District heating in Lombardy Region (Italy): Effects of supporting mechanisms

Niccolò Aste, Michela Buzzetti*, Paola Caputo

Architecture, Built Environment and Construction Engineering Department, Politecnico di Milano, Via Bonardi 9, Milano 20133, Italy

1. Introduction

In Italy district heating networks and distributed generation systems are constantly increasing with many effects related to the relationship between people and their territory (Bottio, Caminiti, Gangale, Stefanoni, & Magnelli, 2008).

In 2010 the Italian district heating plants were about 442 (Ufficio Energia e Clima di Legambiente, 2012), with a total capacity of 6303 MW_{th} (of which 2370 MW_{th} in cogeneration), 153.9 MW_{tc} and 853 MW_{el}. Presently the most part of these plants is fueled by fossil fuels. In fact natural gas is feed in 77.1% of the plants, urban waste in 9%, biomass in 5.3% and the remaining 8.6% is fueled by coal, fuel oil, geothermal and heat from industrial processes. The district heating in Italy is mainly distributed in the north of country with an important diffusion in Lombardy Region, where the total installed capacity is 2354 MW_{th} (nearly 40% of the national plants) (AIRU, 2012).

Several factors may influence the technical and economic performances of district heating systems: goals about climate change and renewable energies integration, climatic and morphology context, improvement of the buildings energy performance; competition with other technologies and other energy sources (in particular with heat pump systems and technologies fueled by natural gas); non-technical barriers; energy policies and market strategies.

Looking at the available data, it is possible to argue that the diffusion of district heating in Italy is constantly increasing despite of the many barriers related to the regulatory, administrative and economic difficulties. In this framework supporting measures play of course a fundamental role (Cansino et al., 2011; FIPER; Lessons, 1998; Lind, 2012; Madlener, 2007; Magnusson, 2012); another important help for their further development and upgrading can come from the coordination among policy and technological aspects (Agrell & Bogetoft, 2005).

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* Corresponding author. Tel.: +39 0223999468; fax: +39 0223999469.
E-mail address: michela.buzzetti@polimi.it (M. Buzzetti).

Nomenclature

Abbreviations

CCGT	combine cycle gas turbines
CHP	combined heat and power
DPB	discounted payback time
GHGs	greenhouse gases
RE	renewable energy

Subscripts

el	electric
tc	thermal cooling
th	thermal heating

In order to overcome the economic barriers, the diffusion of district heating systems is generally supported by incentive policies. Several experiences, as for example the Sweden one (Aberg & Henning, 2011; Nilsson, Reihav, Lygnerud, & Werner, 2008; Persson & Werner, 2011; Rezaie & Rosen, 2012), demonstrate the importance of developing focused and reasonable subsidies. This topic is thus investigated also in the present paper.

The national framework of the incentive policies related to district heating in Italy is mainly related to benefits for the final users and bonus for CHP renewable plants, as briefly described in the following Table 1.

In this context, in order to complete and integrate the supporting framework suggested by the ordinary energy policy, the Italian Ministry of Environment in collaboration with the administration of Lombardy Region has developed several measures for energy efficiency and local renewable integration in the regional territory, within the so-called "Accordo di Programma Quadro in materia di Ambiente e Energia" (Framework Program Agreement in the field of Environment and Energy). So many calls were launched since 1999. These calls were devoted to promote renewable energy sources penetration and energy efficiency, but also to improve expertise and know how about energy issues among public administrations and citizens.

Public supports were provided as grants to finance utilities and privates, on the basis of a public selection. The supported measures include those related to the diffusion or upgrading of district heating plants (52.9% of the total public funding), subject of the present paper, and other related to the installation of solar plants (20.2% of the total public funding), the improvement of energy efficiency of envelopes (14.3% of the total public funding) and heating systems (8.9% of the total public funding) in buildings (Aste, Buzzetti, Caputo, & Manfren, 2014) and actions in the field of innovative fuels and sustainable mobility (3.7% of the total public funding). In particular, district heating was supported by following calls:

- D.G.R. 6/42621 in 1999 for biomass plants (D.G.R. 6/42621, 1999);
- D.G.R. 6/44589 in 1999 for fossil plants (D.G.R. 6/44589, 1999);
- D.G.R. 7/20119 in 2004 for biomass and fossil plants (D.G.R. 7/20119, 2004).

Table 1
The national framework of the incentive policies related to district heating in Italy.

Supporting mechanism	Legal reference
Tax deduction (0.01033 €/kWh of heat) for final users in the coldest climatic zones (zone E and F as defined in D.P.R. 412 (1993)).	Financial laws from year 1999 to today
Energy efficiency titles (white certificates)	D.Lgs. 79 (1999), D.Lgs. 164 (2000), D.M. (2004), Decreto (2007) and D.Lgs. (2008)
Tax deduction (0.01549 €/kWh of heat) for final users in the coldest climatic zones	D.L. 268 (2000) and Financial laws from 2009 to today
Contribution (€ 20.6583 for each kW of heating power) for final users who decide to be connected to a district heating network	Financial laws from 2001 to today
Guarantee fund for district heating utilities	D.Lgs. 28 (2011)
Additional bonus for small plants (<1 MW_{el}) that generate electricity from REs and that are able to cogenerate heat for district heating	D.M. (2012)

As a whole Lombardy is a high density populated region, with many important urban areas (i.e. Milan). Its built environment is very complex, with an important presence of all the sectors: residential, commercial, industrial and urban structures. Lombardy has a large flat land but also many mountain areas, a rather cold climate during winter and a hot and humid climate during summer, especially in the flat land. Many areas have characteristics suitable for developing district heating plants. This situation justifies the decision to use part of the available public funds for these interventions that are characterized by significant investment costs.

For a better understanding of the elaborations provided in the following sections, we outline also the main characteristics of the energy system in Lombardy. The regional energy balances in recent years highlight the remarkable stability of the total final consumption, the importance of the civil sector (43% of total consumptions) and the predominance of the heating consumptions of buildings (68% of the total energy consumptions of the civil sector). In Lombardy power plants are more than enough to cover the peak demand for electricity. The main energy source adopted is natural gas in big combine cycle gas turbines (CCGT) plants. Further, the most part of the national hydro-electric plants are located in Lombardy. These plants and other REs installations determine a penetration of renewable energy sources in line with the European and national objectives related to the year 2020. Not least, in Lombardy there are economic resources that can be activated in the energy field.

This paper is devoted to investigate the actual performance of the district heating plants supported by the mentioned mechanisms. The main aim is to understand the effectiveness of these supports taking into account the so-called "3E" approach (Economy, Environment and Energy aspects). Final considerations about the lessons learned will be provided in order to give directions for future energy policies at district, municipal and regional level.

