Environmental balance study for the construction of a biomass plant in a small town in Piedmont (Northern Italy)

D. Panepinto & G. Genon
DITAG Department, Politecnico di Torino, Italy

Abstract

In consideration of local critical aspects in opposition to overall environmental benefits (decrease of GHG generation), the aim of this work is to verify the local acceptability from the point of view of air quality of the territory in question for a biomass plant. The plant to be realized in a small town located in Piedmont, Northern Italy, will be constructed to produce electricity and heat. In order to verify the aspect of compatibility we performed an evaluation of the emissive flow modification that in the hypothesis of the biomass plant activation should be introduced in the municipal area. The evaluation has been conducted by using mass and energy balances as a tool.
Keywords: biomass plant, district heating, environmental balance, environmental impact, energy recovery.

1 Introduction

Climate change is the major planetary threat of the 21st century, not only for the natural ecosystems, but for some national economies too. In order to reduce immediately the emissions of greenhouse gases, it is strongly proposed to use renewable and clean sources instead of fossil fuels. In this research, one of the most important solutions consists of a modern use of the biomass (Boman and Turnbull [1]; Dornburg et al. [2]).

Fossil fuel such as coal, oil and natural gas are generating a very large proportion of the electricity that is produced annually around the globe. The combustion of these fuels gives rise to carbon dioxide (CO_2), which is a

WIT Transactions on Ecology and the Environment, Vol 143, © 2011 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ESUS110241

"greenhouse" gas discharged into the atmosphere. There is a growing interest in eliminating, as much as possible, the CO_2 emissions from fossil sources. In comparison, the carbon dioxide generated in the combustion of biofuels is not considered to give any net contribution to the CO_2 content of the atmosphere, since it is absorbed by photosynthesis when the new biomass is growing (Albertazzi et al. [3]). Biomass is widely considered to be a major potential fuel and renewable resource for the future (Bridgwater [4]; Caputo et al. [5]; Hanaoka et al. [6]; Hohenstein and Wright [7]; Hustad et al. [8]; Van Den Broek et al. [9]). In this sense, energy from biomass based on short rotation forestry and also from the exploitation of other energy crops can contribute significantly towards the objectives of the Kyoto Agreement in reducing greenhouse gas emissions and consequently the problems related to climate change (Maniatis [10]; IEA Bioenergy [11]).

In this work, we studied the realization, in a little community in Piedmont, north Italy, of a biomass plant for energy generation, with the finality to operate in conditions of cogeneration by producing electric energy to be immitted into the electric net and thermal energy that is destined to satisfy the local requirements with a district heating network. The interested catchment area is the small municipal area where the plant will be located.

In order to verify the environmental acceptability (compatibility) of the biomass plant we performed an evaluation of the emissive fluxes modification at local level, by using environmental balance as a tool.

We have considered the new emissive flux that can be predicted in direct relationship to the biomass plant activation as a result from the thermal power plant, the type of fuel used and the system that will be employed for the environmental impact containment. On the other side we have evaluated the avoided emission flux resulting from the turning off of the domestic boilers able to be substituted from the produced thermal energy.

The calculations that have been performed are based on the knowledge of the emission factors for different plant design solutions and it is defined by considering also the thermal power of the used systems; mass and energy balances were used as a tool in this study.

2 Biomass plant

In Tables 1 and 2 we report the main features (concerning technical and energetic aspects) of the studied biomass plant.

By analyzing the data reported in Table 2 we can observe that the maximum thermal power produced from the plant (7,15 MW) cannot be fully utilized even if all the users of the whole town (6,8 MW) were connected.

In the following table we report the pollutant concentration that, from the technological operating scheme, can be estimated as output of the plant.

In Table 2 we report the main energetic plant features.

Table 1: Main features of the studied plant.

Fuel		Biomass – wood pellets
Technology		Combustion on grate system
Energy recovery		boiler
Availability		7.800 h/y
Treatment emissions	Dust	ESP (Electrostatic Precipitation)
	NO_x	SNCR (Selective Catalytic Reduction)
	SO_x	Injection of CaOH

Table 2: Summary of the biomass plant energetic data.

Gross thermal power	14,6 MW
Available thermal power	13 MW
Maximum thermal power	7,15 MW
Maximum required thermal power*	6,8 MW
* this data represent the maximum required thermal power (by considering all the public and private users present in the municipal area)	

Table 3: Pollutant concentration as output of the plant.

Flow [m^3/h]	Emission time [h/d]	Pollutant substance	Concentration [mg/m^3]
33.000	24 - continue	Dust	10
		NO_x	180
		SO_x	200
		CO	200

3 Catchment area and connectable volumes

The catchment area will be composed of the municipal area where the biomass plant will be located.

