SOLAR AND BIOMASS FOR ITALIAN COMMUNITIES: ANALYSIS OF TWO CASE STUDIES

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Abstract – In the frame of SmartReFlex project, smart and flexible 100% renewable district heating and cooling systems are promoted thanks to the analysis of local case studies.
Italian partners are assessing the feasibility of this kind of projects in the region of Emilia Romagna, supporting local communities willing to go for renewables. In this work, two case studies dealing with existing DH extensions powered by biomass and solar thermal are analysed.
Alternative solutions are assessed in terms of energy performances, economic sustainability and environmental impact. Results show biomass can definitely decrease the CO_2 emissions but increases the pollutant emissions that can definitely be reduced by solar thermal.

Key words: case studies, solar, biomass, local community, feasibility

1. INTRODUCTION

The main aim of SmartReFlex project is the promotion of DHC networks with relevant share of renewable energy sources. This kind of systems have a very local connotation and not only because they use local resources: to go towards a 100% renewable networks, all of the main actors of the process have to be involved, the utility, but also the local authority and the community. The use of renewables such as solar energy and biomass, means important land use, which is now a subject of frequent arguments. It is thus fundamental to design these projects basing on heat planning and mapping, and to analyse every project with a comprehensive approach, looking at every impact they may have. That's why the principle measures implemented by SRF project to promote RES DH are:

- heat mapping and energy planning to integrate RES
- study and support new high-RES DHC projects at local level.

In this frame two case studies are analysed in this paper, principally based on biomass and solar thermal energy, located in Emilia Romagna, SRF project partner.

2. FRAMEWORK

At national level, the Italian transposition of European Directive 2012/27/EU (D. lgs. n. 102/2014) promotes "efficient district heating", using at least 50% RES, 50% waste heat, 75% cogenerated heat, or 50% of a combination of such energy and heat. DH has demonstrated to be an efficient way to exploit different energy sources and among them renewables such as biomass and solar thermal. (Nielsen 2014)

At local level, the regional energy planning (DGR 26/2004) asks the local authorities to include the assessment of efficient DH potential in urban planning: this evaluation should be a cost/benefit analysis taking into account the impact on the air quality. In fact, the region of the two analysed case studies lies in the Po valley, the largest plain area in Italy that, because of its physical conformation and human causes, is experiencing several problems in maintaining air quality standards (infringement proceeding from EU). That's why the Emilia Romagna region has elaborated an integrated air quality plan, PAIR 2020 (DGR 949/2013), to get back as soon as possible within the air quality limit values, in particular regarding particles emissions. Concerning energy production, the PAIR identifies measures to respect air quality and requires from new plants a "zero emission balance": new emission sources fed by biomass do not have to exceed, and better reduce, the emissions level of the energy sources they substitute in certain areas (D.A.L. 51/2011). In this framework, DH especially fed by cleaner renewable energy sources, has definitely a great potential in substituting individual polluting systems such as liquid fossil fuels boilers, and even biomass ones. Despite the great degree of penetration of natural gas in the Italian territory, there are still areas such as historical city centres or mountain regions in which natural gas connection is not present and heating systems are mainly fuel oils or individual biomass burners. Biomass is a renewable, local, and CO_2 neutral source, reasons why its use has been promoted in Italy through many incentives in particular for electricity production. But despite these advantages, biomass burning can have negative impacts on air quality in particular in case of old inefficient technologies. Primary sources of air pollution, such as PM10 and BaP, and secondary ones, such as SOx and NOx, were found to be produced by biomass burners mainly by old firewood boilers and open chimneys. Small scale DH can bring some benefits in these cases by centralizing and moving the polluting source away from residential areas. The installation of DH generation systems, compared to individual ones, is not necessarily less polluting a priori (Genon et al 2009), but it allows the use of higher stacks, high quality filtering systems and qualified employees to optimally manage and operate biomass power systems. Even though substituting the same energy source, with proper filtering and proper management, DH has proven to reduce polluting air impact of biomass (Jonsson 2006). In addition to that, the flexibility of DH systems can reduce the use of biomass by the integration of zero emission systems, such as solar thermal. The "improper" use of agriculture land for dedicated energy production biomass and the difficulties in reaching the net zero emission balance are pushing to find other renewable energy sources for DH. Solar thermal "zero emission technology" has proven to be a perfect candidate to integrate biomass on flexible DH systems in particular in summer time (Mathiesen 2012).