1.1. *Monitoring campaign of a local energy efficiency program for district heating*

At the end of the mentioned national program "Accordo di Programma Quadro in materia di Ambiente e Energia" (Framework Program Agreement in the field of Environment and Energy), the Italian Ministry of the Environment and Lombardy Region financed a monitoring campaign with the scope of deeply analyzing the results achieved and getting useful insights for future programs and projects. The monitoring involved all the supported measures, including district heating plants, and was carried out by our research group of Politecnico di Milano.

The present paper takes into account the most important results of the monitoring campaign related to district heating plants and includes further investigations.

Incentives were provided both for the creation of new plants and district heating networks and for the extension of existing systems. Further, the calls promoted both biomass and fossil fueled plants. The first call dates back to year 1999 (D.G.R. 6/42621, 1999; D.G.R. 6/44589, 1999) and it had the aim of financing new plants and networks. The second one dates book to year 2004 (D.G.R. 7/20119, 2004) and had the aim of financing the expansion of the existing and new thermal networks. The beneficiaries of the subsidies were selected by a public procedure, taking into account the overall performance of the project during the pre-design phase. While the incentives were given after a documented verification of the works, in many cases after many years from the beginning of the works.

The district heating plants that passed the selection received a contribution in terms of a percentage of the allowable investment costs. For plants powered by fossil fuels or connected to waste to existing energy plants the contribution was equal to the 20% in the first call and 30% in the second one. Instead, the biomass plants received a contribution equal to the 40% of the allowable investment costs.

In the first call the allowable costs were the amounts for the realization of the generation, transport and connected infrastructure of the system, and also a part of the expenditure for the restoration, technical and unforeseen costs. In the call referred to biomass plants the costs related to the organization of the supply chain were included. Instead, in the call referred to urban interventions the allowable costs included a percentage of payments for the purchase of the areas needed for implementing the plants.

In the second call the allowable costs were the total amount for the construction of the primary and secondary network, the realization of the heat exchange substations for connecting the users, the implementation of systems of heat exchangers between the primary source and the network, costs for occupied areas, for safety at work, and for other unforeseen expenses.

Not all the funded interventions have been concluded; in the following sections we will refer only to concluded procedures. Definitively the paper deals with 21 interventions on district heating plants: 6 realizations of plants powered by biomass (wood chips), other 6 plants powered by fossil fuels and/or urban waste and 9 network expansions.

As result a total power of about 206.6 MW_{th} (about 10% of installations in Lombardy) and 37.2 MW_{el} were installed. In particular, 97.1 MW_{th} and 9.4 MW_{el} are the thermal and electric power of the plants powered by biomass, while 109.5 MW_{th} and 27.8 MW_{el} are the thermal and electric power of the plants powered by fossil fuels. Considering all the plants, the expansion of the district heating networks was of 73 km; in particular, 50 km due to the first call and 23 km due to the second call.

2. Methodology

This section describes the methodology of analysis of the mentioned cases of district heating plants.

2.1. Data collection and elaboration

The monitoring campaign described in Section 1.1 started with an onerous phase of accurate collection of data that were organized in a suitable database. This includes the main characteristics of the plants (climate, users, built environment, heat demand or consumption, network, electricity generation, sources of primary energy etc.) and of the related contexts. For the aims of this paper, a set of main parameters were selected among the data considered in the monitoring, as reported in Table 2.

2.2. Energy, economic and environmental indicators

After data collection and elaboration, a set of interesting indicators were elaborated in order to assess the effectiveness of the interventions taking into account the subsidies given by the public administration and the investments of the involved utilities and investors.

Table 2
Main data considered for all plants grouped by typologies.

Context parameters	Plant parameters	Thermal network parameters	Economic parameters
Degree days	Fuels	Length	Investment cost
Morphology	Thermal power	Number of substations	Allowable costs
Heated volume	Heat generation	Thermal power of heat exchanger	Subsidy
Urban density	Heat to the network	Served volume	
Heating demand or consumption	Electric power	Type of users	
	Electricity to the network		
	Electricity auto-consumed		

The most significant energy, economic and environmental indicators are shown in Table 3.

Fossil primary energy saving and emissions saving were calculated on the basis of the comparison of the scenario before the realization of the plant to the scenario after, taking into account the first year of full operation of each plant (EN 15603, 2008) during the expected lifetime.

In particular, in case of CHP, the primary energy saving is calculate taking into account also the benefits deriving from power generation. More precisely primary energy saving is equal to the difference between the sum of primary energy for thermal generation consumed before the intervention and primary energy needed for generating a quantity of electricity equal to that cogenerated by the plant, and the primary energy consumed by the district heating plant.

Since biomass is considered renewable and carbon neutral, its primary energy consumption and GHGs emissions were neglected, unless otherwise specified.

The expected lifetime was globally estimated at 20 years. We would like to remark that for this type of interventions, taking into account both the thermal plants and the heating networks, it is not easy to define the real lifetime, component by component. In fact some components have a longer lifetime and others have a shorter lifetime. In order to overcome this difficulty, a global mean value of 20 years was roughly and uniformly assumed according to the technical literature (CIBSE, 2009; COWI, 2011; EN 15459, 2008; European Parliament, 2006) and to information collected during the monitoring campaign.

Since it is very difficult to know exactly the evolution of district heating plants year by year and for all the analyzed plants, the primary energy indicators were calculated in a simplified way. In fact the energy produced during the first year of full operation was

Table 3
Main indicators calculated for all plants, grouped by typologies.

Energy indicators	Economic indicators	Environmental indicators
Primary energy saving during 20 years	Subsidy/CO_{2eq} emission saving during 20 years	CO_{2eq} emission saving during 20 years
Energy efficiencies	Subsidy/Primary energy saving during 20 years	NO_x emission saving during 20 years
	Discount payback time (DPB) with subsidy	SO_2 emission saving during 20 years
	Discount payback time (DPB) without subsidy	

Table 4
The thermal and electric efficiencies used.

	Efficiency (%)
Oil boiler	81 (UNI 11300-2, 2008)
Natural gas boiler	85 (UNI 11300-2, 2008)
Condensation natural gas boiler	96 (UNI 11300-2, 2008)
Electricity generation	48.7 (EEN 3/08, 2008)

kept constant during the entire lifetime. Of course this is a conservative assumption because all the plants are expected to grow during their lifetime. In fact their growth implies few further investments (unknown in the present analysis) against significant energy and environmental benefits.

Among the energy indicators, the gross thermal efficiency was calculated as the ratio between the thermal energy produced and the primary energy (in this case both fossil and/or renewable) consumed by the system; analogously the gross electrical efficiency was calculated as the ratio between the electric energy produced and the primary energy (again fossil and/or renewable) consumed by the CHP unit only.

