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Analysis of the Air Quality of a District Heating System with a Biomass Plant

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Abstract: Heating is one of the major causes of pollution in urban areas, producing high concentrations of aero-dispersed particulate matter (PM) that can cause serious damage to the respiratory system. A possible solution is the implementation of a district heating system, which would decrease the presence of conventional heating systems, reducing PM emissions. The case study considered involves the municipality of Serra San Bruno (Italy), located near a biomass plant, which could play the role of a thermal conversion plant for a possible district heating network. To determine the heating incidence on pollution, the large users in the area were identified. The large users' consumption estimation was carried out, obtaining the thermal energy requirement linked to the residential, which is about 3.5 times that of all the large users. Through air quality measuring devices, PM concentrations were measured for the winter and the summer period. PM emissions were then estimated using emission factors and the decreases in PM concentrations were calculated if part of the domestic users were converted to district heating, compatibly with the possibility of supplying energy to the biomass power plant. The replacement of conventional plants in favor of a district heating network has a positive impact on PM pollution.

Keywords: air pollution; biomass power plant; energy; district heating

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1. Introduction

Heating is one of the major sources of pollution found in urban areas: this applies to domestic systems, but above all, to large users. The latter have large levels of consumption and, consequently, contribute more to worsening the air quality of the areas in which they are present. Conventional heating—that is, the type that involves burning fuel to generate heat—emits a large number of pollutants (CO_2, CO, NO_x, volatile organic compounds, particulate matter); the quantity of these emitted substances depends on the type of fuel used in the heating system [1]. In particular, solid particulate matter is one of the most dangerous pollutants: every concentration value [2], even slightly higher than the limits set by the legislation, can entail significant risks for the health of individuals, as well as a decrease in life expectancy [3]. It is, therefore, evident that in an urban context it is desirable to minimize the presence of harmful substances in the air and to preserve human health [4,5]. Consequently, it is also desirable to significantly reduce emissions due to heating. To achieve this goal, an alternative solution to conventional systems must be found.

This case study concerns the municipality of Serra San Bruno, a small city in the south of Italy, which is shares a neighborhood with a thermal conversion plant for woody biomass. It simultaneously generates mechanical energy, which is subsequently transformed into electrical energy, and heat, which can be exploited for heating purposes. This simultaneous production is called cogeneration.

Woody biomass is a renewable energy source and represents a valid alternative to fossil fuels [6] as long as it is exploited in a sustainable way. Combustion must take place, but if the process is carried out in optimal conditions and with the best available technologies, it emits a quantity of pollutants that is much lower than other conventional energy sources [7]. Furthermore, the use of the aforementioned renewable source involves the emission of CO_2, but other biomass will absorb it. This makes this energy source carbon neutral, or with a net emission of carbon dioxide that is equal to zero [8].

District heating allows heat to be conveyed over longer or shorter distances so that it can be used for domestic heating, in order to obtain domestic hot water and, possibly, for the buildings' cooling and air conditioning. This objective is achieved through a system in which the heat, generated by a thermal power plant, is transported to the various users by means of a heat transfer fluid (generally water or steam). It is, therefore, possible to identify three main elements in a plant of this type [9]:

- Thermal conversion plant;
- Piping network;
- System of sub-exchanges.

The thermal conversion plant can generate heat in many ways. It is possible to exploit numerous energy sources, renewable or not (fossil fuels, biomass, urban waste, geothermal energy, etc.). The high-temperature water that leaves the plant is sent to a pipes network—a process called delivery—which reaches the users, and it is essential that this network is thermally insulated in order to minimize energy losses along the way. The heat distribution can take place directly or indirectly. In the first case, there is a single hydraulic circuit that seamlessly connects the production unit to the user's heating elements. Conversely, in the second case, which is much more common, there are two or more separate circuits that maintain contact through sub-exchanges; in the latter, the heat transfer fluid transfers the heat to the home system, allowing the energy to transfer between the network and the single user in the most efficient way possible [9]. Once the heat exchange has been carried out, the water returns to the starting point by means of a return piping system (which does not necessarily have to be insulated) to be heated once more and then to start its cycle again. The recently developed district heating systems are technologically advanced and based on artificial intelligence to guarantee effective energy production and distribution [10].

