

Article

Building Agro-Energy Supply Chains in the Basilicata Region: Technical and Economic Evaluation of Interchangeability between Fossil and Renewable Energy Sources

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Abstract: In this study, we present a model for the implementation of agro-energy chains based on the actual availability of forest biomass and the real demand for energy (heat) in the area of the Basilicata region, Italy. The demand for energy has been estimated by drawing on the database of the Ministry of Economic Development or by calculating the Annual Energy Requirement (AER) index, while for the estimate of the available forest biomass, reference was made to the public forest lands managed according to forestry management plans. The collected data were cross-checked with a view to detecting the technical and economic feasibility of district heating systems. The technical evaluation has mainly focused on the energetic and plant aspects, while the economic assessment was directed to defining the cost effectiveness criteria [Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period] that can measure the profitability of the investment. In the economic evaluation we also included the national public incentives, designed to encourage the production of energy from renewable sources in compliance with the international agreements signed by Italy for the reduction of greenhouse gases (GHGs).

Keywords: biomass; agro-energetic chain; district heating systems; cost-effective use of biomass; green economy

List of Acronyms:

AEEG	Authority for Electricity and Gas
AER	Annual Energy Requirement
ARF	Annual Requirement of Fuel
DCF	Discounted Cash Flow
EECs	Energy Efficiency Credits
ESCO	Energy Service Companies
FMPs	Forest Management Plans
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GME	Energy Market Managing Board
$H_{V_{fw}}$	Heating value of fresh wood
INEA	National Institute of Energy and Environment
IRR	Internal Rate of Return
MSE	Ministry of Economic Development
NPV	Net Present Value
PRU	Physical Reference Units
RES	Renewable Energy Sources
RU	Research Unit
TOE	Tons of Oil Equivalent
WCs	Water Contents
Wc	White certificates

1. Introduction

The energy market is experiencing profound changes as a result of the liberalization process, the tensions in the oil markets and the impulse given to the production of energy from renewable sources. In particular, the actions and the emission reduction obligations entered into force with Italy's ratification of the Kyoto Protocol (the implementation of which should have ended in 2012) are expected to continue until 2020 without major changes; this is the outcome of the last climate summit held in Doha, Qatar, which gave birth to the second phase, known as Kyoto 2, in view of an international agreement for 2020.

The forecasts proposed in the last report, "OECD Environmental Outlook to 2050" [1] point out an 80% increase in energy consumption by 2050; the expected population growth from seven billion to nine billion, combined with the quadrupling of global gross domestic product (GDP), will result in an increased energy use and a rise in CO₂ concentration, which is expected to reach 685 ppm by 2050. The consequences of these trends will be mainly reflected in the annual mean temperature that is projected to rise by three to six degrees [1] or by four degrees by the end of the 21st century according to the latest scenarios presented by the World Bank [2], as compared to the pre-industrial times.

Hence it is crucial to implement proactive policies aimed at improving energy use efficiency, by allocating new and increasingly large areas to alternative and renewable energy sources, reducing pollution and the impact of human activities on the environment.

In the framework of renewable energy sources (RES), biomasses are perhaps the most striking example of growth factor related to the green economy, which tends to combine the return on investment with beneficial impacts in terms of land protection, sustainable management of agroforestry resources, startup of new enterprises in the area, *etc.* Actually, in contrast to the solar and wind energy investments, which are typically capital intensive, highly profitable and low labor intensive, biomasses, due to their extreme diversification (by sector of origin of the raw material) and their strong link with the territory may generate positive impacts at the local level, in terms of employment, land care and maintenance and optimal use of agro-forestry resources.

The use of biomasses, however, imposes plenty of constraints, such as their temporal availability (biomasses are not available at any time of the year) and the spatial density (biomass production generally involves very large areas). Furthermore, debates over the competition for land use between food and energy crop production have recently heated up at the international level. Actually, the development of energy crops has involved some modifications, with the subsequent change in the use of the soil that instead of supplying food products has become supplier of products destined for energy [3,4]. Moreover, the installation of biomass-based plants has triggered in some cases social conflicts between the local population and the promoters of biomass-based plants [5–7]. In fact, the local people's perceived risk to the potential negative impacts on the landscape and the ecological aspects of the area, exceeds the merely economic benefits associated with the installation of biomass-based systems, thus engendering a hostile approach towards biomass-based plants and renewable energy sources, in a more general sense. The term "biomass" designates a wide range of products, ranging from plants and plant materials derived from agriculture, forestry and food industry, to household waste [8,9]. Over the last few years the use of biomass for energy has become an issue of primary importance, both in the fight against climate change and as a strategy for energy supply security. Currently, biomasses are the main source of renewable energy, so that at the European level they supply 14% of primary energy consumption. In Italy, the total share of renewable energies has increased (from 20% to 22%), and biomasses, in particular, are among the sources that have most contributed to this growth.

The future scenarios point out those biomasses could provide significantly to the production of primary energy. The estimates for 2050 [10,11] indicate a range between 200 and 470 EJ/year (Exajoules = 10^{18} joule).

The use of biomass energy may be an important option both for environmental and economic sustainability, considering that the cost per unit energy of firewood is lower than that of methane [12]. Moreover, the enhancement of biomass could trigger processes of environmental improvement and socio-economic development resulting from the building of micro agro-energy supply chains. This could have multiple impacts at the territorial level (defense of the associated agricultural activities, startup of businesses specialized in the collection and transfer of biomass, new jobs, "active" management of forest areas, *etc.*), as well as on the economic sectors concerned (agriculture, forestry, industry, *etc.*).

To ensure highly efficient energy conversion and the sustainable use of biomass, however, it is necessary to use modern equipment and technologies and plan the reasoned use of biomass [13,14].

The literature includes different studies and research on the entire agro-energy chain that have addressed the problem from the spatial pattern point of view through the integrated use of decision support systems (DSSs) by Geographic Information Systems [15–19]. Other research works deal with the problem from a technical-engineering point of view, for the optimization of agricultural machinery and energy conversion plants [20], from the economic perspective [21–23] and in terms of environmental impacts [24–26].

The applications for the exploitation of the potential energy contained in biomass are diversified and constantly evolving. Currently, the largest energy consuming sectors in Italy are the domestic or industrial heating that make use of individual or network systems (district heating), the production of electricity and of liquid fuels for motor-vehicles. Biomass is, however, a limited resource, so it should be used as efficiently as possible. In order to maximize the mitigation of CO₂, many authors believe that it is more efficient to use biomass for heating or for combined heat and power rather than for the combined production of biofuels [27,28]. In particular, district heating is not only more efficient (high ratio of thermal energy produced to biomass energy) compared to other uses, but it also contributes to mitigate the use of fossil fuels for the heating of buildings, which accounts for about one-third of the total energy demand of our country that is mostly met by the use of methane. Part of this demand is met through the use of methane gas that, compared to other fossil fuels, has a reduced environmental impact, as it does not contain sulfur, so it does not produce sulfur dioxide, preventing the so-called “acid rain” pollution. In addition, methane gas is characterized by a CO₂ emission factor that is about 25%–30% less than oil and about 40%–50% less than coal to produce the same amount of energy.