In order to calculate the mentioned indicators, the efficiencies and emission factors reported in Tables 4 and 5 were considered.

The primary energy factors for fuels are assumed to be equal to 1 (i.e. primary energy losses of the whole energy chain located outside the boundary of the systems are not taken into account) (EN 15603, 2008), following the current Italian building energy certification scheme (UNI 11300-2, 2008). The CO_{2eq} emission factors for the fuels (natural gas, diesel) depend simply on the chemical structure of the fuel (EN 15603, 2008), while the NO_x and the SO_2 emission factors depend both on the fuel and on the adopted technologies.

The emission factors reported in Table 5 are those provided by the regional offices (ARPA; SiReNa) and are referred to the regional energy supply system. Since the emission factors depend on the fuels and on the combustion systems, for thermal generation we can expect analogous values also at national level in relation to the different mentioned boilers. On the contrary, the regional power supply system is mainly based on combine cycle gas turbines (CCGT) and hydro, while the national power generation system includes gas, oil and coal plants with various performances. For this reason the regional average electric efficiency is higher and the emission factors are lower than the national ones.

Finally, as economic indicators, discounted payback time (DPB) (EN 15459, 2008) were calculated for all the interventions. DPB represents the number of year in which the cumulative cash flow for a project becomes equal to 0 and therefore the time required to recover the initial investment.

In this specific case, the cumulative cash flow is the difference between incoming flows and outflows. The incoming flows are those related to sale of heat and electricity and possible contributions (as green certificates). The outflows are the cost of fuels, management and maintenance. The analysis does not take into account the taxes that are on average 30–35% of corporate profits.

Table 5
The Lombardy Region emission factors for different systems (SiReNa; ARPA).

Emission factor	NO_x (mg/kWh)	SO_2 (mg/kWh)	$CO_{2eq.}$ (g/kWh)
Oil boiler	216	360.0	264
Natural gas boiler	137	1.8	200
Condensation natural gas boiler	45	1.8	200
Fuel oil boiler	540	540.0	270
Lpg boiler	216	0.0	225
Biomass district heating	283	3.6	0
Gas district heating	230	0.9	200
Electricity generation	151	34.0	397

Table 6
Description of the assumption for the economic analysis.

Parameter	Unit	Value
Diesel price	€/kWh	0.034
Natural gas price	€/kWh	0.026
Biomass price	€/kWh	0.014
Heat (selling price)	€/kWh	0.050
Electricity (selling price)	€/kWh	0.060
Annual increase rate of diesel price	%	10.0
Annual increase rate of natural gas price	%	4.0
Annual increase rate of biomass price	%	4.0
Annual increase rate of heat selling price	%	5.0
Annual increase rate of electricity selling price	%	2.0
Discount rate of the investment (r)	%	4
Project lifetime (n)	years	20

The costs of fuels are related to the Italian market (AEEG; Ministero dello Sviluppo Economico). As baseline, the data reported in Table 6 are referred to the year 2000 (the first year of operation of the first realized plants).

We would like to stress that all the parameters adopted in the economic analysis were keep constant for all the cases. In other words, contrary to reality, the local peculiarity were not considered and all the mentioned unitary costs and profits are the same for all the cases.

The results of our analysis are described in Section 3.

3. Outcomes of the monitoring

In this section the effectiveness and the economic, energy and environmental performance of the monitored cases are described and commented.

3.1. *Effectiveness of the calls*

In this section the main results about the global financial effectiveness of the mentioned calls were reported.

It can be seen that only 70% of the total available funds were allocated as subsidies: 74% in the case of biomass plants and 68% in the case of fossil/waste plants.

In Fig. 1 three parameters are adopted: the subsidies available for each call; the subsidy financed for the concluded procedures and the subsidies liquidated at year 2013. The subsidies liquidated at year 2013 are less than the subsidies financed because the it can happen that the plant is already in operation during 2013 but the administrative verification is still in progress so a part of funding will be liquidated in the next future, as reported also in Section 1.1.

For the first call it was available a greater amount of money than for the second call, especially for fossil plants, but in the second call were engaged a greater amount of available money. Procedures of the second call took less time to end in respect to those of the first call. This can be justify because the expansion of a plant/network is less onerous than the realization of a new district heating plant. Further it seems that to bring off fossil plants takes more time than biomass plants. In fact the contributions already paid for biomass plants are 90% of the total, while those of the fossil plants are 70% of the total.

Another signal of the encountered barriers is the low ratio between plants in operation and plant selected for funding. Globally they are 32% of the total selected, 26% in the case of biomass plants and 36% in the case of fossil/waste plants.

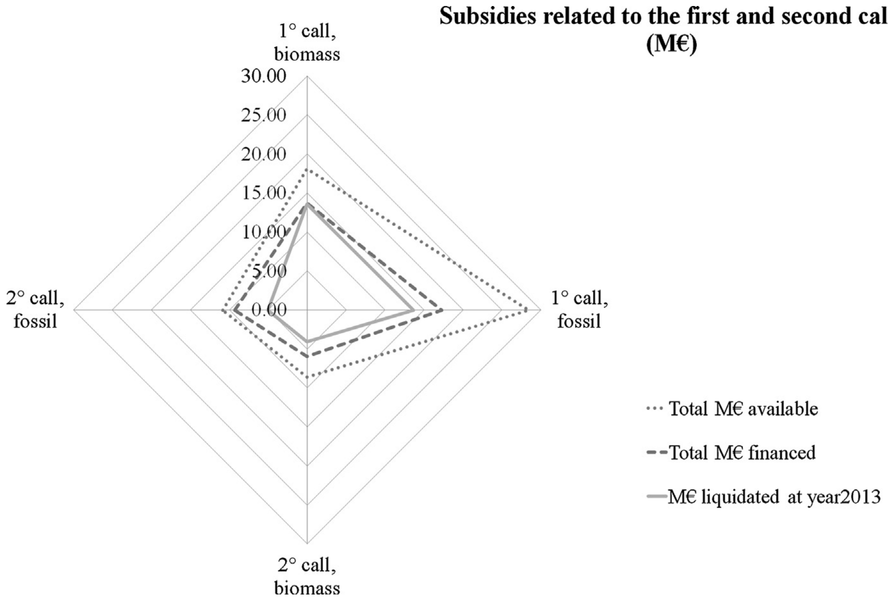

Fig. 1. Subsidies related to the first and second calls.

So far 49% of the projects selected and not failed were completed: 50% of the biomass plants and 48% of the fossil/waste plants; and 76% by the first call and 23% by the second call (Fig. 2).