3. THE CASE STUDIES

The two cases analysed in this paper deal with the extension of existing networks: the main new source is biomass; solar thermal is integrated to reduce its use in summer and reduce the impact on air quality.

3.1 The existing plants

The case studies are described in the following paragraphs in which:

1 - Mirandola (MO) 20'000 inhabitants;
2 - Monchio delle Corti (PR) 1'000 inhabitants.

Case n1 is a DH and small DC system fed mainly by a natural gas internal combustion engine, which recover heat on the return line, from a third party biogas power plant. (Figure 1)

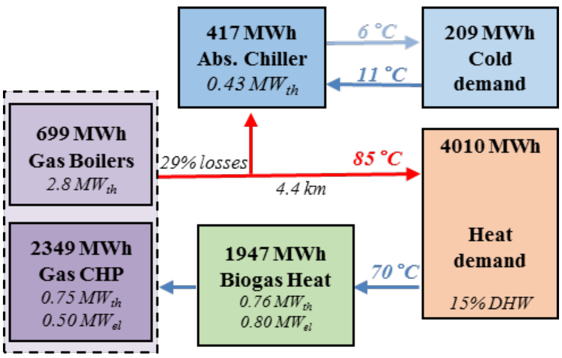

Figure 1 Mirandola actual DHC – Case 1

Together with the local authority and other local actors, the company is elaborating the recovery of local biomass before it becomes a waste. The main aim is to reduce dependency on fossil natural gas and on its price unpredictability and to exploit a local resource that is now wasted.

Case n2 is a very small DH network with a single biomass boiler in a mountain village that is not reached by natural gas network. (Figure 2)

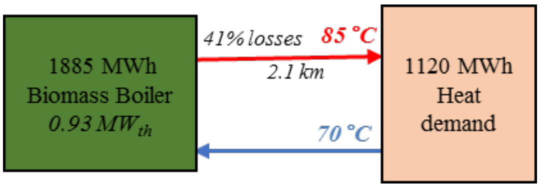

Figure 2 Monchio delle Corti actual DH – Case 2

The purpose of the analysis is the evaluation of extension and also optimization of the existing plant, which is directly operated by the municipality. The integration of solar thermal is foreseen in both cases to reduce the massive use of biomass.

It's important to notice that, even if the networks are both quite small, there's a main difference regarding ownership. The first is managed by a private utility and all the data come from data logger monitoring; the second one, the smallest, is entirely managed by municipality's inner employees without technical knowledge and with no data logging, except for monthly users' data for billing purposes. Consequently, in case study n2 the only monitored reliable data is user consumption, while network losses have been estimated through the following formula (1):

$$q_{lost}= 1/[1+(Q_S/L)/(H_T \cdot 2\pi d_a \cdot G)]\ [\%] \tag{1}$$

Where Q_S is the sold heat [J], L is the excavation length [m], H_T is the total heat transmission [W/m^{2}K], d_a is the average diameter of pipes [m] and G is the degree time number [°Cs]. (Werner 1984) Improper design (piping size and insulation, oversizing of biomass boiler), low heat density and bad operational strategies (temperatures and flow) are causing a very high values of losses (41%).

3.2 Methodology

The main purpose of SmartReFlex case studies is to support local authorities and utilities that are willing to use RES in DH network and help them to choose among different alternatives and options. In order to do that, figures of energy performances, costs and environmental impact are calculated through simulations of future possible alternatives with energyPRO. (Connolly et al. 2010 and Østergaard PA, Andersen AN. 2016). EnergyPRO is a simulation software for technical and economic analyses. Thanks to hourly input data such as energy needs, weather data and electricity market prices, it's possible to simulate different operating strategies and among them, the one optimizing the net production costs. (Figure 3) The main steps for the analysis of the extended network of both case studies are:

1. Building a validated model of the existing network.
2. Using the validated model to simulate the extension.
3. Evaluate alternative system configuration.