The advantages of district heating are numerous: it is possible to exploit a large variety of energy sources and fuels, allowing the best use of the resources available where the plant is located. If the thermal power plant also produces electricity in cogeneration, the overall consumption of fuel is limited compared to separate production; it is possible to prevent users that are served by district heating from installing or, in any case, maintaining conventional heating systems such as boilers, which overall, could have a much more significant environmental impact. In addition to these advantages, there are also social and economic benefits due to the reduction in energy costs [9]. In Italy, district heating systems are widely diffused (above all in the north), while in the Eastern European areas the traditional systems are used more [11]. A district heating network can have a tree, ring or mesh configuration. The tree structure foresees that the main backbone runs through the areas that are contiguous to the major users, and then branches off into different sub-routes destined to reach the minor users. In the ring configuration, there is a single closed circuit that can be traversed in both directions. The delivery and return circuits are in parallel, and at each point of the ring the branches can be created to reach the users. This configuration has the advantage of greater reliability and the possibility of developing future extensions. Further, in the event of a problem, the supply of the service is not suspended, but the water is made to flow in the opposite direction. The knitted configuration consists of several closed rings that are in contact with each other at different points and powered by a minimum of two production plants, depending on the extent of the network. It has greater reliability than the previous configuration and the possibility of further expansions, but it also has higher investment costs.

The use of alternative energy transport systems such as district heating could be useful for the environmental improvement of areas in which there are high levels of pollution and plants that could be used in this sense [12]. Furthermore, district heating systems are a valid support for the renewable fuels use, which would not only lead to CO_2 reduction that in some cases reaches 30–40% [13], but also to an economic advantage in reducing the plant costs [14].

In this case study, the thermal conversion plant at Serra San Bruno is not exploited to its full potential, as the sensible heat of the combustion fumes is not used. From the perspective of environmental impact, given the importance of the decrease in the presence of conventional heating systems in the area, it could be possible to use this latent heat to build a district heating system. This paper also analyzes the reduction in PM concentrations following the possible implementation of the district heating system. This reduction was calculated starting from the data that were measured by the air quality monitoring network in the area considered.

Air quality monitoring has developed in recent years thanks to the use of smart sensors based on Internet of Things (IoT), which, with a high spatial and temporal resolution, are able to provide information on pollutant levels [15]. The subsequent development of the sensors led to the implementation of a new generation of measurement systems called ROMs (Real-Time On-Road Monitoring stations) [16]. Thanks to the moving sensor, these systems allow the pollution levels to be mapped with a resolution of up to km^2, and the data obtained are protected by the blockchain, which guarantees its integrity [17].

2. Materials and Methods

2.1. Large Users Identification

Within the municipality of Serra San Bruno, large users have been identified—that is, those structures that have, from the point of view of heating, the most important consumption compared to domestic users. They are listed in Table 1 and disposed in the area considered, as reported in Figure 1.

Table 1. Large users characteristics.

User	Total Area, m^2
San Bruno Hospital (A)	12,387
Serra San Bruno Hall (B)	1312
L. Einaudi High School (C)	3224
Secondary Public School (D)	1870
A. Tedeschi Primary School (E)	1887
Serra San Bruno Pool (F)	1894
Certosa (G) and Conte Ruggero (H) Hotels	2304

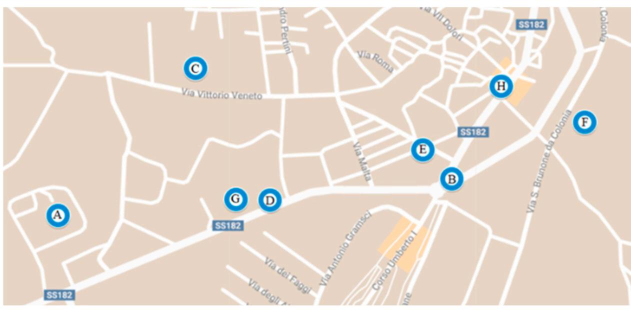

Figure 1. Large users located in Serra San Bruno. (A) San Bruno Hospital, (B) Serra San Bruno Hall, (C) L.Einaudi High School, (D) Secondary Public School, (E) A.Tedeschi Primary School, (F) Serra San Bruno Pool (F), Certosa (G) and Conte Ruggero (H) Hotels.

2.2. Estimated Consumption Due to Heating

Since data relating to the energy consumption of the large users under consideration were not available, the heating consumption was estimated by analogy. The energy needs of the individual users were effectively estimated by referring to similar structures for which the consumption related to heating was known. In particular, users that were similar in size and number to the users under consideration were chosen. It was also verified that they are located in cities where the average monthly temperatures are similar to those of the municipality of Serra San Bruno. Secondly, a literature search was carried out to obtain the specific consumption values (generally expressed in kWh/m^2 year) for each type of user, in order to relate the energy used for heating with the surface of the building.

