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Article

Use of Forest Residues for Building Forest Biomass Supply Chains: Technical and Economic Analysis of the Production Process

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Abstract: In the field of biomass and bio-energy production, an analysis was performed of the whole production process from biomass supply to bio-energy production. The available biomass, harvesting and transportation costs and the distribution of supply area were quantified. The assessment of volumes was based on forest type and its relative increment. The transportation costs, influenced by different species-specific and site-specific factors, were calculated by integrating data in a geographic information system (GIS). The economic values calculated were the main economic indicators (net present value (NPV), internal rate of return (IRR) and Payback Period). The results show that: (a) there is a good supply of forest biomass across most of the territory of Basilicata region, Italy; (b) the harvesting and transportation costs are dependent on biomass density and distances; (c) there are strong margins for economic profits at the level of each single supply basin; and (d) the endogenous value added was estimated to about 150 seasonal workers.

Keywords: biomass; forest energy chain; geographic information systems; cost-effective use of biomass

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1. Introduction

Biomass energy production is an appropriate tool to mitigate the impacts of global warming, reduce green house gas (GHG) emissions and our dependence on fossil fuels [1]. Forest biomass production processes can ensure a significant supply to a high energy-intensive society, while still ensuring a good interaction between environment, services and energy policies [2], in terms of employment [3] and preservation and maintenance of rural areas [4]. However, if bioenergy supply is not viewed in its entirety and considering all steps involved in the production process, some inaccuracies could result when making judgments about its economic, environmental and social impacts. For this reason it is useful to analyze the whole forest energy chain, trying to optimize all steps of the production process.

According to international energy agency (IEA) report [5], energy demand is expected to increase by one third by 2035, with China, India and the Middle-East absorbing about 60%. Hence, it will be crucial to enhance additional energy supply sources, above all renewable resources. In this sense, renewable energies play a strategic role in contributing to energy production, while still reducing the impacts of pollution on the environment.

Plenty of agreements, signed at any decision-making level, agree on the need to suggest proposals and launch actions aimed at increasing the energy stock produced from renewable sources. The so-called “Fifth Energy Bill” [6] and “Heating Bill” [7] have recently been approved at the national level in favor of renewable energy sources.

The sector of renewable energies associated with the use of biomasses is extremely complex because the (a) great diversification of available biomasses (derived from forestry, agriculture, animal production, dedicated crops); (b) number of players involved in the chain; and (c) multiple chemical, physical and thermal processes involved [8]. Despite the availability of the residual biomass derived from in-wood utilization, pruning of urban green areas and cleaning of river channels, residues are quite often considered as wastes. Forest areas are the main biomass sources Forest woody materials at a constant rate and cut logs are intended for different industrial production processes. Unfortunately, wood products may not all be harvested because specific orographic conditions (very steep slopes, difficult access) and the lack of road infrastructures jeopardize the feasibility and cost effectiveness of this practice.

To this end, special emphasis should be laid on Geographic Information Systems (GIS) that are helpful tools of Decision Support Systems (DSS) to plan solutions to conflicting issues on the use of resources [9,10]. GIS modeling may be used in different fields, ranging from the organization of man-made areas and road and energy distribution networks to the agricultural sector and natural areas enhancement [11–13].

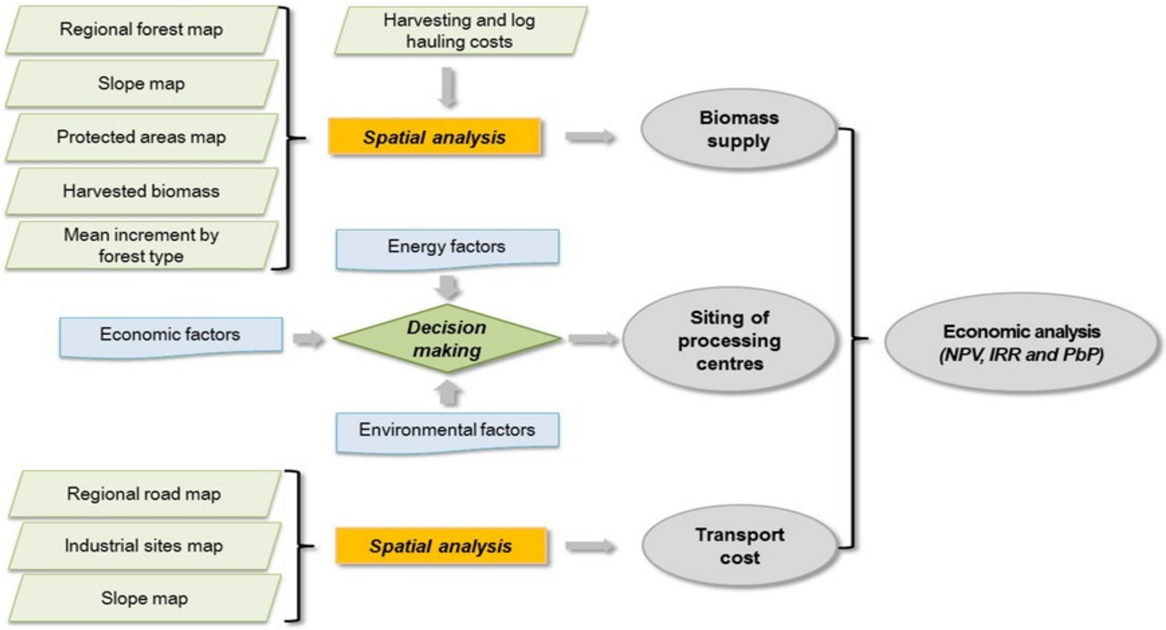
In research literature, different GIS approaches have been applied for the spatial characterization of biomass potentials, costs, demand and supply [14–16]. In fact, specific spatial models have been planned with regard to the development of DSS in the sector of bio-energies [17–19]; other authors have, instead, applied geographic information systems for the detection of potential energy crop locations [20–23], for the design and optimal siting of biofuel production plants [24,25] and for the planning of biomass harvesting and transportation [26,27].