The purpose of the present work is indeed to identify a model for the development of renewable energy chains of high local value added. The setting up of the model requires defining the supply area, as well as carrying out the technical and economic evaluations of the total or partial substitution potential of the energy source. The product resulting from the analysis, if based on the actual energy demand and the real local availability of biomass, represents an objective model, easily transferable to other land areas.

On this basis, the analysis was carried out in the Basilicata region, chosen as pilot area because its percentage of forest cover is in line with the national average. This choice is also related to the fact that in the area under analysis there is no forest-wood system that can ensure the environmental and economic sustainability of wood production.

Therefore, for the purpose of the technical and economic feasibility study, it was decided to implement, at the municipal level, district heating systems powered by the biomass of public forests. The applied reference criterion was the 25% possible substitution of the thermal energy produced from methane.

2. Materials and Methods

The proposed work is divided into four phases. The first phase concerned the estimate of building heat demand, obtained from official statistics and through the calculation of annual energy requirement (AER). In the second phase, the optimal power of biomass conversion plants was calculated as the ratio of the overall volume of buildings to their energy use. The third phase involved

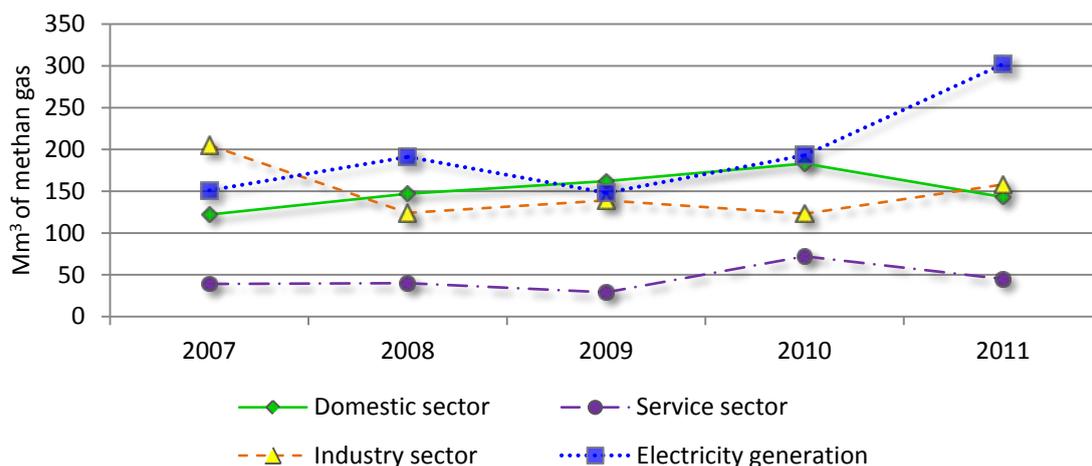
the estimate of the available biomass from the Municipal forests provided with Management Plans. In the last phase, a technical and economic evaluation was proposed so as to indicate the actual cost-effectiveness related to the replacement of methane gas with forestry biomass, through the creation of district heating plants.

2.1. Study Context

According to the data published by the Authority for Electricity and Gas (*Autorità per l'Energia Elettrica e il Gas*, AEEG), the national methane consumption in 2010 amounted to 71,959 million m³, that is 7% more than in the previous year.

In Basilicata, the methane gas consumption for 2010 amounted to 538.2 million m³, showing a substantial increase as compared to the period of 2006–2008. Despite some mismatch between the sources (the main sources are the Ministry of Economic Development and the Authority for Electricity and Gas), the regional consumption by sector shows an increase in natural gas consumption for the domestic sector and a fluctuating trend for the industry, the electricity generation and in the service sector (Figure 1).

Figure 1. Methane gas consumption by sector in Basilicata. Source: Authority for Electricity and Gas (AEEG), statistical data of natural gas consumption for Italian regions, various years (2011 provisional data).



The rise of natural gas demand is differentiated across the territory because only recently the southern Italy regions have been involved in a gradual development of methane gas distribution networks. The wide geographic variability also reflects two distinct phenomena: on the one hand, different climate patterns, which influence domestic consumption, on the other hand, the different degree of industrial development, which affects the volumes consumed by industries.

In Basilicata region, according to the data released by the Ministry of Economic Development (*Ministero dello Sviluppo Economico*, MSE), out of 131 municipalities, only six are not supplied with methane gas distribution networks, and the number of users served is 172,442 for a total length of 2395 km of pipelines.

From the socio-demographic perspective, Basilicata is the second Italian region with the lowest population density, equal to 59 people/km², against the national average of 199.3 people/km². Its economy features a large service sector with an employment rate of 63.2%, followed by the industrial sector with 27.1% and agriculture with 9.5% [29]. Crop production mainly includes cereals, olives and grapes. The per capita GDP recorded in the region in 2011 was €18,639.5, lower than the national average equal to €21,980.9 [30].

With regards to the geographical aspects, the region of Basilicata is situated in the South of Italy, with 47% of its area covered by mountains, whereas 45% is hilly and 8% is made up of plains. The presence of geomorphologically and climatically diversified environments has favored the development of large woodland areas through the years. The forest cover, mapped by the National Institute of Energy and Environment (*Istituto Nazionale Energia e Ambiente*, INEA), includes 354,895 ha of forest area with a forest area index of 35.6%; about 11% of the forest area is managed in accordance with the regional regulations on “sustainable management” for a total of 45 forest management plans (FMPs), involving 33 municipal and 12 regional plans.

2.2. Estimate of Methane Gas Consumption

The estimate of the building heating requirement was necessary to check the energy consumption of municipalities and hence start up the design of district heating plants. For the intended purpose, we considered only the consumption of methane gas (for heating) in the 33 municipalities with FMPs. The data of energy consumption of methane for heating have been extrapolated from the databases of the Ministry of Economic Development, and were only available for 26 municipalities.

For the remaining ones, a proxy variable was estimated, based on the calculated AER. This needs some input data [31], including:

1. the residential surface of the built-up area (*ba*) of the Municipality;
2. the residential surface of the housing clusters (*hc*);
3. the residential surface of scattered houses (*sh*);
4. the resident population, divided into *ba*, *hc* and *sh*.

The surface areas were multiplied by a coefficient of 2.7, namely the average height floor (in meters) of individual homes, as provided for by national building legislation; then the residential volume was calculated per housing typology using the following formulae:

$$V_{ba} = A * h * [P_{ba}/(P_{ba} + P_{hc} + P_{sh})] \quad (1)$$

$$V_{hc} = A * h * [P_{hc}/(P_{ba} + P_{hc} + P_{sh})] \quad (2)$$

$$V_{sh} = A * h * [P_{sh}/(P_{ba} + P_{hc} + P_{sh})] \quad (3)$$

where V_{ba} , V_{hc} , V_{sh} are the residential built volumes of built-up areas, housing clusters and scattered houses, respectively; A is the total residential area; h is the average height of 2.7 m; P_{ba} , P_{hc} , P_{sh} are the populations living in built-up areas, housing clusters and scattered houses, respectively.