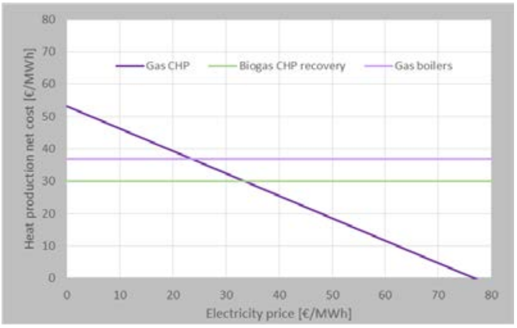

Figure 3 Heat net production cost Case 1

4. INPUT DATA MODELLING

4.1 Heating and cooling demand

Utility and municipality, according to existing users' types mix and consumptions, have estimated additional demand related to the two DH extensions.

Case	*Current user needs*	*Extension needs*	*Total future needs*
	[MWh/y]	*[MWh]*	*[MWh]*
1	. Heat 4010	3790	7800
	. Cold 204	-	204
2	. Heat 1120	577	1697

Table 1 Estimated new heat demand for extension

From these yearly amounts of space heating, space cooling and DHW energy needs, an hourly profile has been derived by summing three components and adding a constant amount all over the year for heat losses along the network.

Space heating/cooling needs: from the total heat demand E_H, the amount referred to the space heating $E_{SH,}$ (~85% $E_{H,}$) has been distributed across the heating season $Q_{SH,i}$, from 15th of October to 15th of April, with a time dependency to external temperature through the degree day method according to the formula (2):

$$Q_{SH,i} = Q_{SH,max} * PLR_i \quad (2)$$

$$Q_{SH,max} = E_{SH} / \sum PLR_i \quad (3)$$

$$PLR_i = (T_{ext,\ balance} - T_{ext,i}) / (T_{ext,\ balance} - T_{ext,\ min}) \quad (4)$$

with PLR_i = Partial Load Ratio and $T_{ext,\ balance}$ = external air temperature for which it is assumed that the internal gains balance the losses (heating need= zero), here fixed at 17 ° C.

The hourly profile for cooling needs follows the same methods that heating needs, with a working period from 1st of June to end of August, from 8h to 20h since cooling is provided to office buildings.

DHW needs: the heat consumption due to the use of DHW is not whether influenced. So its time dependent profile, constant along the year, has been derived by multiplying the daily needs to a peak water consumption profile (Figure 4) for multiple dwelling buildings (EST 2008).

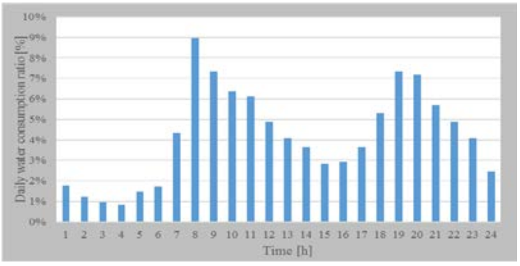

Figure 4 Domestic hot water consumption daily profile

4.2 Electricity market

For case n. 1, in order to properly simulate and optimize CHP operation, it is important to consider time dependent electricity market price, from the day-ahead auction electricity trading (GME 2014), to calculate electricity-sale revenues and electricity consumptions, mainly for network pumping

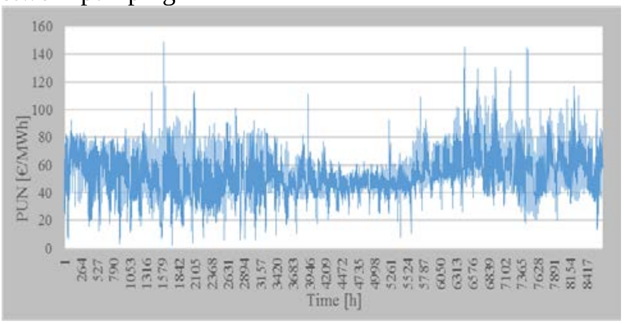

Figure 5 Day ahead auction trade result electricity price (GME 2014),

4.3 Generation systems

Natural gas CHP: In case number 1, a CHP with nominal power of 500 kWel and 750 kWth is installed. According to technical data, partial load performances curves are built and considered in the model:

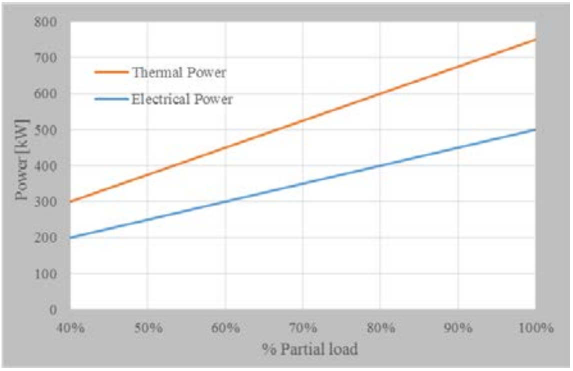

Figure 6 Internal combustion engine (ICE) production profile on partial loads (ICE Technical data sheet)

Biomass boiler:

Case n2 DH is currently fed by a biomass boilers of 930 kWth, whose efficiency curve has been taken from data sheet and modified according to consumption real data.

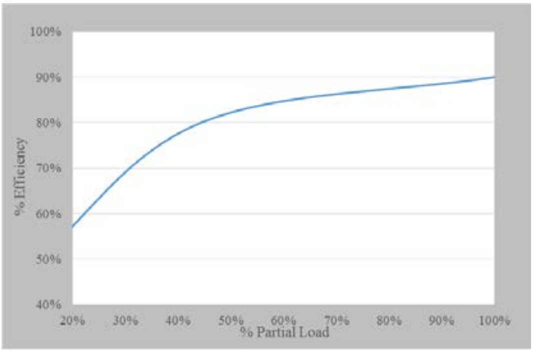

Figure 7 Biomass boiler thermal efficiency profile on partial loads (estimated)

4.4 Operational costs and revenues

The following tables show the operational costs considered in the simulations of both case studies.

Operational costs/incomes [i]			
Natural gas	Gas	36	c€/Sm^3
	Taxes for heat production	1.8	c€/Sm^3
	Taxes for electricity production	0.045	c€/Sm^3
Heat recovery biogas CHP		lower than natural gas (confidential)	
Biomass	Short distribution chain (case 1)	25	€/t
	Market	50	€/t
	Forestry (case 2)	65	€/t
O&M	CHP	4	€/MWh (prod.)
	Gas Boiler	0.8	€/MWh (prod.)
	Bio. boiler case 1	2.0	€/MWh (prod.)
	Bio. boiler case 2	6.0	€/MWh (prod.)
Average users' tariff	Case 1	105	€/MWh (heat)
	Case 2	120	€/MWh (heat)

Table 2 Operational costs and incomes (Source: utility and municipality) natural gas cost (AEEGSI 2015), (D.lgs. 1995, n. 504)

4.5 Investment costs for extensions

In Table 3, different costs used for the financial assessment of the DH extension a the integration are shown:

Element	*Costs for the case studies*		
	n. 1	*n. 2*	
Piping	200	140	€/m linear
Piping other costs	30%	45%	% piping costs
Substations	6.60	10÷100	€/MWh
Woodchip boiler	120	200	€/kW
Boiler installation	40%	45%	% boiler costs
Solar field <1000m^2	400		€/m^2
Solar field 1600m^2	320		€/m^2
Storage <500m^3	600		€/m^3
Storage 500-1000m^3	450		€/m^3

Table 3 Economic parameters

4.6 Emissions

As previously mentioned, emissions coming from generation plants should be kept as low as possible, not only GHG but also particles emissions that affect air quality. Having no measures of them, values have been taken from literature (INEMAR). Values for DH systems but also for substituted individual systems can be found in Table 4.