3.2. Features of the plants

On the basis of the identified parameters and indicators described in Section 2, a comparative framework on the main characteristics of the plants was drawn up in relation to: technical features, energy performance and environmental benefits, as summarized in the following Tables 7–13 (the plants are identified by a number for privacy reasons). The plants indicated as “6a” and “6b” are referred to the same biomass plant, supported by both the calls. In general, in figures and tables, interventions “6a” and “6b” are reported as separate, excepted where a single value, related to the overall plant number 6, results more representative and reasonable. This happens in the calculation of the thermal and electric gross efficiencies and of the DPB time; in these cases the plant is indicated as “6”.

The calls encouraged various types of interventions. For this reason, in order to better analyze the data, the following classification was assumed:

- interventions related to the realization of new district heating plants and networks;

Table 7
Description of the main technical data for the plants.

Plant	Fuel	Total thermal power (MW_{th})[b]	Main thermal power (MW_{th})[c]	Electric power (cogeneration) (MW_{el})	Network length (km)
District heating plant and network					
1	Biomass (wood chips)	18.00	10.00	–	7.8
2	Biomass (wood chips)	17.40	12.90	3.10	15.1
3	Biomass (wood chips)	16.97	12.90	2.75	21.4
4	Biomass (wood chips)	18.00	12.00	–	3.9
5	Biomass (wood chips)	18.73	12.90	2.45	18.0
6a[a]	Biomass (wood chips)	8.00	8.00	1.10	8.3
Biomass plants		97.10	68.70	9.40	74.5
7	Natural gas	78.00	18.00	19.20	15.6
8	Natural gas	22.20	7.20	7.40	2.5
9	Natural gas	1.37	0.53	0.35	2.4
10	Natural gas	7.95	1.05	0.84	4.7
Fossil plants		109.52	26.78	27.79	25.3
Total plants		206.62	95.48	37.19	99.8
Heat exchanger connected to a waste to energy plant and network					
11[d]	Heat from waste to energy	–	–	–	16.8
12[d]	Heat from waste to energy	–	–	–	14.5
Fossil plants		–	–	–	31.3

[a] The subsidy is related to the expansion of an existing biomass plant; the plants starts its operation by 2 modules, a third module was integrated with the existing two. Data here reported are referred only to the third module and related network supported by the subsidy.

[b] Peak power: sum of base and auxiliary power.

[c] Main power without auxiliary power. For biomass plants, equal to biomass power.

[d] The subsidy is referred to the realization of a heat exchanger connected to existing waste to energy plants and to the related network.

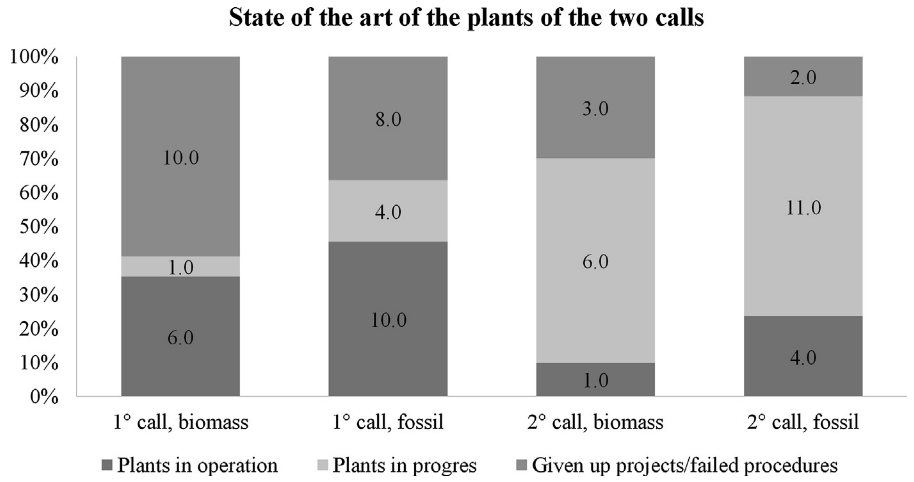

Fig. 2. State of the art of the plants of the two calls.

Table 8
Description of the implementation or expansion of the network.

Plant	Fuel	Network length (km)
6b	Biomass (wood chips)	3.33
Biomass networks		3.33
13	Natural gas	2.24
14	Natural gas	22.00
15	Natural gas, RSU, coal, dense fuel oil	0.62
16	Natural gas, RSU, coal, dense fuel oil	1.52
17	Natural gas	6.68
18	Natural gas	14.10
19	Natural gas	12.90
20	Natural gas	9.54
Fossil networks		69.6
Total networks		72.93

- interventions related to the realization of a heat exchangers (connected to existing plants) and networks;
- interventions related to the implementation or expansion of the networks.

Table 7 reports data about the installed power and network length of the first two groups, while Table 8 reports information about the third group.

Analogously, Table 9 reports heat and electricity data for the first two groups, while Table 10 reports information about heat delivered for the third group.

Further, Table 11 reports heat and electricity efficiency for the first group of plants; the efficiencies are calculated as described in Section 2.2.

Looking at Table 11, it is possible to underline a wide range of variation of the energy performances. In general, for technological and dimensional reasons, the electric efficiencies of the biomass plants are lower than those of the fossil plants. Further, other differences depend on the managements conditions as it will be commented in Section 4.

Table 9
Description of the energy generation for plants.

Plant	Primary energy consumption (GWh/year)	Heat generation (GWh/year)	Heat to users (GWh/year)	Electricity generation (GWh/year)	Electricity to network (GWh/year)
District heating plant and network					
1	6.87	6.50	5.92	–	–
2	113.59	7.83	3.46	19.15	18.11
3	87.00	13.38	6.30	12.14	10.05
4	10.41	9.75	8.78	–	–
5	81.62	10.65	5.33	10.45	8.62
6a	50.00	25.10	8.10	9.00	6.10
Biomass plants	349.49	73.21	37.89	50.74	42.88
7	177.00	149.10	136.90	11.40	7.50
8	80.00	21.51	15.80	27.20	25.38
9	3.39	1.88	1.40	1.10	1.02
10	19.50	14.60	13.10	2.30	2.18
Fossil plants	279.89	187.09	167.20	42.00	36.08
Total plants	629.38	260.30	205.09	92.72	78.96
Heat exchanger connected to a waste to energy plant and network					
11	–	88.90	81.20	–	–
12	7.50[a]	43.20	39.00	–	–
Fossil plants	7.50	132.10	120.20		

[a] Referring only to the auxiliary boiler expressly installed for heating peaks.

Table 10
Description of the heat for new networks.