The inferred values were used for the calculation of AER from Equation (4) [32] for the seven Municipalities lacking methane gas consumption data:

$$\text{AER (kJ)} = [H * V * (\text{HDD} + \Delta c * \text{Hd})] * \lambda * 86.4 \quad (4)$$

where H is the overall heat loss [$\text{W}/(\text{m}^3 \text{ }^\circ\text{C})$]; V is the heated volume (m^3); HDD are the degree days [the degree days are a unit of measurement that indicates the heat requirement of a building in a particular location; they are calculated as the sum, extended to all days of an annual period of conventional heating, of the daily differences (only the positive ones) between the optimal conventional temperature for heated environments ($20 \text{ }^\circ\text{C}$) and the average daily temperature outside the building. In particular, the whole country has been divided into six climate zones identified on the basis of the degree days and mainly depending on the latitude and altitude that establish the running hours per day and the annual operating period of thermal plants] ($^\circ\text{C}$); Δc is the variation coefficient compared to $20 \text{ }^\circ\text{C}$; Hd are the heating days; and λ is the daily heating coefficient.

H , defined as the thermal power dispersed per cubic meter assuming a $1 \text{ }^\circ\text{C}$ temperature difference between inside and outside, is determined by the sum of two terms, namely Ht and Hv .

Ht , namely the specific heat capacity is an index reflecting the building insulation level. The maximum allowed value of Ht ($Ht \text{ max}$) varies depending on the municipality in which the property is situated and on a characteristic parameter, called the shape factor, S/V , where V is the volume calculated by measuring its external surfaces; and S is the total area of surfaces, referred to the heated portions of the building (Table 1). Since the calculation was extended to an entire municipality rather than to a single house, we assumed a single volume equal to a parallelepiped for each type of housing, of which the shape coefficient (S/V) was calculated. Subsequently, due to the lack of sufficient data to calculate the Ht of each unit, it was decided to calculate the $Ht \text{ max}$.

Table 1. Threshold values of the Ht coefficient. Source: [33,34].

Climate zone	A	B	C	D	E	F
HDD	≤ 600	601	900	901	1400	≥ 3000
$S/V \leq 0.2$	0.49	0.49	0.46	0.46	0.42	0.30
$S/V \geq 0.9$	1.16	1.16	1.08	1.08	0.95	0.73

The heat loss caused by ventilation (Hv) measures the heat loss by fresh air supply and was calculated as the product of the number n of air changes per hour times the heat loss rate from buildings, established by the regulations in force, equal to $0.35 \text{ W}/(\text{m}^3 \text{ }^\circ\text{C})$. For buildings of category E.1 (buildings used as residences and similar), n is established by national rules to 0.5 and, therefore, the Hv is reported to be $0.175 \text{ W}/(\text{m}^3 \text{ }^\circ\text{C})$.

For the calculation of AER and H , it was necessary to identify other parameters, including the degree days. According to the location of the municipality and on the basis of the national legislation in the field of domestic heating [33,34], the number of degree-days was determined following the reverse process and considering the climate zone of the municipalities under examination. Based on the altitude range of the municipality and the type of plant, the following values of Hd , λ and Δc were identified and then used for calculating the AER (Table 2).

Table 2. Values of Hd , λ and Δc used for calculating the annual energy requirement (AER) by plant. Source: [33,34].

Altitude range	Heating days	Daily heating coefficient	Plant type	Variation coefficient compared to 20 °C
<i>m a.s.l.</i>	<i>Hd</i>	λ	-	Δc
0–150	100	0.66	Centralized	0
			Independent	–1
			Individual	–1
			Undefined	0
151–300	120	0.71	Centralized	0.25
			Independent	–0.75
			Individual	–0.75
			Undefined	0
301–500	150	0.76	Centralized	0.5
			Independent	–0.5
			Individual	–0.5
			Undefined	0
501–1000	180	0.84	Centralized	0.75
			Independent	–0.25
			Individual	–0.25
			Undefined	0
>1000	200	0.93	Centralized	1
			Independent	0
			Individual	0
			Undefined	0

2.3. Sizing of Processing Plants

Once the energy values relative to the consumption of municipal methane gas (please note that for seven municipalities only the AER was used for estimating the potential thermal energy demand) were estimated, and considering a conversion factor of 38.1 MJ/m³ as reported by the Ministry of Economic Development (MSE), the annual requirement of fuel needed to replace 25% of the thermal energy produced by methane gas was determined. [District heating plants need to serve users with high population density and/or high consumption (buildings, schools, public buildings) in order to reduce installation costs and thermal losses in the network. Through a survey conducted by our Research Unit (RU), we analyzed the social and demographic characteristics of the Municipalities concerned and we estimated the percentage of potential users of district heating plants. The survey showed an average degree of substitution of 25% of thermal energy from natural gas that coincides with the consumption of users located in the residential area of the municipalities.] In the case of a chain not perfectly organized [35] both from a logistical and chronological point of view, this would lead to the use of green wood with water contents (WCs) above 30% which would involve a fuel requirement, as calculated by the following formula:

$$\text{ARF} = \text{Energy required} / (\eta * \text{Hv}_{fw}) \quad (5)$$

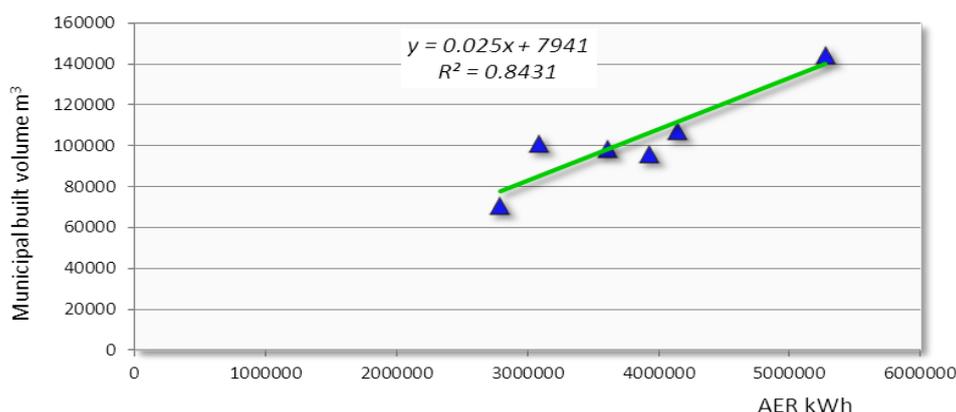
where ARF (t/year) is the annual requirement of fuel (amount of biomass needed to produce the required energy); $Energy\ required$ is the annual energy requirement (kW h/year), corresponding to 25% of energy from methane gas consumed annually; η is the plant performance (80%); and Hv_{fw} is the heating value of fresh wood (2230 kW/t f.w. with WCs of 45%–50%).