All the data that has been found has been summarized in a comprehensive table which is depicted below:

Table 4: Town catchment area.

Population	770
Number of resident families	394
Number of total inhabitations	983
Surface of resident inhabitation [m^2]	43.965
Volume of resident inhabitations [m^3]	131.965
Total inhabitations volume (resident + not resident) [m^3]	390.000

From this, on the basis of the data obtained and their aggregation, we can define the volumes for connection to the future district heating network. These volumes are shown in Table 5.

In the elaboration of the environmental balance we examined four different situations referring to four different scenarios of connection to the district heating system:

- hypothesis 1: the entire volume of the analyzed town (public and private utilities) will be connected to the district heating network (no distinction between residents and non residents, and no consideration of the aspect of volumes effective capacity to be connected or not);
- hypothesis 2: only the volumes of the public and private buildings that can be really connected to the district heating network with an acceptable cost will be considered without distinction between resident and non-residents;
- hypothesis 3: the total volume of residents will be connected to the district heating network (no distinction between effectively connectable and not connectable);
- hypothesis 4: the total volume of residents effectively connectable will be connected to the district heating network.

Table 5: Volume connectable to the district heating network.

Resident connectable volume [m^3]	81.818
Total connectable volume (resident + not resident) [m^3]	300.000

On the basis of the data reported in Tables 4 and 5 we calculated, for each introduced hypothesis, the thermal energy really transferred.

The boilers that are installed in the homes located in the examined town are fed in part (the majority) by methane, and, in part (a small part) by wood. On the basis of the data that were supplied by the local authority it has been possible to

Table 6: Really distributed thermal power.

	Hypothesis 1	Hypothesis 2	Hypothesis 3	Hypothesis 1
Heat specific requirement [kWh/m^3 y]	44	44	44	44
Period of heat requirement [h/y]	2.500	2.500	2.500	2.500
Required thermal power [kW_{th}]	**6.864**	**5.280**	**2.323**	**1.440**

establish, for each of the four analyzed hypotheses, the fuel composition (with consideration of the percentages of methane and wood) and, consequently, the thermal power that today is covered by methane and wood.

The results of this elaboration are presented in Table 7.

Table 7: Definition of the boiler input and of the covered thermal power.

Hypothesis	Boiler feed	Satisfied thermal power [%]	Satisfied thermal power [kW_{th}]
Hypothesis 1	Methane	95	6.521
	Wood	5	343
Hypothesis 2	Methane	95	5.016
	Wood	5	264
Hypothesis 3	Methane	99	2.300
	Wood	1	23
Hypothesis 4	Methane	99	1.426
	Wood	1	14

4 Energetic and environmental balance

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 DH (District Heating) system. That is a consequence of the modified emissions scenario. Therefore it is necessary to estimate the contribution of the existing boilers to the air emissions.

The electric energy distributed by the network substitutes a part of the centralized electric production, and so, the relative environmental impacts expressed in terms of primary energy consumption and atmospheric emissions are avoided. The quantification of this impact derives from the considered comparison terms. At the same time the thermal energy supplied by DH system allows to substitute the operation of existing boilers and the relative impacts, as primary energy consumption and atmospheric emissions. In this case the avoided impacts in a univocal way correspond with those of the impacts effectively substituted. In the draft of an environmental balance the two components of the avoided impacts represent compensation to the environmental load that is introduced by the DH system.

Besides the energetic and environmental balance and in order to evaluate the momentum of the produced impact of the plant, and for this estimation also by taking into account the aspect of its localization, it is necessary to consider the results of the dispersions models. With this approach it is possible to calculate the real air quality modifications; the concentrations (annual mean values and maximum hourly values) that are introduced by the future plant and the ones (eliminated existing domestic boilers) that can be avoided must be compared on the basis of concentration maps (Genon et al. [12]).