Plant	Heat generation (GWh/year)	Heat to users (GWh/year)	New network/total network of district heating length (%)
6b	9.48	6.78	10.0
Biomass networks	9.48	6.78	–
13	24.58	16.71	7.45
14	118.11	67.06	41.94
15	1.80	1.58	0.17
16	4.91	4.31	0.42
17	40.50	34.04	47.71
18	12.15	11.84	100.0
19	75.40	67.10	100.0
20	80.46	75.26	100.0
Fossil networks	357.91	277.89	–
Total networks	367.38	284.67	–

Table 11
Thermal and electric gross efficiencies of plants.

	Gross thermal efficiency (%)	Gross electric efficiency (%)
Biomass plants		
1	95	–
2	7	20
3	15	15
4	94	–
5	13	18
6	88	18
Fossil plants		
7	84	38
8	27	39
9	55	36
10	75	35

3.3. *Energy and environmental aspects*

Next Tables 12 and 13 report the energy and environmental indicators described in Section 2.2. Positive values mean that the system provided a reduction of energy consumption or pollutants, while negative values mean that the system provided an increasing of energy consumption or pollutants.

The overall results, in terms of primary energy saving, amounts to approximately 7035 GWh in 20 years and the emission savings amount to 1,562,925 t of CO_{2eq}, −2,489 t of NO_x and 1,335 t of SO_2, as highlighted in Tables 12 and 13.

On the basis of the preliminary results, it is possible to argue that the penetration of biomass and fossil district heating plants can bring important benefits from the energy and environmental

Table 12
Energy and environmental indicators for plants.

Plant	Primary energy saving (GWh, 20 years)	NO_x emissions saving (t, 20 years)	SO_2 emissions saving (t, 20 years)	CO_{2eq} emissions saving (t, 20 years)
District heating plant and network				
1	98	−9	49	28,732
2	810	−569	28	161,508
3	481	−409	51	101,027
4	162	−18	73	45,879
5	486	−408	47	103,287
6a	451	−221	73	101,327
Biomass plants	2,488	−1,634	321	541,760
7	166	−315	58	40,177
8	70	−29	260	39,642
9	54	−3	9	11,658
10	8	−17	112	20,821
Fossil plants	298	−364	439	112,298
Total plants	2,786	−1,998	760	654,058
Heat exchanger connected to a waste to energy plant and network				
11	1,290	223	−9	262,398
12	591	96	40	127,759
Fossil plants	1,881	319	31	390,157

Table 13
Energy and environmental indicators for network.

Plant	Primary energy saving (GWh, 20 years)	NO_x emissions saving (t, 20 years)	SO_2 emissions saving (t, 20 years)	CO_{2eq} emissions saving (t, 20 years)
6b	205	19	58	50,944
Biomass networks	205	19	58	50,944
13	−124	−113	143	−3786
14	750	−545	146	136,529
15	40	−10	−17	4574
16	110	−25	−45	12,720
17	81	−159	40	17,495
18	202	34	−1	41,093
19	336	−169	181	93,084
20	768	157	38	166,058
Fossil networks	2,164	−829	486	467,766
Total networks	2,368	−810	544	518,710

Table 14
Economic evaluation respect the CO_{2eq} and primary energy saving for plants.

Plants	Subsidy for primary energy saving in time life (€/TOE, 20 years)	Subsidy for CO_{2eq} emission saving in time life (€/tCO_{2eq}, 20 years)
District heating plant and network		
1	174.43	51.05
2	22.59	9.74
3	58.15	23.80
4	97.82	29.71
5	93.98	37.99
6a	61.44	23.49
Biomass plants	61.32	24.20
7	210.11	74.53
8	223.66	33.87
9	28.72	11.44
10	835.50	27.09
Fossil plants	195.82	44.60
Total plants	75.68	27.70
Heat exchanger connected to a waste to energy plant and network		
11	19.32	8.16
12	75.69	30.12
Fossil plants	37.04	15.40

Table 15
Economic evaluation respect the CO_{2eq} and primary energy saving for new networks.

Plant	Subsidy for primary energy saving in time life (€/TOE) 20 years	Subsidy for CO_{2eq} emission saving in time life (€/tCO_{2eq}) 20 years
6b	85.19	29.44
Biomass networks	85.19	29.44
13	−31.39	−88.40
14	15.94	7.53
15	11.52	8.73
16	12.49	9.26
17	107.29	42.87
18	43.09	18.25
19	25.93	8.06
20	11.36	4.52
Fossil networks	24.29	9.66
Total networks	29.56	11.61

point of views. Better results are in general achieved when small cogeneration modules are included in the plant.

The only evident negative effect regards NO_x emissions. This result depends on the emission factors provided: they take into account that gas and oil boilers are able to emit less NO_x per kWh respect the biomass and gas in district heating systems. Probably it could be obtained a better result emission factors of the mentioned plants were taken into account instead of the average values considered in the present study referred to regional databases and dated back to year 2008 (ARPA; SiReNa).

3.4. Economic aspects

The scarcity of available economic resources and the presence of stringent targets on energy and environment determine a condition for which it is absolutely necessary to promote highly effective interventions that are able to lead to significant reductions in energy consumption and emissions at low economic costs. The suggested indicators are precisely devoted to measure the cost of avoided emissions and avoided primary energy consumptions thanks to the supported interventions. These costs can be divided into two components: the public cost, i.e. the subsidies provided to promote the construction of the plants; and the private cost, i.e. the amount invested by utilities and privates that realized and manage the plants.

Unfortunately, for each intervention of the first and second groups (see Section 3.2), it was not possible to disaggregate the cost of thermal power plant from that of the network. So data reported in the following tables refer to the total cost of each intervention.

Looking at data shown, it is possible to argue that in general biomass plants seem to be more complex and more expensive for problems related to the local peculiarities (morphology and so on). While fossil/waste plants seem to be slightly more cost effective as will be explained in the following paragraphs.

3.4.1. Effectiveness of public spending

In Tables 14 and 15 the subsidies in € employed per unit of avoided CO_{2eq} emissions and primary energy saving are shown, for each intervention promoted.

These results were obtained with a contribution of 13.11 M€ for biomass plants, 5 M€ for the fossil plants and 5.99 M€ for plants with heat exchanger connected to existing waste to energy systems.

Looking at the results shown in Table 14 it is possible to observe a wide variety of the performances, depending on the peculiarities of each intervention. But, considering the average values reported, it is possible to observe that the best performance in terms of cost of the avoided primary energy is that related to the interventions composed by heat exchangers and networks (the second group of Section 3.2) with 37.04 €/TOE. These are followed by the biomass plants (61.32 €/TOE) and then by the fossil plants (195.82 €/TOE). These results are justified by the fact that, of course, interventions composed by heat exchangers and networks imply a minor cost of the global intervention and, consequently, of the subsidy. So they are intrinsically more cost effective because they benefit from existing thermal power plants. Analogous considerations justify the performance of interventions related to networks only (the third group of Section 3.2) with a result of 24.3 €/TOE in case of fossil fueled plants.