In the case of an organized chain, which includes measures for the use of forest products during cold and rainy periods as well as the curing and storage of the products during summer, this would lead to a change in the initial WCs from 45%–50% to 25%–30% in the month of September, before wood chipping. This procedure allows an increase in the calorific value (about 3700 kW/t, $WC = 25\%$) of the biomass compared to the calorific value of fresh biomass, with a significant decrease (about 30%) of the amount of biomass required to produce the same quantity of energy. In the second case, the annual requirement of fuel needed to replace 25% of the thermal energy produced from methane gas is equal to:

$$ARF = \text{Energy required} / (\eta * Hv) \quad (6)$$

The sizing of the heating systems to be installed in each municipality was related to the volumes to be heated, assuming, for the area under analysis, a required power of 30 W/m³ [36]. The first step consisted in building a relationship between the AER and the heated volumes, in the 6 municipalities in which the AER had been previously calculated (Figure 2). The results show a good correlation between the variable AER and the variable V , with R^2 of 0.84. The interpolating function has then been used to estimate the volumes of all the municipalities in the examined area (Figure 2).

Figure 2. Correlation of municipal built volume (m³)-AER. Source: elaboration of the Research Unit (RU).



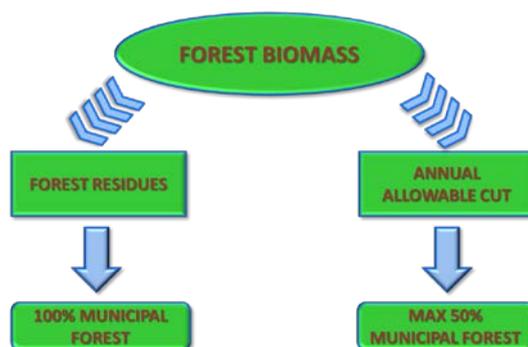
The estimate of the built volume has actually allowed for the sizing of plants, assuming the replacement of 25% of the energy currently supplied by methane gas. The results showed very different plant powers, ranging from 250 kW in San Costantino Albanese to 10 MW in Venosa.

2.4. Municipal Forests

To characterize the bio-energetic supply, we considered the municipal forests currently provided with FMPs, assuming the recovery of all of forest residues and a maximum of 50% of the annual allowable cut so as to leave the remaining part for normal uses that are largely focused on the firewood market (Figure 3). (A survey conducted by our RU among timber enterprises operating in Basilicata has identified different issues concerning firewood market. In particular, they complained about the

poor demand for firewood, high stumpage value, and low supply of forests, too much competition, over-fragmentation and insufficient forest road services; as for the demand side, some recovery in the use of firewood for domestic heating has been recorded over the last few years, although the required quantities are significantly below the supply. In particular, this is reflected in a reduced use of forests and, among these, public forests are the least used. Taking into account the above issues and trends, we have envisaged a 50% maximum utilization of the annual allowable cut, considering this value as being representative and well below the maximum usable value.)

Figure 3. Characterization of bio-energetic supply. Source: elaboration of the RU.



The municipal forests with FMPs are currently 33, of which 85% in the province of Potenza, and covering a total area of 22,614.60 ha. 79% of this area is covered with forests, while the remainder, namely 3942.29 ha, is made up of clearings, roads, streams, rock outcrops, *etc.* In our study, we considered only 30 municipalities, excluding from the analysis the forest area of three municipalities in which the forest utilization was not provided for.

In order to consider the varying residue supply from different forest formations (in relation to the species and the silvicultural system), the database was reorganized and classified into eight types of forests that are the most representative of the regional context: beech, oak, chestnut, hornbeam, riparian hygrophilous formations, maquis shrubland with holm oak communities, mountain pine forests and Mediterranean pine forests.

As regards the definition of the parameters related to the percentage of residues (branches and treetops), reference was made to the literature relating to similar experiences in national contexts [37] and to the values of bundle and brushwood reported by the stereometric and growth tables built for the Italian forests [38]. These data have been validated by a direct survey conducted in collaboration with some timber harvesting and processing enterprises operating in different regional contexts, resulting in the definition of the parameters shown in Table 3.

Lastly, for the parameters of volume density used for the conversion of fresh wood into the commercial form, reference was made to what is reported by Giordano [39], considering these values as being representative of the regional context, thus applicable to the present study (Table 4).

The estimated final figure represents the average annual quantity of biomass with 25% *WCs* potentially derivable from uses of managed woods, and it ranges between 29.24 t/year for the town of Palazzo San Gervasio and 1,542.25 t/year for the Municipality of Forenza (Table 5).

Table 3. Percentage of waste by type of wood. Source: elaboration of the RU on [37,38].

Species	Tall Trees	Coppice
	% Residues	
Beech	8%	25%
Oak	15%	20%
Chestnut	15%	16%
Hornbeam	15%	20%
Hygrophilous formations	100%	100%
Holm oak	25%	32%
Mountain pine forests	100%	-
Mediterranean pine forests	100%	-
Plantations and reforestation	15%	-

Table 4. Density of different types of woods in Basilicata. Source: [39].

Species	Fresh wood		Commercial Moisture Content (12%–15%)		Commercial/ Fresh
	$\text{Kg} \times 10^2/\text{m}^3$	$\text{m}^3/\text{Kg} \times 10^2$	$\text{Kg} \times 10^2/\text{m}^3$	$\text{m}^3/\text{Kg} \times 10^2$	
(1) Beech	10.5	0.095	7.5	0.133	0.7
(2) Oak	11.0	0.091	9.0	0.111	0.8
(1) Chestnut	10.0	0.100	5.8	0.172	0.6
(3) Hornbeam	10.0	0.100	8.0	0.125	0.8
(4) Hygrophilous formations	8.6	0.116	5.6	0.179	0.7
(1) Holm oak	11.0	0.091	9.6	0.104	0.9
(5) Mountain pine for.	9.0	0.111	5.6	0.179	0.6
(6) Mediterranean pine for.	9.5	0.105	6.4	0.156	0.7

(1): Beech reference value; (2) Turkey oak reference value (most frequent); (3) hornbeam reference value; (4) black alder reference value; (5) black pine reference value; (6) value averaged for Aleppo pine, *Pinus pinea* and maritime pine.

Table 5. Municipal available biomass. Source: Elaboration of the RU.

Municipality	Allowable cut		Forest residues		Total	
	Total 50% WCs (t)	Annual 50% WCs (t) *	Total 50% WCs (t)	Annual 50% WCs (t)	50% WCs (t)	25% WCs (t)
Acerenza (PZ)	7,339.51	366.98	1,100.93	110.09	477.07	357.80
Albano di L. (PZ)	12,840.94	642.05	1,926.14	192.61	834.66	626.00
Aliano (MT)	1,924.30	96.22	288.65	28.86	125.08	93.81
Cancellara (PZ)	6,401.97	320.10	960.29	96.03	416.13	312.10
Castelmezzano (PZ)	7,001.77	350.09	1,050.27	105.03	455.11	341.33
Castronuovo di S. (PZ)	14,185.44	709.27	2,127.82	212.78	922.05	691.54
Cersosimo (PZ)	7,808.20	390.41	1,171.23	117.12	507.53	380.65
Fardella (PZ)	13,539.43	676.97	1,143.36	114.34	791.31	593.48
Forenza (PZ)	31,635.87	1,581.79	4,745.38	474.54	2,056.33	1,542.25
Francavilla sul S. (PZ)	14,565.54	728.28	1,472.70	147.27	875.55	656.66
Ginestra (PZ)	15,232.72	761.64	2,284.91	228.49	990.13	742.60
Gorgoglione (MT)	4,447.33	222.37	2,197.05	219.70	442.07	331.55

Table 5. Cont.