2.3. Emission Factors Definition

A pollutant emission factor is defined as the ratio between the quantity of the substance emitted and a term relative to the considered source consumption. In this case study, the emission factors relating to conventional heating systems must be considered. They were obtained from "Energy and environmental impacts of fuels in residential heating" [18] and are summarized in Table 2.

Table 2. Emission factors for domestic heating.

Fuel	CO_2 [kg/GJ]	CH_4 [kg/GJ]	NOx [kg/GJ]	CO [kg/GJ]	NMVOC [kg/GJ]	SO_2 [kg/GJ]	PM_{10} [g/GJ]	$PM_{2.5}$ [g/GJ]
Coke	105.93	0.015	0.07	5	0.005	0.682	439	219.5
Steam coal	91.66	0.2	0.05	5	0.2	0.646	439	219.5
Wood	92.71	0.32	0.06	5.39	0.638	0.013	403.9	400.2
Diesel	73.69	0.007	0.05	0.02	0.003	0.047	3.6	3.6
GPL	64.94	0.001	0.05	0.01	0.002	-	2	2
Natural gas	56.76	0.003	0.03	0.03	0.005	-	0.2	0.2

2.4. Air Quality

Pollutants concentrations, particularly of $PM_{2.5}$ and PM_{10}, were measured with two measuring devices. The measuring devices are part of the city's air quality network and allow the real-time measurement of the particulate matter $PM_{2.5}$ and PM_{10} and the meteorological parameters (temperature, relative humidity, pressure, wind intensity and direction).

The measuring devices are equipped with laser scattering sensors for the detection of particulate matter with an accuracy of ± 5 µg/m^3. For the meteorological parameters measurements, the devices have a band-gap sensor for the temperature and a capacitive sensor for the relative humidity (accuracy of ± 0.3 °C and $\pm 2\%$, respectively). The wind intensity and direction are given by an ultrasonic sensor with an accuracy of $\pm 5\%$ m/s and $\pm 0.3°$, respectively. The sensors used for measuring the air quality are IoT-based, and the data are processed every three minutes and then sent to a central server, where this information is recorded and stored.

During the network design phase, the measurement systems were positioned in sensitive points of the considered area [19]. The first (S1), was positioned near the biomass power plant, while the second, (S2), was placed in the city center; Figure 2 shows their positions together with those of the major users considered.

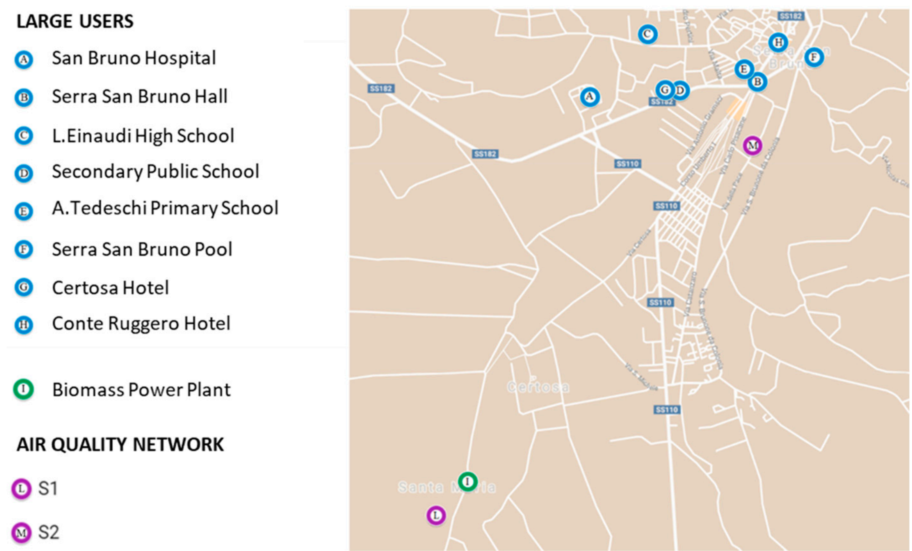

Figure 2. Large users and air quality monitoring devices located in Serra San Bruno.