In order to have a basis of comparison, we considered an average value of the energy efficiency titles (white certificates) for the Italian market. This value is around 100 €/TOE (GME, 2012). Since the indicator "subsidy per avoided TOE (in € /TOE)" calcu-lated among all the considered interventions (first and second call) results equal to 50 €/TOE (value calculated as ratio between total subsidy and total primary energy saving), we can conclude that the public spending toward primary energy consumptions reduction was globally cost effective.

The same considerations can be repeated referring to the other indicator taken into account: the public cost of the avoided CO_{2eq}. In particular we can recall the wide variety of the performances, depending on the peculiarities of each intervention.

Also for CO_{2eq}, in order to have a basis of comparison, we considered an average value of the market value of the EU emission trading system (ETS) (Ellerman & Joskow, 2008; European Commission Climate Action). This value is around 7 €/t_{CO2eq} (GME, 2012). However, since we know that the EU ETS is governed by a market mechanism, a more appropriate approach would consider the ratio between the value of the Italian efficiency titles (about 100 €/TOE, as reported before) and the average Italian CO_{2eq} emission per primary energy (the ratio t_{CO2eq}/TOE). Considering this last over the time frame of the analysis we found a value of 2.42 t_{CO2eq}/TOE (IEA, 2012). So finally we took into account as benchmark a value around 41 €/t_{CO2eq}.

Since the indicator "subsidy per avoided ton of equivalent CO_{2eq} (in € /t_{CO2eq})" calculated among all the considered interventions (first and second call) results equal to 19.2 € /t_{CO2eq} (value calculated as ratio between total subsidy and total avoided CO_{2eq}), we can conclude that the public spending toward GHGs reduction was globally cost effective.

Table 16
Total cost (without subsidy) and investor costs (with subsidy) for total power (€/kW) and length network (€/m) for the new system realizations.

Plants	Total cost/total power (€/kW)	Investor cost/total power (€/kW)	Total cost/length network (€/m)	Investor cost/length network (€/m)
District heating plant and network				
1	358	276	823	636
2	801	711	925	820
3	487	345	386	273
4	682	606	3,154	2,803
5	601	391	625	407
6a	1,618	1,320	1,557	1,271
Biomass plants	670	535	874	698
7	401	362	1,998	1,806
8	449	389	3,990	3,453
9	602	524	340	296
10	462	391	779	660
Fossil plants	418	372	1,809	1,611
Total plants	536	449	1,111	929
Heat exchanger connected to a waste to energy plant and network				
11	–	–	1,352	1,224
12	–	–	1,545	1,280
Fossil plants	–	–	1,441	1,250

Table 17
Final and investor costs for length of network (€/m) for new networks.

Plants	Total cost/length network (€/m)	Investor cost/length network (€/m)
6b	1,143	692
Biomass networks	1,143	692
13	1,444	1,294
14	421	374
15	650	586
16	577	500
17	647	535
18	338	285
19	825	767
20	805	727
Fossil networks	592	527
Total networks	617	536

But we have to remark again the wide range of variability of all the indicators reported. This condition makes very difficult to draw general considerations about the effectiveness and profitability of district heating plants in Lombardy.

3.4.2. *Effectiveness of the investments*

Generally speaking, it has to be mentioned that in Italy district heating is considered as a public service and is managed by municipal utilities or by private companies with public participation. Several indicators could be considered in order to evaluate the cost effectiveness of the investments.

For example, the cost per unit of thermal power can be taken into account. This indicator varies significantly among the considered interventions as reported in Table 16. In general, it shows higher values for biomass plants, also due to the different economies of scale. For our plants this indicator is in the range 0.3–1.6 €/W, that seems to be realistic, since it is confirmed by technical references that set its mean value in the range 0.5–2 € /W (AFO; Caputo, 2011).

In addition we can consider the cost per unit of network. Also this indicator varies significantly among the considered interventions as reported in Tables 16 and 17. Values reported in Table 16 are not representative because they take into account the global cost (power plant and network). Differently, values reported in Table 17 are referred only to the costs of the networks. In same cases, these values seem to be overestimated since in (IC46, 2014) is reported a range between 200 and 600 €/m.

Another useful indicator is the linear heat density, i.e. the heat delivered to users for each meter of network. As mentioned in the report (IC46, 2014), a district heating network is considered feasible if its density is higher than 2.5 MWh/m, taking as reference a value of annual heat demand equal to 130 kWh/m^2 (average among all the users).

In Fig. 3, it can be seen that the fossil plants and networks respect this target while biomass plants, collocated in low density mountain areas, have in general lower targets.

Again we stress the wide range of variability of all the indicators reported that makes less significant global considerations about the features and performances of district heating plants in Lombardy.

For a better understanding of the cost effectiveness and of the profitability of the several interventions, also the discounted pay back time was calculated taking into account net investment cost (difference between the total investment cost and the public subsidy), as reported in Fig. 4.

This indicator was calculated taking into account the assumptions in Sections 2.2 and 3.2 and in relation to the first two groups of intervention reported in Section 3.2 (network expansions only were not considered). The obtained DPB demonstrate that, a part one exception, fossil plants are economically feasible (DPB less than the assumed lifetime). On the contrary, biomass plants have in general worse economic performance: three of them do not appear economically feasible since they have a DPB plenty more than the assumed lifetime; two of them have a DPB between 20 and 30 years and only one appears plenty economically feasible, with a DPB less than 10 years.

These results were compared also with the technical literature. For example, IC46 (2014) reports an average rate of return, evaluated among a wide sample of Italian district heating plants, equal to 8%. Anyway, also in this case, the large variety of the rate of return, case by case, was stressed. The best performances are those related to district heating networks connected to existing incinerators by heat exchangers. Also this performance is confirmed by our study (see cases 11 and 12).

4. Comments to results

In Section 3 we described the main outcomes of the survey and we stressed the large range of variation of the described indicators.

