	4.500

Table 5 Emission factors considered for biomass plants [14]

	mg/MJ			g/MJ
	Dust	NO_x	SO_x	CO_2
Biomass plant with flue treatment	4	30	10	–

By examining the Table 6, the emission factors represent the milligrams, respectively of total dust, nitrogen oxides and sulphur oxides and the grams of dioxide carbon, for each produced MJ when it is used a boiler with natural gas, gas oil, fuel oil or biomass. By examining, now the Table 7 the emission factors represent, respectively, the milligrams of total dust, nitrogen oxide and sulphur oxide and the grams of carbon dioxide, for each generated electric kWh.

2In order to obtain the “substituted emissions” it is necessary to operate 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 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 6 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 7 by the electric kWh produced by the biomass plant.

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.

Table 6 Emission factors for the main fuels for heating use [14]

Fuels	mg/MJ			g/MJ
	Dust	NO_x	SO_x	CO_2
Natural gas	0	40	0	55.6
Gas oil	3.5	60	100	746
Fuel oil	5	100	140	84.5
Biomass	60	150	10	–

Table 7 Emission factors for electricity production [14]

Fuels	mg/kWh			g/kWh
	Dust	NO_x	SO_x	CO_2
Electricity	600	943	29	675

From the point of view of the analyzed pollutant parameters the analysis with reference to the considered scale is as follows:

- On the local and global scales, the considered parameters are: dust, nitrogen oxide and sulphur oxide;
- On the global scale only, the considered parameter is carbon dioxide.

Subsequently, after performing the environmental balance analysis, an external costs analysis was performed in order to establish the damage or the advantage derived from the studied biomass plant. In order to perform the external costs analysis we used the data, expressed in terms of €/kg (€/t only for the parameter CO_2) reported in Fig. 4.

Environmental Balance on the Local Scale and Analysis of the External Costs

As the ratio of energy that will be effectively transferred varies on the local level, we tested different hypotheses for the district heating network connection, expressed as percentage values. The obtained results are reported in Table 8 and in Fig. 6. In Table 8 we report the numerical value of the added emissions (attributable to the introduced biomass plant) and the values of the avoided emissions (attributable to the substitution and hence the shut-down of some domestic boilers) with reference to the connection percentage to the district heating network.

In Fig. 6 we report the results expressed as environmental balance.

By considering the results reported in Fig. 6, we observe that the environmental advantage of the plant is obviously correlated to the percentage of connection to the district heating network, and therefore, from the local environmental balance point of view, to the amount of thermal energy that can be effectively transferred.

If we examine the graph in more detail, considering the dust parameter we have a general worsening of the air quality (because the values of the environmental balance are positive for every percentage of connection). Considering nitrogen oxide we observe an improvement in air quality (from the environmental balance point of view) when the connection rate exceeds 90%. Finally, considering sulphur oxide we can observe an improvement in air quality when the connection rate reaches 30%.

The results of the external cost analysis are also very interesting. These results are reported in Fig. 7.

By analyzing these results we can see that we have an advantage with a connection rate of 70% or higher. In fact if the connection is less than 70% the balance of impacts leads to an increase and to an additional external cost, for more the 70% there is a contrary aspect.

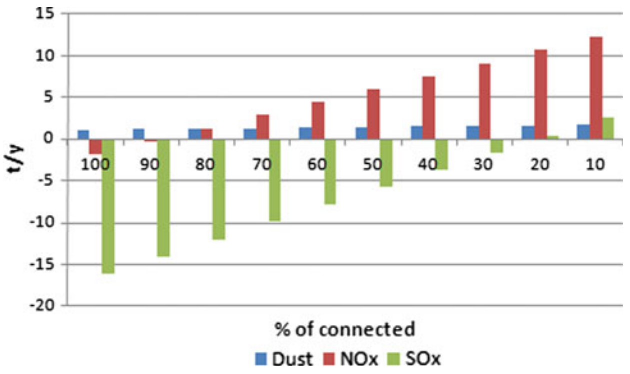

Fig. 6 Environmental emissions balance as a function of the connection percentage (local scale)

Table 8 Added and avoided emissions (local scale)

	Biomass plant emissions [ton/year]	Emissions avoided, on local scale, in function of the connectable percentage [ton/year]									
		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Dust	1.8	0.7	0.63	0.56	0.49	0.42	0.35	0.28	0.21	0.14	0.07
NO_x	13.8	15.6	14.04	12.48	10.92	9.36	7.8	6.24	4.68	3.12	1.56
SO_x	4.6	20.7	18.63	16.56	14.49	12.42	10.35	8.28	6.21	4.14	2.07