3. Results

3.1. Estimated Consumption per Analogy

Energy consumption, as previously mentioned, was estimated for each large user by analogy with the structures reported in previous case studies. For user A, from the "Report on data collection for the determination and characterization of the types of systems for winter and summer air conditioning in hospital buildings" [20], which was drawn up by the ENEA, it is possible to obtain the total annual consumption per place and bed according to the size of the structure. From the data-set provided by the Italian Ministry of Health [21], it is possible to know the number of beds in the San Bruno Hospital, which is 34. Considering that the specific consumption for a hospital of this size is equal to 36,447 thermal kWh per year per bed, a total of about 1239 MWh/year is obtained. For user B, it is possible to make an analogy with a municipality with a population and average temperature similar to the one considered, and for which an energy diagnosis of the municipal building is available [22]. From the aforementioned energy diagnosis, the average consumption relating to the heating of the municipal building can be obtained, which is quantified at about 128 MWh/year. To obtain the information relating to the consumption of school users C-D-E, similar school structures with a comparable number of students and located in climatic conditions similar to the place considered were used as a reference. Considering the data reported in the APEA CT document [23], it is possible to estimate a consumption of about 617 thermal MWh/year for user C. From the energy census [24], it is possible to obtain a consumption of about 112 MWh/year for user D, and since user E is similar to D, it is reasonable to assume that the consumptions are similar and, therefore, also in this case equal to 112 MWh/year. The pool (user F) consists of five semi-Olympic lanes (length of 25 m). An energy audit is used as a reference relating to a plant that is similar in size to the swimming pools [25], from which a consumption of approximately 700 MWh per year is assumed. The energy consumption due to the heating of both hotels (users G and H) can be assimilated to those of a hotel for which data from an energy census carried out by APEA CT, already used previously, are available [23]. From the aforementioned energy census, data can be obtained regarding the heating needs for the reference hotel, which requires, on average, 379,32 kWh per year. Assuming that the two users G and H have a consumption, in thermal kWh/year, that equals double that of the hotel considered (reasonable hypothesis examining the number of rooms and floors of the buildings), it is possible to estimate the energy needs of both hotels of 759 MWh/year. The results are summarized in Table 3 and reported in Figure 3.

Table 3. Thermal consumption estimated for the large users.

User	Thermal Consumption Estimated, MWh/year
San Bruno Hospital (A)	1239
Serra San Bruno Hall (B)	128
L. Einaudi High School (C)	617
Secondary Public School (D)	112
A. Tedeschi Primary School (E)	112
Serra San Bruno Pool (F)	700
Certosa (G) and Conte Ruggero (H) Hotels	759

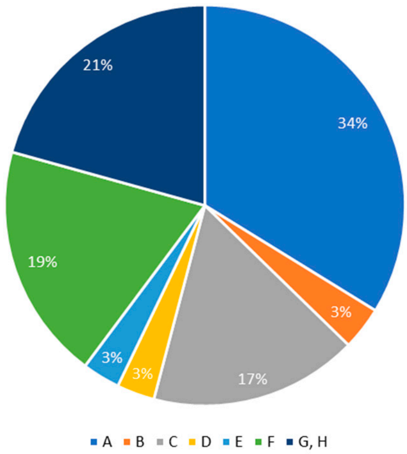

Figure 3. Thermal energy consumption for the large users.

It is clear from Figure 3 that user A has the greatest thermal consumption at almost double that of user F, which is instead the second user for estimated consumption. The users C, G and H, representative of the school and the accommodation facilities, make a contribution that equals about 20% of the total, and therefore, almost comparable to that of user F. On the other hand, the consumptions due to users B, D and E are negligible. If considered individually, they consume about a tenth of the most energy-intensive structure (A) and represent just 3% of the total consumption considered.

3.2. Estimated Consumption with Coefficients

From a literature analysis, after taking into account the considered building area, it is possible to identify coefficients that allow us to obtain the annual thermal consumption. The coefficients were obtained from detailed energy analyses of structures that were used for the same purposes as those considered. In particular:

- For a hospital building (user A), a specific thermal consumption value of 15.93 thousandths of tons of oil equivalent (mTEP) per year per square meter was obtained, which is equal to approximately 185.3 kWh/m^2 year [26];
- For primary and secondary schools (users D, E) a specific consumption, due to heating, of 130 kWh/m^2 year was obtained [27];
- A value of 160 kWh/m^2 year was obtained for a high school [27];
- For an outdoor swimming pool (user F) there is a specific consumption of 82 mTEP per year per square meter. However, this is due to both the heating and the electricity used. Assuming that the thermal rate is 50% of the total, a coefficient of 476.5 kWh/m^2 year is obtained [28];
- The accommodation facilities (users G, H) and the municipal building (user B) share the same specific consumption as a house located in a climatic zone E (the same to which the municipality of Serra San Bruno belongs) with a high surface/volume form factor, i.e., 110 kWh/m^2 year [29].

By multiplying the coefficients that were obtained for the considered area (Table 1), it is possible to obtain an annual thermal consumption value expressed in MWh/year. The results are summarized in Table 4.