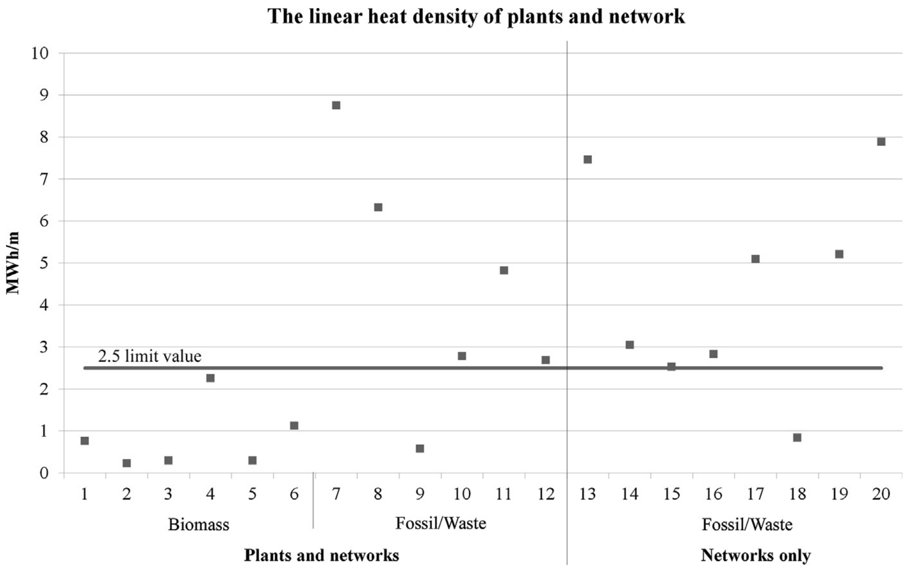

Fig. 3. The linear heat density of plants and network.

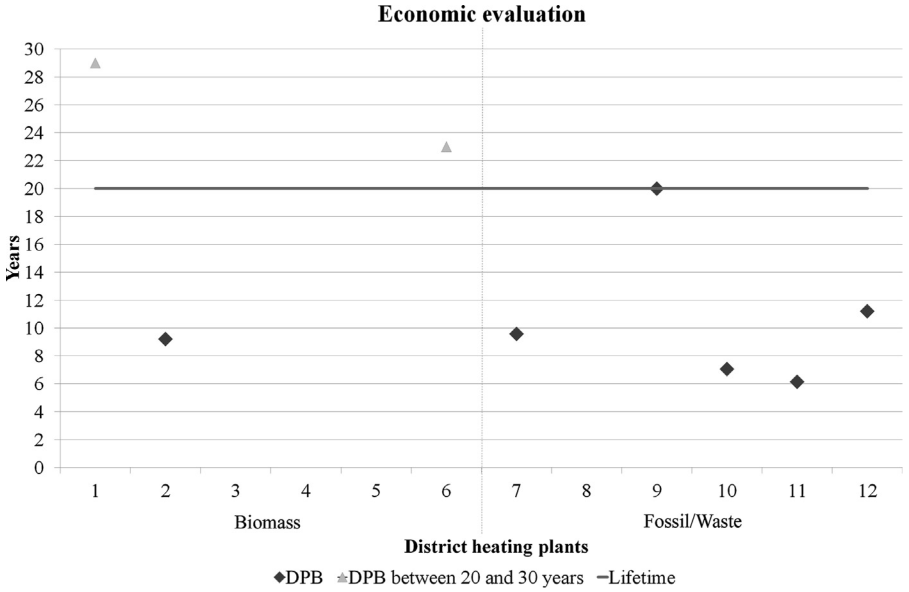

Fig. 4. Economic evaluation of district heating plants: DPB.

Despite of this, we can argue some general considerations, as follows.

The supporting mechanisms resulted too complex and too long as described in Section 3.1 and Figs. 1 and 2; this reveals the need to simplify and clarify the procedures and to set up an effective monitoring procedure.

As described in Section 3.2 and Table 11, we realized that some CHP plants have an unconventionally low thermal efficiency. This means that these CHP plants are electric driven and mainly devoted to electricity generation. The heat is lost when the plant operates outside the heating season and in general it is used inefficiently. This situation could be justified by the following reasons:

- in Italy power generation is more supported than the thermal one by mechanisms related to green certificates etc., as described in Section 2.2 and Table 11, so the companies are encouraged to push electricity generation at the expenses of the thermal ones;
- we referred to the first year of operation while some district networks are still in progress because they faced many problems for acquiring new users; so, for now, part of heat is dissipated while in the future is can be supplied to the new users.

Small CHP units represents a way for improving the global energy efficiency and also the economic performance of the plant, due to the electricity generation and consequent benefits of green certificates. But the cogeneration of heat and power should be optimized taking into account more energy and environmental aspects than economic benefits; this can reduce the risk of perverse effects (too low thermal efficiencies). To that end, supporting mechanisms for heat generation should be optimized both at local and national level.

Anyway the monitored mechanisms seem globally effective from the environmental and energy point of view as described in Section 3.3 and Tables 12 and 13.

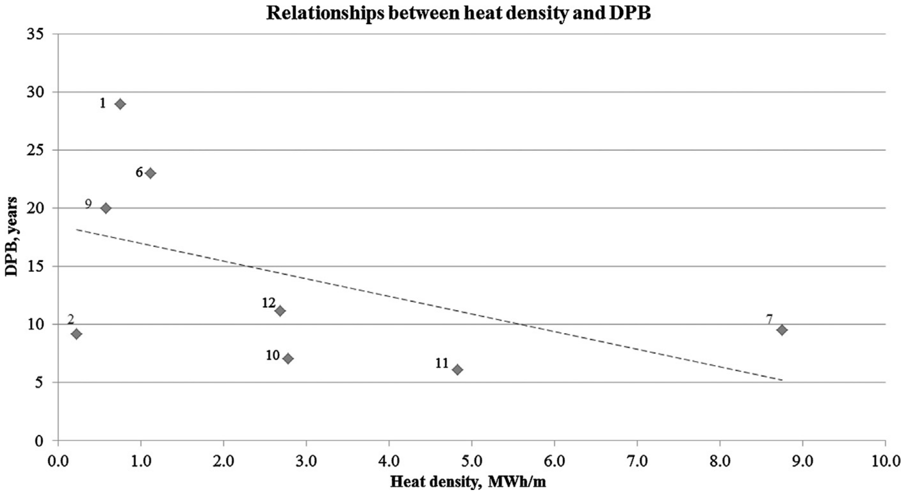

Fig. 5. Relationships between density and DPB.

But it must be stressed the worse performance of the fossil plants. This poor result is justified by the fact that, in almost the cases, district heating plants fueled by natural gas substituted natural gas boilers. So the results are obvious, since the thermal efficiencies of the boilers are higher than those of the district heating plants. Only high efficiency CHP plants can bring to better results. Also in the case of the avoided CO_{2eq}, the worse performance of the fossil plants must be stressed. Furthermore, the negative result regarding NO_x emissions should be better investigated taking into account the real emissions of each plant.