Generation		*CO_2*	*SO_2*	*NO_x*	*PM_{10}*	*BaP*
		kg/GJ	*g/GJ*	*g/GJ*	*g/GJ*	*mg/GJ*
Natural gas	CHP	55.8	0.29	140	1.60	6e-04
	DH boil.	55.8	0.24	100	0.71	6e-04
	Indiv. boil.	55	0.5	35	0.16	6e-04
Biomass	DH boil.	0	20	250	40.0	1.1
	Indiv. boil.	0	13	100	76.0	50
Oil	Indiv. boil.	75.7	146	150	14.40	0.08

Table 4 Emissions per fuel consumptions (INEMAR)

6. CASE N. 1 SIMULATION

Before considering any extension nor integration, the model of the existing DH system is built in order to simulate the actual operation. Once validated with monitoring data, it can be considered a reliable tools thanks to which the extension and the different alternative new energy sources can be assessed. Validation has been made comparing energy production of every generation systems of the plant with satisfactory results (all deviations are much lower than 5%).

The potential extended network can be seen in Figure 8 in green. Red areas have been found to be the most demanding ones by a parallel EU project RES HC Spread who performed a heat mapping of the region. (Ref ARPAE ER, RES H/C SPREAD EU project).

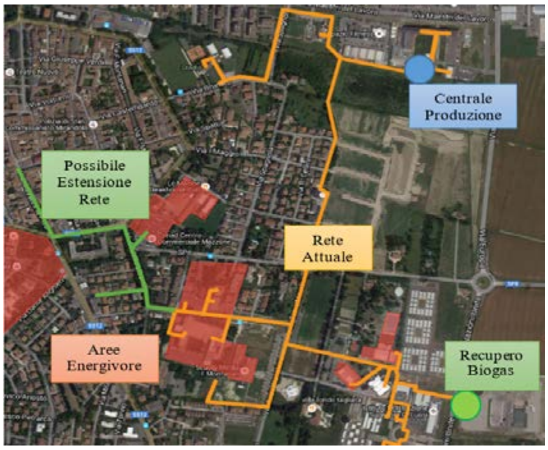

Figure 8 Case 1 Extension of DH network

Being the network currently oversized, the project is mainly based on the increase of connection on the existing network than in the extension of network length.

A ruinous earthquake affected the area in 2012. A beneficial consequence should be a decrease in heat losses. Linear heat density should in fact increase from 0.9 MWh/m to 1.4 MWh/m, closer to the value of certain profitability defined between 2-2.5 MWh/m (UP-RESProject, EU commission)

Several alternatives have been simulated referred to three main configurations of additional systems summarized in Table 5. The alternative integrations foresee additional smaller biomass boiler to increase efficiency at partial loads, storage tank and different sizes of solar thermal field sized in order to avoid stagnation.

Alternatives	*Biomass P_n boiler*	*Solar thermal Area*	*Storage tank Volume*
1	1 MW	-	200 m^3
2	1 MW	1600 m^2	160 m^3
3	1 MW	2500 m^2	1000 m^3
4	-	1600 m^2	160 m^3

Table 5 Alternative solutions for Case 1 extended

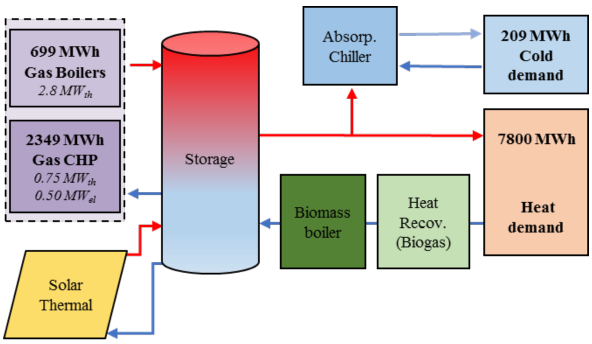

Figure 9 Case 1 DH extension

6.1 Energy results

Energy results follow:

Alt.	*Natural gas* [MWh]	*Bio sources* [MWh]	*Solar energy* [MWh]	*SF* [%]	*Electricity produced* [MWh]
1	4249	5359	0	0	2861
2	3215	5031	1361	15	2152
3	2496	5002	2127	23	1704
4	5969	2277	1361	15	2669

Table 6 Energy results of case 1 extension

The solution with the highest solar fraction, n. 3, is also the one with the lower use of CHP plant, so lower operational costs but also lower electricity production that could affect the economy of the plant.