Table 4. Consumption due to heating considering the surface of the buildings.

User	Total Area [m^2]	Consumption [kWh/m^2 year]	Consumption [MWh/year]
San Bruno Hospital (A)	12,387	185.3	2295.3
Serra San Bruno Hall (B)	1312	110	144.3
L. Einaudi High School (C)	3224	160	515.5
Secondary Public School (D)	1870	130	243.1
A. Tedeschi Primary School (E)	1887	130	245.3
Serra San Bruno Pool (F)	1894	476.5	902.5
Certosa (G) and Conte Ruggero (H) Hotels	2304	110	253.4
Domestic heating			
Residential buildings	244,460	75	18,334.5

To evaluate the domestic heating consumption, the residential buildings' total area of Serra San Bruno was estimated; subsequently, we defined a specific average consumption per house, but only the quantity of energy used annually for heating was obtained. In particular, in the area considered, there are 2586 residential buildings, and the average surface area per dwelling is 97.4 m^2 [30]. Furthermore, the data relating to the total area occupied by dwellings are directly known, which is equal to 244,460 m^2 [30] (see Table 4). An intermediate specific thermal consumption value of 75 kWh/m^2 year can be used, which is obtained from Annex C of D.Lgs 311/2006 [29], in which the limit values of the energy performance index for winter air conditioning are expressed. By multiplying this value by the total surface considered, an annual consumption of 18,334.5 thermal MWh is obtained (Table 4).

3.3. Comparison between Heat Consumption Estimated by Analogy and Obtained through Coefficients

By comparing the thermal consumption of large users obtained by analogy and those obtained considering a specific annual consumption per square meter of surface, it is possible to verify that the values belong to the same order of magnitude (Table 5). For further computations, the greater of the two values, or the more critical, will be taken into consideration.

Table 5. Consumption due to heating calculated for analogy and considering the surface of the buildings.

User	Consumption Estimated for Analogy, MWh/year	Consumption Estimated Considering the Surface, MWh/year	Critical Value, MWh/anno
San Bruno Hospital (A)	1239	2295.3	2295.3
Serra San Bruno Hall (B)	128	144.3	144.3
L. Einaudi High School (C)	617	515.5	617
Secondary Public School (D)	112	243.1	243.1
A. Tedeschi Primary School (E)	112	245.3	245.3
Serra San Bruno Pool (F)	700	902.5	902.5
Certosa (G) and Conte Ruggero (H) Hotels	759	253.4	759

3.4. Air Quality Analysis

The values recorded by the S1 and S2 measuring devices are reported in Figures 4 and 5, and for the period 1 February 2021–15 April 2021 as well as 16 April 2021–5 July 2021. The daily emission limit is represented by a red horizontal line and is 25 μg/m^3 for $PM_{2.5}$ and 50 μg/m^3 for PM_{10}. As can be seen from Figures 4 and 5, the trend of average concentrations is similar for both PM_{10} and $PM_{2.5}$ in the winter as in the summer. Only the concentration values vary, which appear to be slightly higher for PM_{10}. However, this was predictable, since $PM_{2.5}$ is a fraction of the latter.