Most studies on biomass energy production are focused only on some aspects of the chain, whereas a holistic approach would be necessary to assess the bio-energy chain in its entirety. This is the starting point of the present work that is aimed at developing an integrated model of energy forest chain, including, in a single application framework, the whole sector and, subsequently, all steps of the production process, starting from the forest up to energy production. In the first step of the research the available biomass derived from the management of the regional forest heritage was estimated; secondly, transportation costs were analyzed and biomass supply areas marked out. Lastly, the cost effectiveness of the forest-energy chain was assessed, assuming the installation of cogeneration plants for each single basin being examined. The application of the model has been carried out in the Basilicata regional territory, Italy. In spite of the narrow focus (of the study), the same concepts may apply to a much wider land, by adjusting for morphologic and climatic differences, forest formations and the current incentive policies.

2. Methodology

Figure 1 shows a schematic representation of the methodology followed for this study.

Figure 1. Methodology procedure.



2.1. Data

A GIS is a set of tools to store, retrieve, transform and display spatial [28] and non-spatial data [29], with advanced ability to model geographic data [30]. Within the GIS the geographic data may be represented both in vector and raster formats. Vector models are usually preferred for the representation and analysis of discrete objects, whereas raster models can better represent continuous data. In the proposed work both vector and raster models have been used to exploit the operational potentials of both; in particular the starting data used for the analysis of the forest-energy chain include the following:

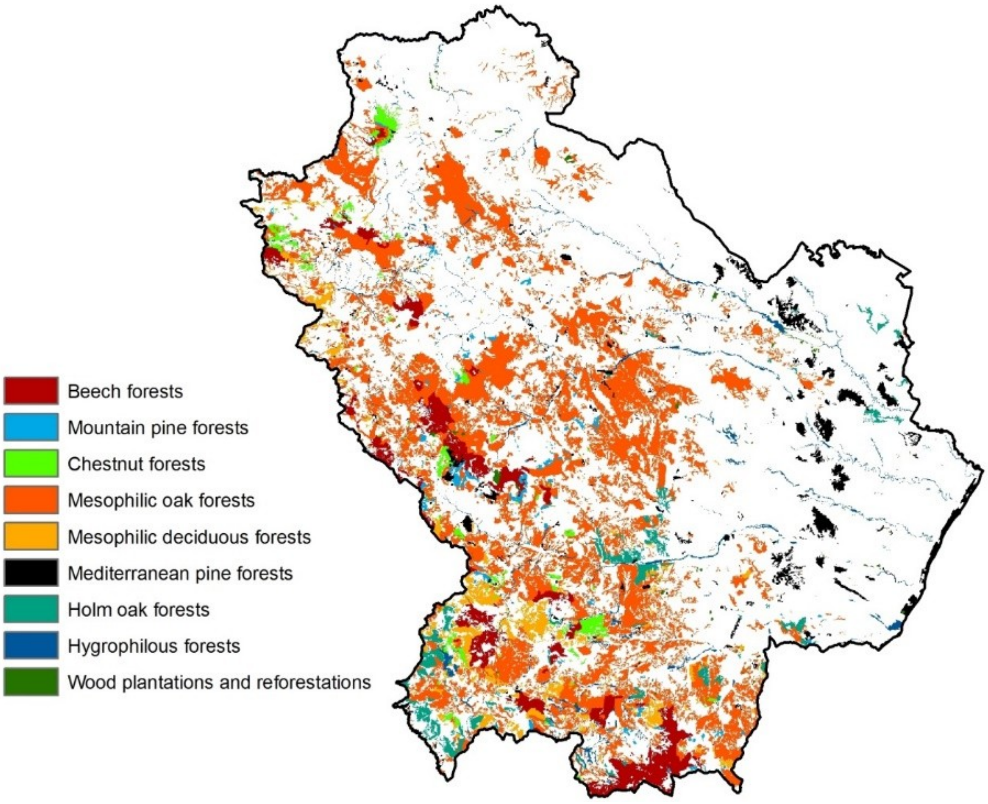
- Regional Forest Map (RFM) in the *vector* format [31];

- Digital Elevation Model (DEM) of the Basilicata region in the *raster* format where each pixel equals one hundred meters a side;
- Map of protected areas (National and Regional Parks, Sites of Community Importance (SCI) and Special Protection Areas (SPAs) in the *vector* format;
- Map of the regional road system in the *vector* format;
- Map indicating the location of regional industrial sites in the *vector* format.