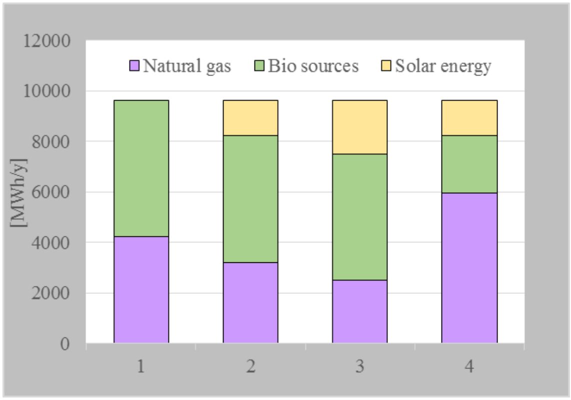

Figure 10 Energy results of case 1 extension

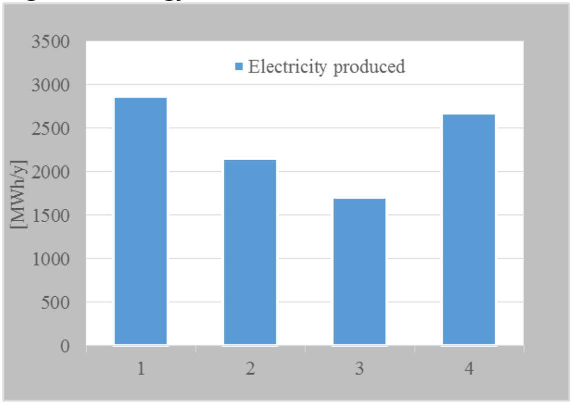

Figure 11 Electricity production for case 1 extension

6.2 Environmental impact results

On the opposite side, alternatives 4 has a quite important solar fraction but also a higher use of natural gas, less environmental friendly (high values of CO_2), but with a lower impact on air quality (lower primary and secondary particulate emissions).

Altern.	*CO_2* t	*NO_x* kg	*SO_2* kg	*PM10* kg
1	1551	7214	192	256
2	1173	6076	179	231
3	916	5518	182	226
4	1877	4381	9	58

Table 7 Environmental impact of case 1 extension

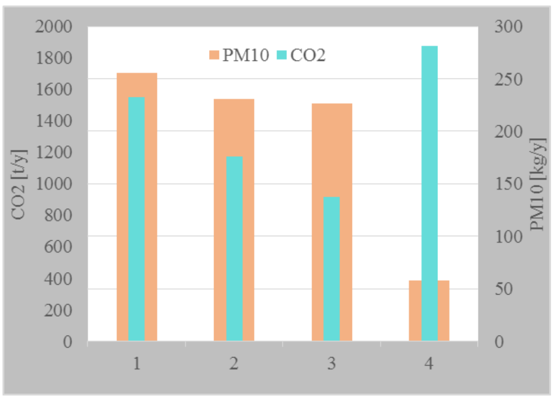

Figure 12 Emissions results of case 1 extension

6.3 Economic figures

Considering investment costs defined in Table 3, operational costs and revenues defined in Table 2 and incentives schemes for solar thermal (Conto Termico – in these cases approx.. 35€/m^2 for 5 years) and DH (White certificates) the economic figures that come out are in Table 8. It's important to notice that the economic assessment has been done in a differential way: in order to evaluate just the extension, the existing part is supposed to be already paid back; the investment costs for extension, additional costs and revenues (calculated as extended network operational costs-current existing ones) have been allocated only to the new additional demand. (same for case n.2) and costs and revenues of the existing generation systems to the current demand.