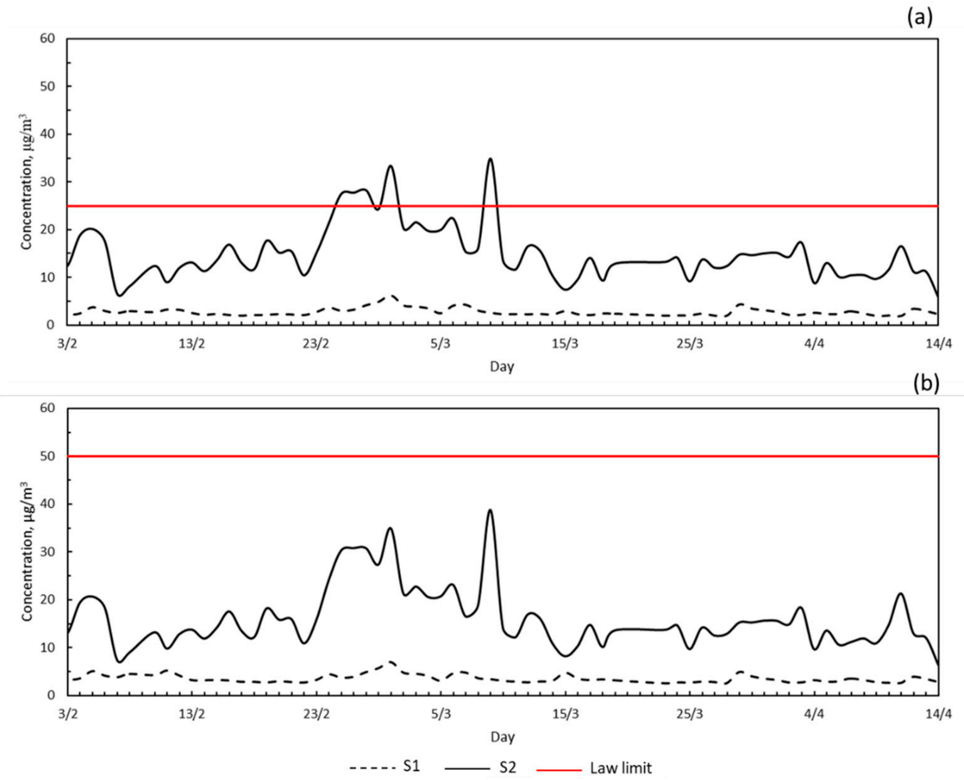

Figure 4. Daily average concentration of (**a**) $PM_{2.5}$ and (**b**) PM_{10} measured in S1 (black dashed line) and S2 (solid black line) in the period 1 February 2021–15 April 2021. Red solid line represents the law limit concentration for PM_{10} and $PM_{2.5}$ according to D.Lgs 155/2010.

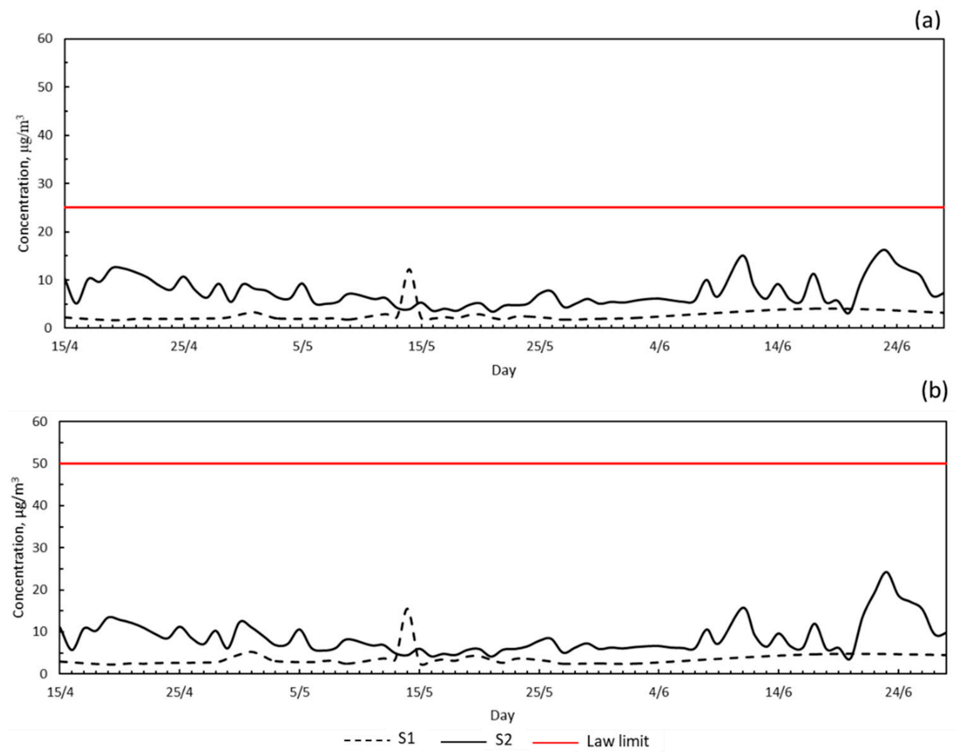

Figure 5. Daily average concentration of (**a**) $PM_{2.5}$ and (**b**) PM_{10} measured in S1 (black dashed line) and S2 (solid black line) in the period 16 April 2021–5 July 2021. Red solid line represents the law limit concentration for PM_{10} and $PM_{2.5}$ according to D.Lgs 155/2010.

It is important to highlight the presence of some peaks in concentrations during the winter period, for which values are very high from the average calculated previously. This led to the $PM_{2.5}$ emission limit being exceeded, which was set at 25 μg/m^3. These peaks occurred between 24th of February and 1st of March and 9th of March recorded by S2 (Figure 4).