In general, and with a first qualitative approach, it is possible to consider that a single plant against many individual boilers can be advantageous for a lot of aspects, among which are the smaller amount of pollution, specific production

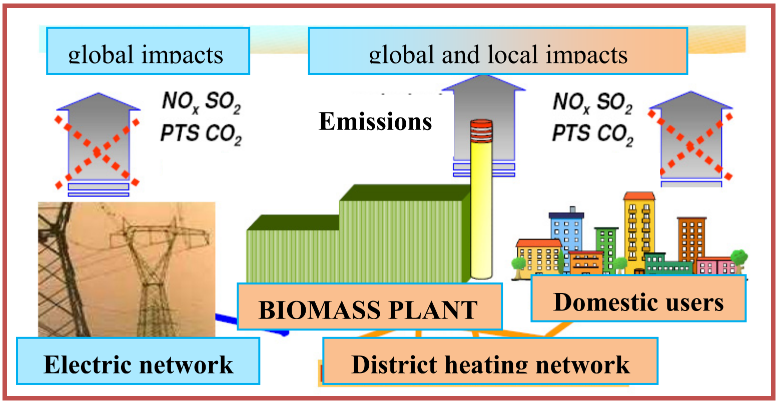

Figure 1: Environmental balance.

capacity and the major energetic efficiency. A large plant should have higher thermal efficiency and better smoke control in comparison with the performances of small plants.

Also the aspect of higher emissions point of the chimneys, and of higher atmospheric emissions flow-rates and consequent higher dispersion capacities must be taken into account as an aspect of advantage for concentrated solutions.

4.1 Initial considerations

In this work we will examine the terms of environmental balance: the bases for this estimation is provided by the following equation:

Local / global emissions (added/eliminated) = biomass plant emissions – substituted emissions (1)

From the point of view of the "biomass plant emissions" we refer to the data that were reported in Table 3.

From the point of view of the "substituted emissions", it is necessary to make reference to the data of Table 7 and to the emission factors for domestic boilers fed by natural gas and wood. In the following table we report the used emissions factors.

Table 8: Methane emission factor [Source Piedmont Region].

Fuel	Emission factor [mg/MJ]				
	Dust	NO_x	SO_x	CO	COV
Methane	1,98	50	0,51	25,25	4,64

Table 9: Wood emission factor [Source Piedmont Region].

Fuel	Emission factor [g pollutant/kg fuel]				
	Dust	NO_x	SO_x	CO	COV
Wood	4,91	2,3	0,34	50	8,24

By using equation (1) we defined an environmental balance for each of the considered scenarios.

The pollutant parameters that were considered in the estimation were:

- dust;
- nitrogen oxides (NO_x). For this pollutant parameter we considered two different situations:
    - NO_x emission treated with $DeNO_x$ SNCR system as considered by the plant designers (data in Table 3);
    - NO_x emission treated with $DeNO_x$ SCR system; in this case, in comparison with an higher investment cost there is an improvement in the performance as regards the removal of pollutant (in fact with an SNCR system the estimated pollutant concentration in output corresponds to 180 mg/m^3, as it is reported in Table 3, while with an SCR system it is possible to arrive to a pollutant concentration in output of 108 mg/m^3).
- sulphur oxide (SO_x);
- carbon monoxide (CO);
- Volatile Organic Carbon (VOC).

4.2 Environmental balance on annual scale

The initial point was the evaluation of hypothesis 1. In this hypothesis it is foreseen that the all town volume will be connected to the district heating network.

The results of the elaborations are reported in Table 10.

Table 10: Environmental balance, hypothesis 1.

	Biomass plant (+)	Methane boilers (-)	Wood boilers (-)	Environmental balance
Dust [t/y]	2,5	0,12	1,21	+ 1,17
NOx (SNCR) [t/y]	46,3	2,93	0,57	+ 42,8
NOx (SCR) [t/y]	27,8	2,93	0,57	+ 24,3
SOx [t/y]	51,5	0,03	0,08	+ 51,39
CO [t/y]	51,5	1,48	12,35	+ 37,67
VOC [t/y]	5,15	0,27	2,035	+ 2,85

By analyzing the results of Table 10 we observe that the biomass plant environmental impact will be higher in comparison with the substituted domestic boilers. We can observe that this impact is conspicuous in particular for the parameters NO_x (both considering a SNCR system or a SCR system), SO_x and CO.

As for hypothesis 2, in this case it is considered that only the effectively connectable town volume will be connected to the district heating network.
In Table 11 we reported the results of this hypothesis.

By analyzing the results we can observe that in this case the pollutant load introduced by the biomass plant is significantly higher in comparison with the avoided one arising from the substitution of the domestic boilers that are effectively connectable to the district heating network. As in the previously hypothesis, the parameters that mainly suffer from the biomass plant introduction are the NO_x, the SO_x and the CO; also the parameters dust and VOC undergo a worsening at balance level, but to a lesser measure.

Hypothesis 3 is based on the assumption that only the volume corresponding to residents will be connected to the district heating network.

In Table 12 we report the result referred to this hypothesis; we can see that the trend is similar to the trend of the previous situations.

Table 11: Environmental balance, hypothesis 2.