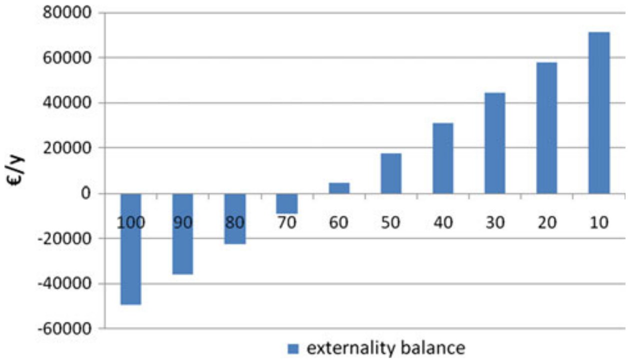

Fig. 7 External costs analysis (local scale)

Environmental Balance on the Global Scale and Analysis of the External Costs

In this case, there is a difference compared to the previously reported local-scale evaluation where the “avoided impact” consists exclusively of the produced and transferred thermal energy; on the global scale this avoided impact aspect consists of two parts: produced and transferred thermal energy and produced and transferred electricity.

In the performed evaluations we used the following hypotheses:

- For electricity, we considered that it is fully transferred to the network;
- For thermal energy we have evaluated several different scenarios of connection rates of the domestic boilers to the district heating network.

Our results are as follows. In Table 9 we report the additional new plant emissions and the avoided existing plants emissions as a function of the percentage of the thermal energy substituted. In Fig. 8 we report the global-scale environmental balance in reference to the pollutant parameters: dust, nitrogen oxide and sulphur oxide, as a function of the percentage of connection to the district heating network. In Table 10 and in Fig. 8 we report the environmental balance, on the global scale, in reference to the parameter carbon dioxide as a function of the percentage of connection to the district heating network.

If we now examine in detail the two graphs (8a and 8b), considering the sulphur oxide parameter we observe a general improvement in air quality from the point of view of environmental balance: this improvement obviously changes as a function of the percentage of connection to the district heating network and therefore as a function of the effectively transferred thermal energy. Considering nitrogen oxide we observe an improvement when the connection percentage to the district heating network exceeds 90%. Considering the dust parameter, from the results reported in the Fig. 7b, it is possible to observe an improvement of the global quality when the percentage of district heating network connection exceeds 60%.

Next we analyze the carbon dioxide parameter.

By analyzing the results reported in Fig. 9 we observe, at the level of global environmental balance, a situation of general improvement, although this improvement depends on the connection rate to the district heating network. It is also important to clarify that the results reported in Fig. 9 represent the carbon dioxide environmental balance “at the chimney.” Actually, in a context of general comparison, it would be necessary to also consider other sources of CO_2 emissions, such as, for example, transportation and fuel production. This aspect would need to be considered in the case of an actual LCA analysis instead of a sample carbon dioxide emission balance.

Next we analyze the results of the external cost analysis. The obtained results are reported in Fig. 10. (The contribution of dust to the externality balance can be disregarded in comparison with the other contributions.)

By analyzing the results reported in the Fig. 10 we can see that the external costs trend is similar to the environmental balance referred to in the carbon dioxide parameter trend. The reason for this similarity is that on the global scale the parameter CO_2 is the predominant pollutant relevant to global environmental balance.

For determining the total cost of the proposed solutions, it is necessary to consider together the external costs connected to the different types of impact and the industrial costs directly incurred to the plant operators. In the specific case of energy production, both generation, in terms of the construction and operation of the thermal plant, and heat demand, in terms of the network required for heat transmission, must be considered.

Table 9 Added and avoided emissions (global scale)

	Biomass plant emissions [ton/year]	Emissions avoided, on global scale, in function of the connectable percentage [ton/year]									
		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Dust	1.8	2.1	2.03	1.96	1.89	1.82	1.75	1.68	1.61	1.54	1.47
NO_x	13.8	44.4	42.84	41.28	39.72	38.16	36.6	35.04	33.48	31.92	30.36
SO_x	4.6	65.9	63.83	61.76	59.69	57.62	55.55	53.48	51.41	49.34	47.27