Alternatives	*Investment*	*NPV (30)*	*PBT*	*IRR*
	M€	*M€*	*years*	*%*
1	0.64	2.83	5	35
2	1.26	2.70	6	22
3	1.77	2.55	8	17
4	0.81	1.87	6	24

Table 8 Economic results of case 1 extension

All payback time are much lower than systems life time and economic figures are very positive: this is mainly due to the particular condition that allows the payment of materials and not installation of piping.

For a higher investment costs, solution with a higher SF, have very interesting values of NPV at 30 years with reasonable IRR.

7. CASE N. 2 SIMULATION

Case 2 DH currently has a very simple configuration with a single biomass boiler, oversized, which causes two main problems:

- municipality cannot guarantee feeding continuity having no back-up systems
- oversizing implies that the boiler is always working at very reduced load, with very low efficiency

Since no natural gas network is available in Monchio delle Corti, a preliminary analysis has been done to see what kind of individual systems the current DH has substituted.

Previous individual systems were (% on energy):

- 24% oil;
- 61% GPL;
- 15% pellets.

Current DH had mainly three effects:

- majority of customers are paying 60% less than what they used to pay with previous fuels;
- CO_2 emissions balance is now zero;
- particles emissions have increased a lot both because of bad performances of DH present systems (40% losses, low boiler performances) and because of intrinsic characteristic of biomass. See Table 9:

Emissions		*Current DH*	*Replaced individual systems*
CO_2	t	0	225
SO_2	kg	201	55
NO_x	kg	2260	234
BaP	g	11	121
PM_{10}	kg	249	234

Table 9 DH impact compared to previous systems

The present situation can thus benefit from introduction of clean solar thermal system.

The new part of the network for case 2 is the orange one in Figure 13. Also in this case the DH is penetrating the areas with higher demand, even if the foreseen new connections calculated by the municipality are still far from the saturation: the total new demand would be the 30-40% of the total mapped one. (Heat mapping ref. ARPAE ER)

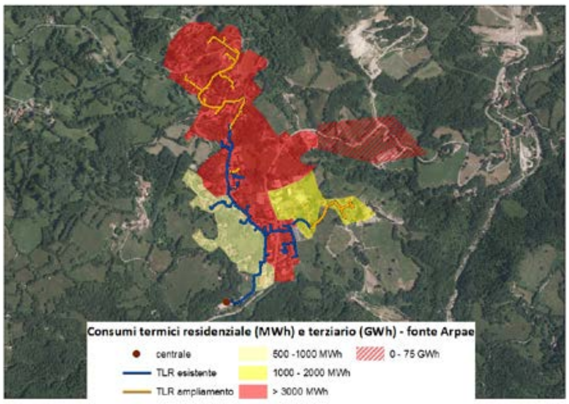

Figure 13 Case 2 Extension of DH network

Two alternative configurations are assessed: the first with an additional smaller biomass boiler to enhance efficiency at partial loads, and the other one with solar thermal.

Alternatives	*Biomass*	*Solar thermal*	*Storage tank*
	P_n boiler	*Area*	*Volume*
1	200 kW	-	-
2	200 kW	280 m^2	10 m^3

Table 10 Alternative solutions for case 2 extension

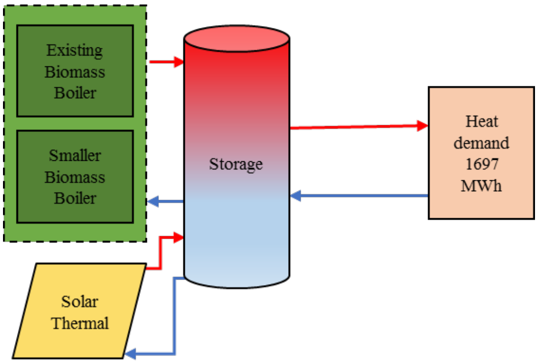

Figure 14 Case 2 DH extension

7.1 Energy results

Table 11 and Figure 15 show energy results

Alternative	*Biomass [MWh]*	*Solar energy [MWh]*	*SF [%]*
1	3059	-	-
2	2874	187.90	7