Also the public spending was globally effective as described in Section 3.4 and Tables 14 and 15. Differently the DPB times indicate some economic unfeasibility.

So the economic results were deeply analyzed trying to identify the possible causes of the economic unfeasibility. Firstly the several simplifications could strongly affect the results; so the reported DPB times have to be considered as approximate results that can be further refine taking into account the real parameters instead of the mean ones. For this reason a time range greater than the life time was considered in Fig. 4, to have a look also of the plants that are not far away from the economical feasibility and that may appear feasible adopting more precise assumptions. In the case of biomass plants, it has to be stressed also that the economic performance is strongly affected by the biomass (wood chips) market price. At the time of the calls this price was very competitive, while during the last years there was a strong increasing of the biomass price and/or a decreasing of the biomass quality. The main reason of this trend is the increasing of the biomass request in the same period in Italy due to the growing of the biomass plants, in particular of the big plants for power generation. This conditions resulted in a complete saturation of the market, increasing also biomass importations (Toka, Iakovou, Vlachos, Tsolakis, & Grigoriadou, 2014). A rough sensitivity analysis was carried out varying the price of the wood chips and keeping constant all the other mentioned parameters. It demonstrate that the full economic feasibility of CHP biomass plants could be obtained with a market price of about 0.012 €/kWh, i.e. slightly lower than the price that we have at the time of the calls and much lower than the present market price. So, a major control of the biomass market should be implemented in order to make the economic performance of biomass plants more stable. While, in urban areas, whenever possible district heating systems able to use energy resources such as municipal waste and waste heat of industrial systems (Brückner, Schäfers, Peters, & Lävemann, 2014) should be promoted instead of the fossil fueled ones, because of the better performances, as described in Section 3.3 and Table 12.

In the previous section we presented a set of indicators separately, but correlations among different indicators are possible, i.e. between environmental and energy indicators. In general, the higher the efficiencies of the plants the higher the primary energy saving. But, as described in Section 2.2, primary energy saving depends on the characteristics of the substituted energy systems (energy sources and efficiencies of the components) and of the district heating plants, so the correlation between efficiencies and primary energy saving is complex and differs case by case. Since biomass is considered renewable and carbon neutral, the primary energy and CO_{2eq} savings are in general higher than other type of plants, as reported in Section 2.2.

Other correlations are more complex: for example it is not possible to relate the DPB time with the efficiency because the DPB time depends more on other factors affecting the management of the plant.

While, if we consider the relation between heat density and DPB, it is possible to find out an inversely proportional relation between them as illustrated in Fig. 5. In fact the heat density affects the cost of the realization of the network that represents the most expensive part of the plant. On the contrary it is not possible to argue analogous consideration about the relation between heat density and energy efficiency, due to the peculiarities of each plant (heat generation or CHP, level of development of the district heating network, size of the plant, etc.).

5. Conclusions and developments

The main features and economy, environment and energy performances of the district heating plants supported by Lombardy Region were investigated.

The investigation demonstrates that the district heating is still an innovative field of knowledge far from standard, at least in the north Italian context. Due to the large range of variation of the results related to the described indicators, indeed each plant has to be evaluated on the basis of its specific characteristics and the resulting average figures cannot be considered as representative.

Despite of this, as described in Section 4, we can assert that the public spending was globally effective, taking into account the 3E approach mentioned in Section 1.

As future developments of the work, the national efficiency and emission factors for power generation could be taken into account for analyzing the substituted heating and electric systems, while the typical emission factors of each plant could be taken into account for analyzing the implemented district heating and CHP systems. In particular, if the negative result regarding NO_x emissions were confirmed, technological and management improvements should be taken into account in order to face this problem that affects in particular urban areas.

The state of the art of the analyzed supporting mechanisms (Section 3.1) reveals the need to simplify and clarify the procedures in case of future calls. This implies different mechanisms of optimization that today are easy to be accomplished, unlike in the past, thanks to innovative tools. To that end, for example the procedures could be fully on line (savings economic resources in managing the process); the text of the calls more easily and unambiguously to be interpreted, with an indication of quantitative criteria easily comprehensible, transparent and easy to be monitored. Further, in order to be more compatible with the economic balance of the companies the payment time of the subsidy should be drastically reduced.

Observing the data collected (see Section 3.2) we can argue that biomass district heating (located in small communities on the mountains with cold climate) have, in general, smaller power (so they are not able to benefit from economies of scale) if compared with the others (located in larger communities in plain urban areas and for the most part fueled by natural gas). Further, a part some exceptions, in biomass plants cogeneration is provided by small CHP units and represents the only way for improving the economic performance of the plant, as described also in Section 4. In fact, in contrast to electricity from renewable energy sources, no comparable legal instrument to support thermal energy generation from renewable sources has yet been implemented (IEA, 2013). On the contrary, in large metropolitan areas, district heating is provided in general by big CHP units or connecting heat exchangers to existing waste to energy plants. This characteristics in general improves the economic performance of the interventions. In addition, in some cases the district heating systems can use energy resources such as municipal waste and waste heat of industrial systems otherwise lost.

Despite the economic barriers, on the other hand biomass district heating plants are powered by renewable resource locally available, as it is possible to note from the fossil primary energy avoided (see Section 3.3). So in general they have better environmental performance if well managed and they positively contribute toward the regional, national and European goals related to renewable energies integration. We stressed also that the economic performance of the biomass plants is strongly affected by the market price that has been constantly increasing during the last years (see Section 3.4). So we can argue that, for the future, in order to guaranty the cost effectiveness, the following features have to be verified in the case of biomass plants (Gebremedhin, 2014): a reasonable and stable biomass market price; presence of small CHP units; stable operational supporting mechanism related to electricity and heat generation; an adequate linear heat density. While, in general, fossil and waste plants presented better economic performance; they could be able to be relatively cost effective also without dedicated supporting mechanisms.

Furthermore, it has to be stressed that district heating plants in general constantly evolve and increase during each year of their life. This configuration improves the overall efficiency and changes significantly their initial performance and features, but, unfortunately, the data collected and the state of the art of the interventions monitored did not allow a complete evaluation of these evolutions in the present work.

In order to evaluate similar processes, criteria and key performance indicators to support effective monitoring of technical and financial results and processes should be defined in advance. In this way monitoring can be considered as the most useful tool in providing information on the effectiveness of the public spending and, in particular, in identifying the most promising technologies, their characteristics and sizes, and in effectively improving energy and environmental performances of communities and territories.

In conclusion we hope that our analysis can be of interest for the implementation of the information in the Italian district heating sector in order to stimulate the diffusion of these technologies in a reasonable and sustainable way.

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