Municipality	Allowable cut		Forest residues		Total	
	Total 50% WCs (t)	Annual 50% WCs (t) *	Total 50% WCs (t)	Annual 50% WCs (t)	50% WCs (t)	25% WCs (t)
Lagonegro (PZ)	18,787.27	939.36	1,502.98	150.30	1,089.66	817.25
Latronico (PZ)	23,834.57	1,191.73	3,029.03	302.90	1,494.63	1,120.97
Noepoli (PZ)	20,899.96	1,045.00	2,471.66	247.17	1,292.16	969.12
Palazzo S. G. (PZ)	599.84	29.99	89.98	9.00	38.99	29.24
Pietragalla (PZ)	10,228.61	511.43	3,409.36	340.94	852.37	639.28
Pietrapertosa (PZ)	20,111.29	1,005.56	3,016.69	301.67	1,307.23	980.42
Pignola (PZ)	29,564.05	1,478.20	3,273.40	327.34	1,805.54	1,354.16
Rotonda (PZ)	27,874.60	1,393.73	2,229.97	223.00	1,616.73	1,212.55
San Chirico R. (PZ)	3,845.48	192.27	576.82	57.68	249.96	187.47
S. Costantino A. (PZ)	15,151.58	757.58	2,017.26	201.73	959.30	719.48
San Mauro F. (MT)	2,859.39	142.97	428.91	42.89	185.86	139.40
San Severino L. (PZ)	20,720.92	1,036.05	1,657.67	165.77	1,201.81	901.36
Sasso di Castalda (PZ)	15,570.90	778.54	1,284.65	128.47	907.01	680.26
Spinoso (PZ)	7,268.64	363.43	604.85	60.49	423.92	317.94
Stigliano (MT)	2,395.37	119.77	359.31	35.93	155.70	116.78
Tito (PZ)	7,705.13	385.26	843.60	84.36	469.62	352.22
Tricarico (MT)	13,272.44	663.62	1,990.87	199.09	862.71	647.03
Venosa (PZ)	5,861.47	293.07	879.22	87.92	381.00	285.75

2.5. The Incentive Scheme: White Certificates and Energy Saving Companies

Rational use of energy has been promoted in Italy since the 1980s. The first incentives concerned the construction industry, agriculture and industry, with capital funding and interest aimed to promote the use of renewable energy sources and reduce energy consumption. Twenty years later a new scheme was enacted by White Certificates (Wc) or Energy Efficiency Credits (EECs) that is regulated and managed by the Authority for Electricity and Gas, while the Energy Market Managing Board (*Gestore Mercati Energetici*, GME) is entrusted with the management of the EEC market.

The innovation lies in the fact that the promotion of energy efficiency is pursued through a gradual shifting from fossil towards renewable and more environmentally friendly energy sources, promoting energy efficiency by more performing technologies and systems, according to an integrated approach consistent with the development of the liberalized market. The scheme integrates innovative and original elements of tariff and market direct control. The element of direct control concerns above all the energy saving obligations imposed to electricity and gas distribution companies, as well as the activity carried out by the Authority for Electricity and Gas for the certification of savings achieved and the verification of compliances. Tariff regulation concerns the system of aids recognized in the bill to partially cover the costs of energy saving measures. The market-related element, finally, is constituted by the creation of an artificial and regulated market for energy saving, known as “market for energy efficiency credits” or “white certificates,” where market participants may trade the EECs.

The demand for EECs is generated by the obligation imposed to electricity and gas distribution companies to “stick” to binding targets of primary energy savings that are to be achieved through

energy efficiency measures at the level of final consumers. The national targets are allocated every year by the Authority for Electricity and Gas among electricity and methane gas distributors on the basis of their respective market shares. The proposals are submitted to the above Authority that assesses and certifies the energy savings and authorizes the Energy Market Managing Board to issue the Wc based on the certified savings [for each tons of oil equivalent (TOE) saved, one Wc is issued for a period of five years]. As an alternative to carry out their own energy saving measures at the level of final consumers, the “obliged” distributors (*i.e.*, those who supply a number of customers above 50,000 units) may opt to satisfy their obligations by purchasing, in whole or in part, EECs by other parties that represent the side of the supply of credits or certificates, including smaller distributors who are not subject to the obligations, companies monitored by electricity and methane gas distributors and companies operating in the field of energy services [Energy Service Companies (ESCO)]. The EECs may be sold either by bilateral contracts or on an organized market managed by the GME on the basis of specified and transparent rules established in agreement with the Authority for Electricity and Gas.

The white certificate scheme identifies three methods for the evaluation of the proposals:

- standardized assessment methods, whose savings associated with the procedure are determined on the basis of the number of physical reference units (PRUs) involved in the proposed intervention;
- analytical evaluation methods that quantify the energy savings on the basis of a specific algorithm for each type of intervention;
- ex-post evaluation methods applied to the proposals that include heterogeneous interventions in relation to the evaluation method and to which the above methods are not applicable.

The recognition of energy efficiency certificates by the Authority for Electricity and Gas (AEEG) requires the achievement of a minimum level of energy savings, as reported in Table 6.

Table 6. Minimum threshold values. Source: Authority for Electricity and Gas (AEEG).

Project type	Minimum project size	
	Obligated subjects—Energy manager	Voluntary subjects
Standardized	25 toe/year	
Analytical	100 toe/year	50 toe/year
Ex-post	200 toe/year	100 toe/year

Depending on the type of energy saving, we can have four types of recognized certificates:

- type I: certifying the achievement of primary energy savings through a reduction of power consumption;
- type II: certifying the achievement of primary energy savings through a reduction of natural gas consumption;
- type III: certifying the achievement of savings of primary energy forms other than electricity and natural gas not intended for use in motor vehicles;
- type IV: certifying the achievement of savings of primary energy forms other than electricity and natural gas intended for use in motor vehicles.

As this paper envisages the setting up of district heating systems to replace the thermal energy produced from methane gas, there is the possibility of access to type II certificates, assessed by analytical methodology.

As mentioned previously, only the obliged and non-obliged entities operating in energy services can access the white certificate scheme; in our specific case, for having access to this market it has been suggested to set up ESCO companies in public-private partnership, for each municipality under examination. The setting up of this type of company could represent a valuable tool of long-term territorial energy planning. In particular, the advantages of public bodies' involvement include the energy planning of their territory and the long-term management of action plans that would be integrated into the political and business local system; moreover, the presence of the public component in ESCO companies can ensure the fair distribution of the economic and social benefits resulting from the implementation of biomass-based plants. The main advantages for the population may be summarized as follows:

1. more employment, associated with energy production-related activities (cut, harvest, logging, transportation, operation of the system, *etc.*);
2. reduction of energy costs, with regards to energy supply for housing.