Considering the average monthly temperatures of February and March, that are, respectively, 6.3 °C and 8.6 °C [31], it is found that the minimum measured is very close to them, in some cases even lower (for 01/03 and 09/03). In addition, 27th and 28th February are weekend days, leading to a greater presence of people inside their homes and, consequently, to an intensive use of heating. This means that it is possible to attribute the peaks in PM emissions largely to the prolonged use of domestic heating systems, with the other main source being vehicular traffic.

The pollutants' dispersion is strongly influenced by meteorological phenomena; in particular, wind and rain can affect pollution levels. In the winter period there were about 25 days of rain, which corresponds to 35% of the period, while the wind had an average intensity of 7–35 km/h [31]. The rain and the high intensity of the wind certainly lowered the concentrations of airborne pollutants on some days, positively influencing the measurements. In different meteorological conditions, an increase in the concentrations of pollutants cannot be excluded. However, the introduction of the district heating system could mitigate this effect, offsetting the increase in pollutants due to stagnation.

With reference to the summer period, it can be noted that PM concentrations never exceed the law limit; in this case, values that differ slightly from the average value may be due to an intense presence of vehicles or fires. Another aspect to take into consideration is the considerable difference between the concentrations that was detected by the two different measuring devices, S1 and S2. This highlights that the quantity of pollutants emitted by the biomass power plant (measured by S1) is much lower than that measured in the inhabited center (measured by S2). This discrepancy is due to two factors, namely the presence of heating systems in the inhabited center and vehicular traffic. These elements do not influence the measurements of S1, as it is located in an area where there are no other buildings and far from main roads. On the contrary, S2 is located in the city center, therefore, it is in a very busy area with a high presence of heating systems.

3.5. Domestic Heating Contribution Evaluation

Starting from the values measured by S1 and S2, it is possible to calculate the average concentrations of $PM_{2.5}$ and PM_{10} for the winter period (1 February 2021–15 April 2021) and the summer period (16 April 2021–5 July 2021); values are reported in Table 6. The winter period is characterized by the presence of domestic heating, while the summer period is characterized by the heating remaining switched off.

Table 6. Average particulate matter concentration during the summer and winter period.

	Winter Period	Summer Period
$PM_{2.5}$ average concentration, μg/m^3	15.0	7.3
PM_{10} average concentration, μg/m^3	16.0	8.5

Assuming that vehicular traffic and any other sources that emit particulate matter contribute in the same way in both winter and in summer, the difference between the average concentration calculated in the winter and summer period represents the contribution due to heating of 7.7 μg/m^3 for $PM_{2.5}$ and 7.5 μg/m^3 for PM_{10}. Therefore, emissions due to heating comprise51% of the total $PM_{2.5}$ emissions during the winter period, while those of PM_{10} are 46.5%.

To evaluate the impact due to domestic heating in relation to the particulate emissions into the atmosphere, the emissions of large users and residential buildings are evaluated by means of emission factors (Table 2, [18]). Finally, the weight of homes is evaluated in the

PM issue. Given the characteristics of the area considered, the fuel used for heating homes is assumed to be 40% wood and the remaining natural gas [30], while for large users it is considered to be exclusively diesel. The estimated energy consumption and the relative PM_{10} and $PM_{2.5}$ emitted are reported in Table 7.

Table 7. PM_{10} and $PM_{2.5}$ emissions for the large users and the residential buildings.

User	Estimated Energy Consumption [MWh/year]	PM_{10} Emitted [kg/year]	$PM_{2.5}$ Emitted [kg/year]
San Bruno Hospital (A)	2295.3	29.75	29.75
Serra San Bruno Hall (B)	144.3	1.97	1.87
L.Einaudi High School (C)	515.5	8	8
Secondary Public School (D)	243.1	3.15	3.15
A.Tedeschi Primary School (E)	245.3	3.18	3.18
Serra San Bruno Pool (F)	902.5	11.7	11.7
Certosa (G) and Conte Ruggero (H) Hotels	253.4	9.84	9.84
Total	5206.5	67.48	67.48
Residential buildings			
Wood	7333.8	10,663.64	10,565.95
Natural gas	11,000.7	7.92	7.92
Total	18,334.5	10,671.56	10,573.87

It is, therefore, clear that homes account for 99.4% of particulate emissions due to heating. This result is not in line with the statistics published by ISPRA [32], according to which the residential sector is responsible for 64% of $PM_{2.5}$ emissions, considering all sources. This contribution reaches about 76% if the rate due to productive activities is eliminated. This discrepancy may be because in the municipality in question, due to both its small size and mainly agricultural economy, there are fewer working activities than in other inhabited centers; another explanation could be found in the great difference between the fuels used by homes, with a quantity of wood very close to that of natural gas, and those used by the large users that were examined.