Table 11 Energy results of case 2 extension

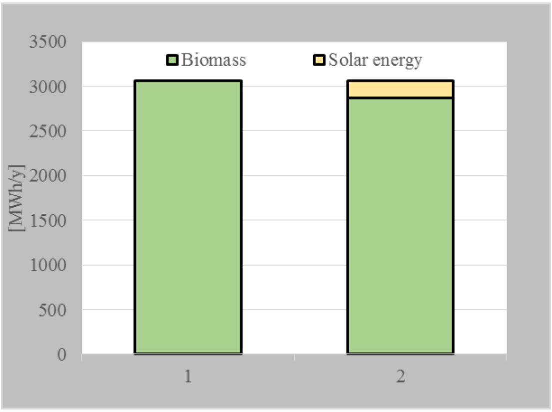

Figure 15 Energy results of case 2 extension

7.2 Environmental impact results

The solar energy comes out to be the only emission-free technology: as Figure 16 shows, the solar energy production has a direct impact on air pollutants reduction.

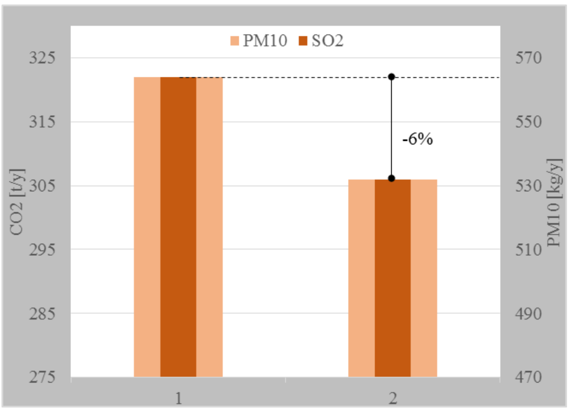

Figure 16 Emissions results of case 2 extension

7.3 Economic figures

Economic results in Table 12 show that, even if the two solutions with solar thermal increase the PBT, the values are similar and all still lower than lifetime.

Alternatives	*Investment M€*	*NPV (30) M€*	*PBT years*	*IRR %*
1	0.55	0.20	17	6.70
2	0.73	0.21	19	6.15

Table 12 Economic results of case 2 extension

The reason of the high PBT values of the extension lies mainly in the big amount of losses and general inefficiency of the system due to oversizing. A fourth simulation run has consequently been tried to see a future scenario with a densification: a higher demand has been simulated, without any network extension. For a total demand of 3400 MWh, alternative's 2 PBT decrease to 17 years, with a NPV(30) of 0.42 M€.

4. CONCLUSIONS

In the framework of SRF project, the use of biomass and solar thermal energy for the extension of existing DH systems has been simulated. Results show biomass can definitely decrease the CO_2 emissions but as a drawback it causes an increase in the pollutant emissions that can definitely be reduced by solar thermal. The economic figures show that integration of biomass and solar thermal is definitely feasible and sustainable and it can have a beneficial social impact with the use of local resources. Nevertheless, a better management and more accurate design are needed in the DH owned and operated by local authority.

Since the alternative solutions have all pros and cons, a specific multicriteria analysis could be used to evaluate all the aspects, environmental, financial and also social to assess the best solutions. In any case all the calculated figures will support the decision managers in choosing the best configuration.

NOMENCLATURE

DHC - District heating and cooling;
CHP - Cogeneration Heat and Power
PM10 - Particulate Matter smaller than 10µm
BaP - Benzo[a]pyrene
NOx - Nitric oxides
SO2 - Sulfur oxides
RES - Renewable energy sources
ICE - Internal combustion engine
PBT - Payback time
NPV - Net present value
IRR - Internal rate of return

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[i] Economic figures used in this work have been provided by AIMAG SPA and by local authority of Monchio delle Corti. Considering the confidentiality of some data and the temporal variability of some others, they should not be considered official and binding for the company with respect to third parties. They are average values still appropriate and a representative for the research work developed in this papaer.