On the other hand, the private sector participation in the ESCO could compensate for the lack of adequate skills and insufficient equipment and financial asset resources needed to run major investment plans in the area that, in this case, actually involve the setting up of district heating plants.

In a recent study [40], carried out in 38 countries, a positive correlation was found between the ESCO indicators (age of ESCO market, number of ESCO companies, total value of ESCO projects and the percentage of the sectors targeted by ESCOs) and socioeconomic indicators (countries per-capita GDPs, energy consumptions and CO₂ emissions). Moreover, in richer countries, ESCOs find more opportunities in the commercial and municipal sectors [40].

3. Results

3.1. Technical Evaluation

After estimating the annual fuel requirements and the plant power required to meet the energy needs of each municipality, the next step was to assess the possible replacement of methane energy source with forest biomass.

The results of the analysis have shown how the poor supply of biomass obtainable from the management of public forests in some municipalities and the reduced natural gas consumption in others, constitute the two limiting factors for the development of district heating systems. In fact, it results that in only 50% of the examined municipalities, the replacement of the energy source is feasible (Table 7).

Table 7. Availability and evaluation of forest biomass energy (in gray the municipalities for which the AER was calculated, because the natural gas consumption data were not available). Source: elaboration of the RU.

	A	B	C	D	E	F	G	H	I	L	M	N
Municipality	Methane gas consumption (m ³ × 1000)	AER (GJ)	Energy produced from methane gas (MW h)	25% energy from methane gas $D = C \times 25\%$ (MW h)	Climate zone	Estimated built volume (m ³ × 1000)	25% built volume potentially supplied by district heating $G = F \times 25\%$ (m ³ × 1000)	Plant power $0.03 \text{ KW/m}^3 \times G$ (MW)	ARF (annual requirements of fuel) (t _{WC} = 25%)	Annual available biomass (t _{WC} = 25%)	Deficit/surplus of available biomass of ARF $M = L - I$ (t _{WC} = 25%)	Feasibility
Acerenza (PZ)	917.00	-	9,704.64	2,426.16	E	250.56	62.64	1.88	819.65	357.80	-461.85	Insufficient biomass
Albano di Lucania (PZ)	453.00	-	4,794.12	1,198.53	E	127.79	31.95	0.96	404.91	626.00	221.09	Positive
Aliano (MT)	-	11,128.55	3,091.18	772.79	D	85.22	21.31	0.64	261.08	93.81	-167.27	Insufficient biomass
Cancellara (PZ)	312.00	-	3,301.91	825.48	E	90.49	22.62	0.68	278.88	312.10	33.22	Positive
Castelmezzano (PZ)	-	10,051.31	2,791.95	697.99	E	77.74	19.43	0.58	235.81	341.33	105.53	Positive
Castronuovo di S. A. (PZ)	-	12,998.64	3,610.63	902.66	D	98.21	24.55	0.74	304.95	691.54	386.59	Positive
Cersosimo (PZ)	110.00	-	1,164.13	291.03	D	37.04	9.26	0.28	98.32	380.65	282.33	Positive
Fardella (PZ)	130.00	-	1,375.79	343.95	E	42.34	10.58	0.32	116.20	593.48	477.28	Positive
Forenza (PZ)	848.00	-	8,974.42	2,243.60	E	232.30	58.08	1.74	757.97	1,542.25	784.27	Positive
FrancaVilla sul Senni (PZ)	594.00	-	6,286.32	1,571.58	D	165.10	41.27	1.24	530.94	656.66	125.72	Positive
Ginestra (PZ)	188.00	-	1,989.61	497.40	D	57.68	14.42	0.43	168.04	742.60	574.56	Positive
Gorgoglione (MT)	-	14,152.15	3,931.04	982.76	E	106.22	26.55	0.80	332.01	331.55	-0.46	Insufficient biomass
Lagonegro (PZ)	1,436.00	-	15,197.24	3,799.31	E	387.87	96.97	2.91	1,283.55	817.25	-466.31	Insufficient biomass
Latronico (PZ)	693.00	-	7,334.04	1,833.51	E	191.29	47.82	1.43	619.43	1,120.97	501.54	Positive
Noepoli (PZ)	245.00	-	2,592.84	648.21	E	72.76	18.19	0.55	218.99	969.12	750.13	Positive
Palazzo S. Gervasio (PZ)	1,743.00	-	18,446.23	4,611.56	D	469.10	117.27	3.52	1,557.96	29.24	-1,528.72	Insufficient biomass

Table 7. Cont.

	A	B	C	D	E	F	G	H	I	L	M	N
Municipality	Methane gas consumption (m ³ × 1000)	AER (GJ)	Energy produced from methane gas (MW h)	25% energy from methane gas $D = C \times 25\%$ (MW h)	Climate zone	Estimated built volume (m ³ × 1000)	25% built volume potentially supplied by district heating $G = F \times 25\%$ (m ³ × 1000)	Plant power $0.03 \text{ KW/m}^3 \times G$ (MW)	ARF (annual requirements of fuel) (t _{WC} = 25%)	Annual available biomass (t _{WC} = 25%)	Deficit/surplus of available biomass of ARF $M = L - I$ (t _{WC} = 25%)	Feasibility
Pietragalla-Filiano (PZ)	912.00	-	9,651.73	2,412.93	E	249.23	62.31	1.87	815.18	639.28	-175.90	Insufficient biomass
Pietrapertosa (PZ)	-	18,328.19	5,091.02	1,272.76	E	135.22	33.80	1.01	429.98	980.42	550.44	Positive
Pignola (PZ)	1,708.00	-	18,075.83	4,518.96	E	459.84	114.96	3.45	1,526.67	1,354.16	-172.52	Insufficient biomass
Rotonda (PZ)	718.00	-	7,598.62	1,899.66	E	197.91	49.48	1.48	641.78	1,212.55	570.77	Positive
San Chirico Raparo (PZ)	-	14,906.28	4,140.52	1,035.13	E	111.45	27.86	0.84	349.71	187.47	-162.24	Insufficient biomass
San Costantino A. (PZ)	100.00	-	1,058.30	264.58	D	34.40	8.60	0.26	89.38	719.48	630.09	Positive
San Mauro Forte (MT)	336.00	-	3,555.90	888.98	D	96.84	24.21	0.73	300.33	139.40	-160.93	Insufficient biomass
San Severino L. (PZ)	257.00	-	2,719.84	679.96	E	75.94	18.98	0.57	229.72	901.36	671.64	Positive
Sasso di Castalda (PZ)	214.00	-	2,264.77	566.19	E	64.56	16.14	0.48	191.28	680.26	488.98	Positive
Spinoso (PZ)	-	18,991.51	5,275.27	1,318.82	D	139.82	34.96	1.05	445.55	317.94	-127.61	Insufficient biomass
Stigliano (MT)	2,188.00	-	23,155.68	5,788.92	E	586.83	146.71	4.40	1,955.72	116.78	-1,838.94	Insufficient biomass
Tito (PZ)	2,405.00	-	25,452.20	6,363.05	D	644.25	161.06	4.83	2,149.68	352.22	-1,797.46	Insufficient biomass
Tricarico (MT)	2,132.00	-	22,563.03	5,640.76	D	572.02	143.00	4.29	1,905.66	647.03	-1,258.63	Insufficient biomass
Venosa (PZ)	5,065.00	-	53,603.08	1,3400.77	D	1,348.02	337.00	10.11	4,527.29	285.75	-4,241.54	Insufficient biomass