3.6. District Heating System Definition

It is possible to estimate the PM concentration variation if part of the utilities considered were converted to a district heating network. The presence of this system would entail the total replacement of the heating system currently present and, consequently, the emissions of particulate matter for the user considered.

Downstream of the analyses carried out in the previous sections, it is clear that, in the situation under consideration, the impact of homes is much greater than that of large structures: for this reason, the possible replacement of only domestic heating systems is considered. Due to the net losses caused by the distribution network, the biomass thermal conversion plant can deliver a power of 1 MW in the winter months (about 150 days), which translates into an energy equal to 3600 thermal MWh per year. They can be used, through district heating, in place of the energy that is generated by conventional domestic systems. In particular, two scenarios are considered:

1. Fair replacement of wood and natural gas systems;
2. Replacement of wood heating systems only.

3.6.1. Scenario 1

The contribution of the biomass power plant is removed half from the consumption that is due to wood-fired plants and half from those of gas plants. The results of this replacement are summarized in Table 8.

Table 8. PM_{10} and $PM_{2.5}$ emissions obtained by replacing wood and gas systems.

User	Estimated Energy Consumption [MWh/year]	PM_{10} Emitted [kg/year]	$PM_{2.5}$ Emitted [kg/year]
Wood	5533.8	8046.4	7972.7
Natural gas	9200.7	6.62	6.62
Total	14,734.5	8053	7979.3

A decrease in PM_{10} concentration of 1.81 μg/m^3 is obtained, while for $PM_{2.5}$ the reduction is equal to 1.86 μg/m^3.

3.6.2. Scenario 2

If the contribution of the biomass power plant is removed exclusively from the consumption linked to wood heating systems, the effects summarized in Table 9 are obtained.

Table 9. PM_{10} and $PM_{2.5}$ emissions obtained by replacing wood and gas systems.

User	Estimated Energy Consumption [MWh/year]	PM_{10} Emitted [kg/year]	$PM_{2.5}$ Emitted [kg/year]
Wood	3733.8	5429.08	5379.38
Natural gas	11,000.7	7.92	7.92
Total	14,734.5	5437	5387.3

This results in decreases in the concentrations of PM_{10} and $PM_{2.5}$ of 3.6 μg/m^3 and 3.72 μg/m^3, respectively.

4. Discussion

The impact of heating (downstream of the considerations made) on PM emissions into the atmosphere is evident. In particular, about 50% of particulate pollution is attributable to it (51% for $PM_{2.5}$, 46.5% for PM_{10}).

It is also clear that the impact of a user does not depend exclusively on the amount of energy used, but also on the type of fuel used. This is the case of homes which, despite having an estimated consumption that is about 3.5 times that of all large users added together, weigh on particulate pollution for 99.4%. PM_{10} and $PM_{2.5}$ emissions are practically entirely due to residential systems; in fact, it is verified that, of the 7.59 μg/m^3 of $PM_{2.5}$ due to heating in general, 7.54 μg/m^3 derives from domestic heating systems. The reason for this high importance is not to be found only in energy consumption, which could be decreased by improving the thermal efficiency of the houses, but above all in the energy mix used (which was considered to be composed of 40% wood and 60% from natural gas).

The implementation of a district heating system, exploiting the heat of the fumes leaving the plant, could be particularly advantageous if it were carried out in a residential environment. This would allow the most to be made of the plant's potential, which uses woody biomass, an energy source that is renewable and, if used correctly, carbon neutral. The district heating network would, therefore, make it possible to reduce the use of conventional heating systems, with a consequent decrease in particulate emissions. Specifically, if gas and wood-fired systems were to be replaced in equal measure, a reduction in the concentration of PM emissions due to heating would be obtained by approximately 24.5% (approximately one eighth of the total); if, on the other hand, only conventional heating systems that use wood were replaced, the decrease in the concentration of particulate emissions due to heating would be about 49% (about one eighth of the total). It is evident that wood, being a fuel with a very high PM emission factor, has a greater impact on particulate pollution. In fact, the decrease in concentration is significantly greater if they are eliminated, compatibly with the energy that the biomass power plant can only supply heating systems that use this energy source.

Furthermore, as shown in Figures 4 and 5, the emissions of the thermal conversion plant are much lower than those due to the heating systems in the city center, even the net of the contribution of vehicular traffic.

Undoubtedly, since the construction of a district heating network is not without difficulties, other studies are needed to verify the actual benefits—not only environmental but also socio-economic—that the introduction of this system could entail.

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