	Biomass plant (+)	Methane boiler (-)	Wood boiler (-)	Environmental balance
Dust [t/y]	2,5	0,09	0,94	+ 1,47
NOx (SNCR) [t/y]	46,3	2,24	0,44	+ 43,62
NOx (SCR) [t/y]	27,8	2,24	0,44	+ 25,12
SOx [t/y]	51,5	0,022	0,064	+ 51,4
CO [t/y]	51,5	1,14	9,5	+ 40,86
VOC [t/y]	5,15	0,21	1,57	+3,37

Table 12: Environmental balance, hypothesis 3.

	Biomass plant (+)	Methane boiler (-)	Wood boiler (-)	Environmental balance
Dust [t/y]	2,5	0,04	0,08	+ 2,38
NOx (SNCR) [t/y]	46,3	1,04	0,04	+ 45,22
NOx (SCR) [t/y]	27,8	1,04	0,04	+ 26,72
SOx [t/y]	51,5	0,01	0,006	+ 51,48
CO [t/y]	51,5	0,52	0,83	+ 50,15
VOC [t/y]	5,15	0,1	0,14	+ 4,91

Hypothesis 4 shows that only the volume for residents effectively connectable will be connected to the district heating network.

In Table 13 we report the results relative to this hypothesis.

Table 13: Environmental balance, hypothesis 4.

	Biomass plant (+)	Methane boiler (-)	Wood boiler (-)	Environmental balance
Dust [t/y]	2,5	0,025	0,05	+ 2,43
NOx (SNCR) [t/y]	46,3	0,64	0,023	+ 45,64
NOx (SCR) [t/y]	27,8	0,64	0,023	+ 27,14
SOx [t/y]	51,5	0,006	0,0034	+ 51,49
CO [t/y]	51,5	0,32	0,504	+ 50,68
VOC [t/y]	5,15	0,06	0,083	+ 5

As expected, in this case the load introduced by the plant is much higher than the subtracted ones arising from shutdown of domestic boilers connectable to the district heating network.

4.3 Percentage of pollutant increase with consideration of background value

In the previous sections we evaluated pollution loads introduced by the future biomass plant and those which may be eliminated by the substitution of a number of public and private boilers.

In this calculation we have not considered the background load deriving from other existing sources operating in the area, as in particular agricultural activities, animal farms, production operations, transport.

In Table 14 we report the contribution that can be estimated for these emission sources for the examined town, with consideration of the principal categories.

Table 14: Emissive contribution and subdivision for emission sources.

Emissive contribution expressed in t/y					
	NO_2	PM_{10}	NH_3	CO	SO_2
Agriculture	2,16	0,28	1,03	-	-
Zootechnic	-	-	8,66	-	-
Productive activity	0,10	0,02	0	-	-
Transport	2,88	0,87	0,05	-	-
Urbanization	2,84	1,32	0	-	-
TOTAL (t/y)	7,98	2,49	9,74	54,49	0,44

The percentage increase, for each evaluated hypothesis, has been calculated with the following equation:

% of increase = ((introduced load – substituted load)/background value)*100 (2)

with:

introduced load (t/y) = biomass plant emission + background value

The obtained results are reported in the following figures.

If the results that are reported in figure 2 are analyzed, for all the scenarios and for each pollutant parameter taken into account, we can see an important percentage increase deriving from the activation of the new biomass plant. Among the five pollutants, the parameters that present a smaller percentage increase are the dust and the carbon monoxide. On the contrary, the pollutant parameter SO_x presents the highest increase percentage among the five pollutant parameters examined). From the point of view of the pollutant parameter NO_x, there is a difference in the increase percentage in function of the adopted pollutant removal system (SNCR or SCR). If we use a SNCR removal system the increase percentage is in the order of 400 to 500%, while in case of use of a SCR the increase is only in the order of 200 to 300%.