3.2. Economic Evaluation

Once established the energy feasibility, meant as the availability of the biomass obtainable from managed forest areas to replace part of methane gas, the economic viability of the investment was evaluated. For the cost analysis, considering the large number of cases and the technological and system types currently available on the market, reference was made both to the estimates provided by some companies operating in the sector and some bibliographic data [36,41] that were then interpolated so as to obtain the unit investment costs of the thermal plant and of the district heating network. This was integrated by the annual management cost, estimated in proportion to the size and equal to 3% of the plant cost; unit costs take account of mechanical and electrical equipment, including the installation. For the machinery room the estimated average costs were, respectively, €40,000 for biomass plants with a power exceeding 500 kW and €30,000 for the others, because the cost of the latter is highly dependent on the volume and type of applied material (Table 8).

Table 8. Summary of panel installation costs and biomass supplies. Source: elaboration of the RU on [36,41].

Thermal plant biomass		District heating network		Machinery room	Annual running	Chip fuel	
Power (kW _t)	Cost (€/kW _t)	Power (kW _t)	Network length (m)	Cost (€/m)	Cost (€)	costs as a percentage (%)	cost (€/t) WCs = 25%
≤100	400.00	≤100	500	190.00	30,000	3	30.00
100 < P ≤ 300	300.00	100 < P ≤ 250	800	190.00	30,000	3	30.00
300 < P ≤ 450	260.00	250 < P ≤ 500	1200	190.00	30,000	3	30.00
450 < P ≤ 700	170.00	P > 500	1500	190.00	40,000 *	3	30.00
P > 700	120.00			190.00	40,000	3	30.00

* For plants with a power <500 kW the cost of machinery room has been estimated to €30,000.

Regarding the cost of the fuel, we considered the costs for the processing stages in the forest, for transportation and chipping. These costs have been estimated to €9/t for chipping, €11/t for in-forest practices (cut, preparation and logging) and €8/t for transportation. The above data represent the averaged observations made by the RU across the regional territory. Finally, considering that the public institution, owner of the forests, might be involved in the ESCO companies, we could presumably exclude the stumpage charges from our assessment of costs. This can be justified by the creation of new business opportunities, new jobs and new local value added, in addition to the savings in energy bills. Additional benefits may be derived from the revenues obtained by the ESCO that could benefit the entire local community.

Once the total costs were obtained, the price of Break Even Point (the point at which cost or expenses and revenue are equal) was estimated as the selling price of the energy produced from forest biomass, at which the discounted total revenues and discounted total costs are equal. In this way it was possible to identify the difference between the price of the thermal energy produced from forest biomass and the price of thermal energy produced from methane gas. Because of the considerable differences in investment costs of plants in different cases, the price of Break Even Point of the thermal energy produced from forest biomass varies from a minimum of €31/MW ht to a maximum of €119/MW ht. Compared to the price of €80/MW ht of methane gas, it is evident that the difference, and therefore the economic viability of substitution, is largely dependent on the installation costs

(biomass power plant and district heating network). In fact, a breakdown of the costs, shown in Table 8, indicates higher unit costs for low power plants compared to more powerful plants.

The economic evaluation of the investment was conducted making use of the major economic indicators, namely Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period applying the criterion of the discounted cash flow (DCF), based on the discounting of cash flow and assuming the lifetime of the power plant is 20 years. In view of the high number of plant types and the resulting wide range of Break Even Point prices of thermal energy produced from biomass, the reference selling price was taken to €95/MW ht assuming also the access to the market of EECs. Based on the information contained in the databases of the AEEG, the above credits were evaluated at an average price of €86.98/toe, which corresponds to a value per MW h equal to €7.48. From the energy selling price we may also deduct a tax credit equal to €25.82/MW h, as provided for in the national legislation; this would result in a consumer energy price of €69.18/MW ht.

It is also assumed that users can gradually get connected to district heating plants in the first four years, considering that in the first year only public structures are served [35]. Based on a survey carried out by our RU on the average consumption of electricity by public users, it resulted that such consumption is, on average, equivalent to 30% of the thermal energy produced from biomass. The estimated distribution of energy in the first 4 years is reported in Table 9.

Table 9. Share of energy from biomass. Source: elaboration of the RU.

Year	% energy supplied from biomass	Served users
Year 1	30%	Public users
Year 2	55%	Public and private users
Year 3	80%	Public and private users
Year 4–20	100%	Public and private users

Before carrying out the economic evaluation, it was necessary to choose the discount rate to be applied, which is largely influenced by the goals and the financial conditions of the investor, as well as the estimated level of risk of the initiative, *etc.*

In our analysis a discount rate of 5% was applied, taking into account the above factors and assuming a loan of seven years at a real interest rate of 4.2% (on the basis of information provided by the Loan and Deposit Bank).

The NPV analysis was conducted using the formula below:

$$NPV = \sum_{k=0}^n \frac{FC_{ki}}{(1+r)^k} \quad (7)$$

where FC_{ki} is the flow at year k_i obtained from revenues minus costs; k is the length of the project in years; r is the capital cost.

In parallel we also calculated the IRR on investment, namely the discount rate for which the equation is satisfied:

$$NPV = \sum_{k=0}^n \left[\frac{R_{ki} - C_{ki}}{(1+r)^k} \right] = 0 \quad (8)$$

where R_{ki} are the revenues at year k ; C_{ki} are the costs at year k ; r is the capital cost; k is the length of the project in years.

Table 10. Table summarizing the economic evaluation of facility investments. Source: Elaboration of the RU.