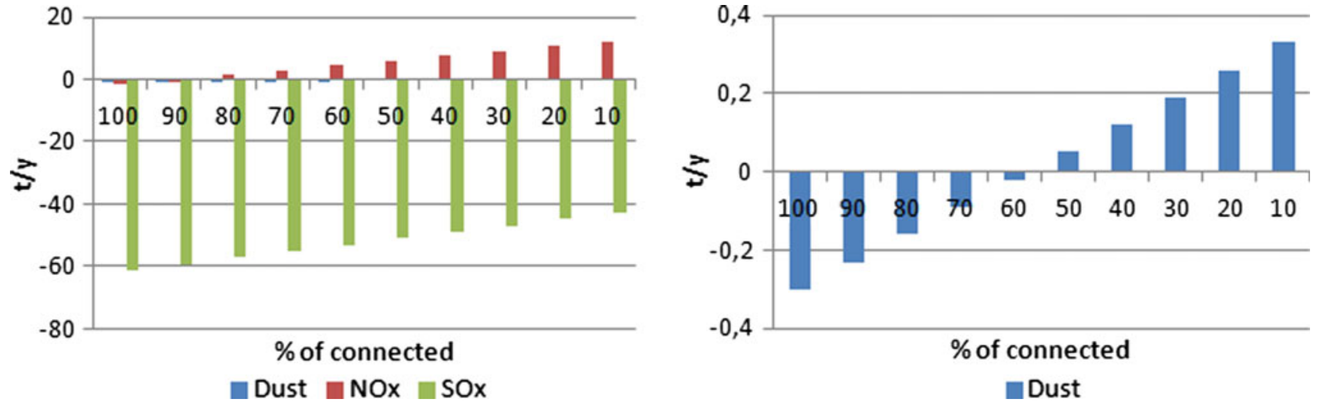

Fig. 8 **a** Environmental emission balance as a function of the connection percentage (global scale) **b** Detail of the environmental emissions balance in reference to dust

Table 10 Environmental balance on the local scale

Pollutant parameters	Emission balance, local scale
Dust [ton/year]	+1.59
NO_x [ton/year]	+9.12
SO_x [ton/year]	−1.61

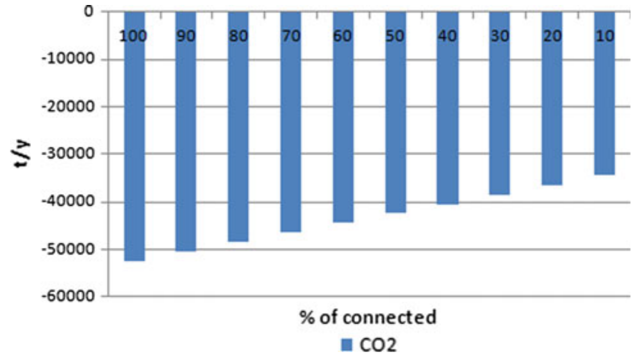

Fig. 9 Environmental emissions balance as a function of the connection percentage (global scale) in reference to the parameter CO_2

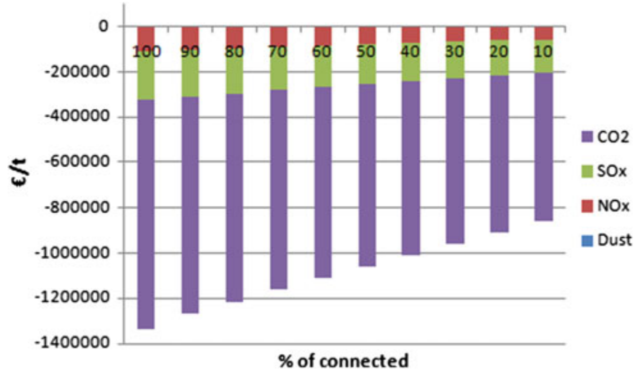

Fig. 10 External costs analysis (externality balance)

Environmental Balance and External Costs Analysis Based on Hypothesis About Connection Rate

After having introduced the environmental balance factor, on both local and global scales, by simulating different scenarios and evaluating different percentages of connection to the district heating network, we now assume the percentage of connection that seems to be the most appropriate for the proposed situation. Based on this percentage we can individuate the corresponding environmental balance values.

If we adopt the hypothesis of transferring 100% of the produced thermal energy, this corresponds to the connection of all civil users to the district heating network and to the use of the residual quotient (about 30%) for other uses (like industries, public and private facilities, and so on). If we were able to connect the entire municipal area to the district heating network, the resulting percentage of utilization of the produced thermal energy from the biomass plant would be about 70%. Because of the dispersion of property ownership (in the zone under consideration) we can estimate that the percentage of connection to the district heating system will probably not exceed 30% of the civil facilities, and because today the public and commercial facilities are not favorably disposed to a connection to the district heating system (mainly because of the cost of connection) this appears to be the most realistic connection percentage. By using this percentage we can identify the corresponding values for the environmental balance. These values are summarized, for simplicity, in Table 10.

By examining the Table 10 (data derived from Table 8 and Fig. 6) it can be concluded that, after the biomass plant activation, we would experience a worsening of the air quality, at the environmental balance level, relative to the parameters of dust and nitrogen oxide, and an improvement in the pollutant parameter sulphur oxide.

Table 11 Environmental balance on the global scale

Pollutant parameters	Environmental emissions, local scale
Dust [ton/year]	+0.19
NO_x [ton/year]	−19.68
SO_x [ton/year]	−46.81

We can now examine the situation on the global scale. In this case the adopted hypothesis corresponds to transferring all the electricity produced to the electric network, and directing 30% of the thermal energy, with a district heating network, to domestic boilers.