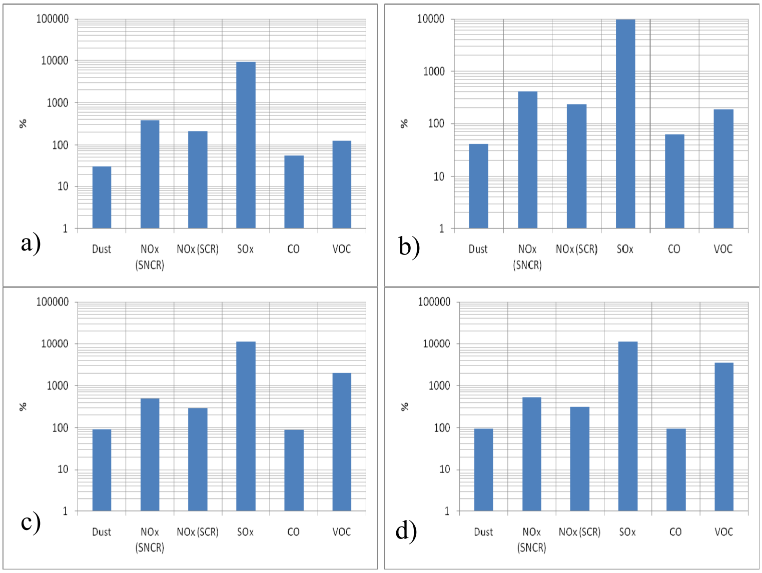

Figure 2: Percentage of pollutant increase with background value: a) hypothesis 1 b) hypothesis 2 c) hypothesis 3 d) hypothesis 4.

4.4 Effects on air quality

The calculated values are the starting point for an evaluation of the effects of the introduction of the new plant on the air quality for the considered area: in this case, together with these values, we must have at disposal a dispersion model that is calibrated for the specific area and a reliable estimation of the meteorological conditions (wind direction and intensities, local turbulent dispersion, height of mixing boundary layer).

In the considered case, while we consider that the emission scenarios are properly defined and absolutely reliable, it is necessary to say that the dispersion model is at the moment absolutely not at disposition, and it will be very difficult to define, also taking into account the complex topographical and geographic situation of the considered area: in these conditions a direct application of the commercial dispersion models could clearly be used, but in our opinion the reliability of the results would be very poor.

In these conditions we think that the indication arising from emissions scenarios is a good basis for evaluation of the sensible worsening of the local air quality: in fact, the previously indicated effects of higher dispersion possibilities for the new plant must be carefully considered, and also the consideration of its localization in less populated areas cannot absolutely be disregarded, the influence of the increased emission fluxes is so high that a consideration of worsening in air quality can be reasonably introduced.

5 Conclusion

In the presented work we evaluated the acceptability, from the environmental point of view, of a plant for the generation of thermal and electric energy with biomass combustion, to be realized in a little city in Piedmont.

This acceptability has been evaluated by using the tools of the environmental and energy balance, on the basis of some hypothesis of connection (total volume of existing buildings or only volume of the buildings that really can be connected to the network, appreciation of the difference between buildings for residents and buildings for non residents).

From the obtained results the main conclusion is that an effective convenience (and so an effective acceptability), from the environment point of view, could eventually be obtained only with a very high value of energy utilization, and this is related to the possibility to transfer all the produced thermal energy. In this way the emissions produced from the biomass plant are at least in part balanced by the values of avoided emissions, due to the turn off of some domestic boilers.

A sophisticated dispersion model for air quality prevision could confirm this indication, but its implementation seems to be quite difficult for the considered area, and not able to substantially modify the previously reported conclusions.

References

[1] Boman U.R., Turnbull J.H., Integrated biomass energy systems and emissions of carbon dioxide. *Biomass and Bioenergy*, Volume 13, Issue 6 (1997), 333 – 343;
[2] Dornburg V., Van Dam J., Faaij A., Estimating GHG emission mitigation supply curves of large – scale biomass use an a country level. Biomass and Bioenergy, Volume 31, Issue 1 (2007), 46 – 65;
[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, Catalysis Today, 106 (2005), 297-300;
[4] Bridgwater A.V., The technical and economic feasibility of biomass gasification for power generation, Fuel, 74 (2005), 631-653;
[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 and Bioenergy*, Volume 28, Issue 1 (2005), 35 – 51;
[6] Hanaoka T., Inove S., Uno S., Ogi T., Minowa T., Effect of woody biomass components on air – steam gasification. *Biomass and Bioenergy*, Volume 28, Issue 1 (2005), 69 – 76;
[7] Hohenstein W.G., Wright L.L., Biomass energy production in the United States: an overview. *Biomass and Bioenergy*, Volume 6, Issue 3 (1994), 161 – 173;
[8] Hustad J., Skreiberg Ø., Sonju O., Biomass combustion research and utilization in IEA countries. *Biomass and Bioenergy*, Volume 9, Issues 1 – 5 (1995), 235 – 255;
[9] Van Den Broek R., Faa Ij A., Van Wick A., Biomass combustion for power generation. *Biomass and Bioenergy*, Volume 11, Issue 4 (1996), 271 – 281;
[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., Torchio F. Marco, Poggio A., Poggio M., Energy and environmental assessment of small district heating systems: global and local effects in two case-studies, Energy Conversion and Management, 50 (2009), 522 – 529.