Country	A	B	C	D	E	F	G	H	I	L	M	N	O	P
-	25% energy from methane gas (kW h)	TOE saved per year	TOE Subsidised by national legislation	Total cost (€)	Annual payment (4.2%) (€)	Annual running cost (€)	Cost of wood chips (€30/t)	Break Even Point (€/KW h)	Selling price of energy (€/kW h)	Revenues from energy sales (€)	Revenues from White Certificates (€)	NPV (€)	IRR (%)	Payback Period (years)
Albano di Lucania	1,198,528.94	90.60	304.42	440,014.50	73,853.42	12,000.44	12,147.25	0.042	0.095	113,860.25	132,390.52	742,435.96	>50%	4.6
Cancellara	825,476.89	62.40	209.66	440,373.90	73,913.74	12,011.22	8,366.32	0.056	0.095	78,420.30	87,535.56	311,462.96	19.3%	7.0
Castelmezzano	697,988.09	52.76	177.28	424,118.26	71,185.34	11,523.55	7,074.20	0.062	0.095	66,308.87	74,016.34	183,656.67	13.6%	8.2
Castronuovo di S. A.	902,658.06	-	-	413,386.13	69,384.03	11,201.58	9,148.56	0.049	0.095	85,752.52	-	353,481.06	19.8%	6.3
Cersosimo	291,033.52	22.00	73.92	341,349.79	57,293.22	9,340.49	2,949.66	0.111	0.095	27,648.18	22,503.47	NEGATIVE	-	-
Fardella	343,948.70	26.00	87.36	340,554.95	57,159.78	9,316.65	3,485.97	0.095	0.095	32,675.13	26,595.00	NEGATIVE	-	-
Forenza	2,243,603.84	169.60	569.86	534,071.25	89,640.20	14,822.14	22,739.23	0.031	0.095	213,142.37	247,830.37	1,802,114.08	>50%	2.8
Francavilla sul Sinni	171,580.99	118.80	399.17	473,589.19	79,488.70	13,007.68	15,928.19	0.036	0.095	149,300.19	173,598.16	1,120,700.82	>50%	3.7
Ginestra	497,402.74	37.60	126.34	370,478.48	62,182.27	10,214.35	5,041.24	0.074	0.095	47,253.26	49,449.17	31,947.79	6.6%	10.7
Latronico	1,833,511.16	138.60	465.70	497,162.90	83,445.39	13,714.89	18,582.88	0.034	0.095	174,183.56	202,531.19	1,386,291.01	>50%	3.3
Noepoli	648,211.02	49.00	164.64	417,771.68	70,120.11	11,333.15	6,569.71	0.065	0.095	61,580.05	64,441.74	137,801.69	11.1%	8.9
Pietrapertosa	1,272,755.33	96.21	323.27	446,694.88	74,974.67	12,200.85	12,899.55	0.040	0.095	120,911.76	140,589.63	817,699.58	>50%	4.3
Rotonda	1,899,655.14	143.60	482.50	503,116.00	84,444.57	13,893.48	19,253.26	0.033	0.095	180,467.24	209,837.51	1,453,359.08	>50%	3.2
San Costantino A.	264,575.93	20.00	67.20	335,396.83	56,294.06	9,161.90	2,681.51	0.119	0.095	25,134.71	16,366.16	NEGATIVE	-	-
San Severino L.	679,960.13	51.40	172.70	421,819.69	70,799.54	11,454.59	6,891.49	0.063	0.095	64,596.21	72,104.61	172,432.09	12.8%	8.5
Sasso di Castalda	566,192.48	42.80	143.81	340,314.32	57,119.43	9,309.43	5,738.44	0.062	0.095	53,788.29	56,287.29	154,568.96	13.6%	8.2

Finally, we calculated the Payback Period, *i.e.*, the time which actually defines the level of risk of an investment, because it measures the time within which the proceeds achieved through the investment can restore the capital employed. In fact, the impossibility of a rapid restoration of the invested capital can induce the investor, even in the presence of positive NPV, to stop the project. It is clear that the payback period does not measure the risk of a given investment, but only the length of exposure to the capital risk. The Payback Period is expressed in years and is obtained by the formula:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Net Benefits}} \quad (9)$$

where the initial investment is given by the ratio of the total cost (letter D, Table 10) to the revenues, obtained by adding the annual energy revenues (L) and the revenues of white certificates distributed over twenty years (M/20), and subtracting the management costs (G) and the cost for the supply of wood chips (F).

The results of the economic evaluation reported in Table 10 show that out of a total of 33 initial municipalities, the implementation of district heating plants powered by biomass produced from the management of public forests is technically and economically viable in 13 municipalities. For these municipalities the results of the economic analysis show positive values both in terms of NPV and IRR, with Payback Periods between three and eleven years.

4. Conclusions

International conventions on research and climate protection have induced several countries to commit themselves to reduce emissions of greenhouse gases by encouraging, *inter alia*, the use of renewable energy. In this context, a strategic priority is the use of multiple sources of energy, potentially available in the area, along with the decentralization of production and the development of small networks of local users. At the national level, due to the wide availability of forest land, a viable alternative to fossil fuels could be represented by the biomass that enables the achievement of a twofold objective: the enhancement of local resources (raw materials and labor) and savings in energy costs for families and public bodies. This would ensure positive social and economic outcomes for local communities.

Biomass is a renewable source of energy, whose main peculiarity is its intrinsic link with the territory, as it is available and widespread everywhere, obviously to varying extents and with different characteristics. Thanks to its versatility, many conversion technologies that can produce as many final forms of energy may be applied. This clearly indicates the need to build up a sound agro-energetic chain and choose, at the same time, the most efficient systems of energy production from biomass. In fact, a correct use of biomass involves coherent planning actions combined with adequate technical know-how in the energy field. It is extremely useful to assess, on the other hand, the negative aspects associated with biomasses, such as the competition for land use between energy production and food production, the social rejection of biomass-based systems and the local population's perceived risks relating to health, environment and landscape. These concerns may often cause social conflicts between the concerned parties. Therefore, information, education and training, combined with public consultation initiatives, might offer more guarantees among all concerned parties both for environmental and more strictly economic issues.

In our specific case, based on the comparison of thermal energy demand and biomass energy supply, we tested the possibility to substitute methane gas for heating with thermal energy from biomass; the results have shown how the feasibility of this replacement in both energy and economic terms depends, respectively, on the biomass availability and investment costs.

More specifically, as to energy, the availability of biomass in the area is of primary importance, as it represents the distinctive element of the supply chain. In fact, the use of off-site biomass (*i.e.*, biomass supplied by external areas) would only increase the negative externalities of the investment with uneconomic impacts related to transportation (costs and energy); so the analysis excluded all the municipalities that did not have an FMPs, as well as the Municipalities that, despite the presence of managed forest lands, showed quantities of potential biomass well below the minimum amounts required to ensure the goals of energy sustainability related to the substitution of methane gas.

From the economic point of view, however, the analysis has highlighted how the higher unit costs that characterize small-power plants make their implementation inefficient. To this end, the tax credit provided by the current national legislation and the new incentives on the production of thermal energy from renewable sources and on energy efficiency could give significant impetus to expand the market of thermal energy from renewable sources.

The proposed model shows a possible strategy for the use of biomass tailored to the characteristics of the territory, in terms of energy demand and actual supply of biomass. A limitation to the application of this model is constituted, however, by the inability to correctly identify the transformation center and the subsequent inaccuracy in defining the size of district heating networks. This would result in a variation of plant implementation costs, either their reduction or increase. For this purpose, it would be necessary to carry out a more detailed analysis, focusing on each geographical area with a view to properly siting the transformation center and sizing more accurately the district heating network based on site-specific needs.

Conflicts of Interest

The authors declare no conflict of interest.

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