Analysis of the results reported in Table 11 (data derived from Table 9 and Fig. 8) leads to the observation of a substantial improvement in the air quality for the pollutant parameters nitrogen and sulphur oxide. On the other hand, we would experience a slight worsening of the dust parameter.

The avoided CO_2 is equal to 38.368 tons/year (from Fig. 9). From the point of view of the external costs, this percentage of connection results in a value of − 957.459 €/year on the global scale and + 44.453 €/year on the local scale. This result is justified because a large part of the benefit comes from the CO_2 avoided.

Conclusion

In this work we evaluated the acceptability, from the environmental point of view, of a biomass combustion plant for the generation of thermal and electrical energy, to be constructed in a small city in Piedmont, in northern Italy. This acceptability was evaluated using the tool of environmental and energy balance. The evaluation was performed based on specific hypotheses:

- For electricity: all the energy produced by the plant would be transferred to the electricity network;
- For thermal energy: we performed different simulations with reference to different hypotheses, expressed in terms of percentage of connection to the heating network.

We then identified the scenario (i.e., the percentage) that represents the best situation. The main conclusion was that the most effective scenario (for both convenience and acceptability), from the environmental point of view, is to transfer all the produced thermal energy. In this way the emissions produced from the biomass plant are balanced by the values of avoided emissions attributable to the shutdown of many of the domestic boilers. In the case where all the produced energy is transferred to the network, the balance will lead to an improvement in air quality. This improvement (and hence the advantage) decreases with a decreasing percentage of transferred thermal energy.

On the global scale, and in particular concerning greenhouse gases, these plants are always advantageous: the CO_2 produced from biomass combustion is balanced by the quantity that is absorbed by the plants during their lifetimes. The global advantage, in this case, is therefore in no doubt.

The above reported considerations are also confirmed by taking into consideration the results of the external costs analysis. In fact it has been verified from the results connected with the external costs that this advantage aspect can be confirmed.

References

1. Boman, U.R., Turnbull, J.H.: Integrated biomass energy systems and emissions of carbon dioxide. Biomass Bioenergy **13**, 333–343 (1997)
2. Dornburg, V., Van Dam, J., Faaij, A.: Estimating GHG emission mitigation supply curves of large–scale biomass use an a country level. Biomass Bioenergy **31**, 46–65 (2007)
3. Albertazzi, S., Basile, F., Brandin, J., Einvall, J., Hulteberg, C., Fornasari, G., Rosetti, V., Sanati, M., Trifirò, F., Vaccari, A.: The technical feasibility of biomass gasification for hydrogen production. Catal. Today **106**, 297–300 (2005)
4. Bridgwater, A.V.: The technical and economic feasibility of biomass gasification for power generation. Fuel **74**, 631–653 (2005)
5. Caputo, A.C., Palumbo, M., Pelagagge, P.M., Scacchia, F.: Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass Bioenergy **28**, 35–51 (2005)
6. Hanaoka, T., Inove, S., Uno, S., Ogi, T., Minowa, T.: Effect of woody biomass components on air–steam gasification. Biomass Bioenergy **28**, 69–76 (2005)
7. Hohenstein, W.G., Wright, L.L.: Biomass energy production in the United States: an overview. Biomass Bioenergy **6**, 161–173 (1994)
8. Hustad, J., Skreiberg, Ø., Sonju, O.: Biomass combustion research and utilization in IEA countries. Biomass Bioenergy **9**, 235–255 (1995)
9. Van Den Broek, R., Faa Ij, A., Van Wick, A.: Biomass combustion for power generation. Biomass Bioenergy **11**, 271–281 (1996)
10. Maniatis K.: Progress in Biomass Gasification: An Overview, 2002
11. IEA Bioenergy: The role of bioenergy in greenhouse gas mitigation, Position paper, IES Bioenergy, New Zealand, 1998
12. Genon, G., Marco, Torchio.F., Poggio, A., Poggio, M.: Energy and environmental assessment of small district heating systems: global and local effects in two case-studies. Energy Convers. Manag. **50**, 522–529 (2009)
13. European Commission edited by Bickel Peter and Friedrich Rainer: ExternE—Externalities of Energy Methodology 2005 update, Institut für Energiewirtschaft und Rationelle Energieanwendung—IER Universität Stuttgart—Germany (2005), ISBN: 92-79-00423-9
14. Fracastoro G.V. et al.: Politecnico di Torino: Requisiti tecnici per impianti a cippato superiori a 350 kW. http://www.fire-italia.it/forum/pellet/all_oltre_350.pdf. Accessed 15 July 2009