2.2. Biomass Supply

The estimate of the potential biomass resulting from the management of forest areas of the Basilicata region was made using the RFM drawn by the Istituto Nazionale di Economia Agraria (INEA) in 2006 and re-edited in GIS (Figure 2).

Figure 2. Reclassified regional forest map.



Source: Derived by authors from [31].

For each forest type, the annual mean growth, expressed in $m^3\ ha^{-1}\ year^{-1}$, was calculated; this value varies according to the species and the silvicultural system. Annual mean growth values were derived from different literature studies, carried out in similar climatic regions, and included the growth values of different species [32–41]. The growth values have been further supported by way of field surveys (Table 1).

Moreover, the RFM did not include some biomes, such as the shrubs and Mediterranean scrublands that are not subject to cutting for their particular woody vegetation.

Table 1. Mean increments by forest type (m^3 ha^{-1} $year^{-1}$).

Forest Types	**High Forest**	**Coppice Forest**
Beech forests	3.4	3.5
Chestnut forests	3.5	14.5
Mesophilic oak forests	2.53	6
Mesophilic deciduous forests	4.44	4.2
Holm oak forests	2.5	2.2
Mountain pine forests	5.54	-
Mediterranean pine forests	6.5	-
Hygrophilous forests	5	3.6
Wood plantations and reforestations	2	-

In order to ensure *sustainable* harvesting levels, the Guidelines developed by the Basilicata Region for the development of Forest Management Plans (FMPs), indicate the allowable harvest levels as not exceeding 60% of the annual increment for high forest and 90% for coppice forest. Moreover, for the quantification of the available biomass for energy use, forest formations have been categorized as follows: For Mediterranean pine forests, mountain pine forests and hygrophilous formations, the whole biomass was considered [42], whereas for the other forest types only the share of residues of the mean annual cut was taken, as shown in Table 2 [43,44].

Table 2. Harvested biomass (in %) for each species.

Species	**High Forest Residues**	**Coppice Forest Residues**	**Type of Biomass Harvesting**
Beech forests	8%	25%	Forest residues
Mesophilic oak forests	15%	20%	Forest residues
Chestnut forests	15%	16%	Forest residues
Mesophilic deciduous forests	15%	20%	Forest residues
Hygrophilous forests	100%	100%	Total
Holm oak forests	25%	32%	Forest residues
Mountain pine forests	100%	-	Total
Mediterranean pine forests	100%	-	Total
Wood plantations and reforestations	15%	-	Forest residues

The analysis of the regional forest map has enabled the derivation of further information that could be effectively used to identify the potential biomass supply. In particular, through the modeling in GIS, potential biomass quantities were mapped. The following areas were excluded from the analysis:

1. The SCI and SPAs that require, for their nature and protection value, special management and/or improvement actions that go beyond ordinary sylviculture;
2. The areas with a slope exceeding 40% that necessitate machines and wood hauling (cableways, harvesters, *etc.*) are mostly absent in the area under study. For this purpose two types of hauling commonly used by local logging companies were adopted: hauling by tractor and pulleys, and by basket and/or carriage.

The processing of the above data enabled the development of the raster map of potential biomass supply in the region.

2.3. Harvesting and Log Hauling Costs

Once the potential available biomass has been identified, the utilization costs are estimated.

As to the costs for cutting and preparation, we assumed a felling area including three (two qualified and one skilled) labor units. Based on the mean productivity (m^3/h) and the hourly labor and equipment cost applied in the felling areas of the region, the mean cost was estimated to be €10/m^3.

A more complex calculation was performed for the biomass harvest and collection costs [45,46] that increased proportionately with the distance from road. The road distance was obtained using GIS by the *distance* functions; the result was the mapping of the distances of forest areas from loading sites. The road network available in the vector format was classified based on the type of road (highways, expressways, state, province and township roads); for the implementation of the model, only province and township roads were considered. The model developed is based on equations that depend on the slope and the distance from the landing [47].

Wood hauling equations were obtained by integrating bibliographic data [48–53] and field information collected in the forest areas of the regional territory. The results obtained enabled the assessment of the extraction costs, differentiated according to the distance, average slope and the applied extraction technique. In particular, extraction techniques varied according to the extracted woody material and the silvicultural system. In fact, in coppice forests, the most common technique was wood harvesting in assortments mainly intended for domestic use in fireplaces and stoves; in high forests it was common to extract cut-to-length wood, without prunings. Hauling techniques often depended on potential assortments and on the available machinery of the logging company; for the purpose of this work and considering the most commonly applied techniques in the regional territory, we got six equations, each referring to a specific hauling type and technique (Table 3).

Table 3. Wood hauling equations.

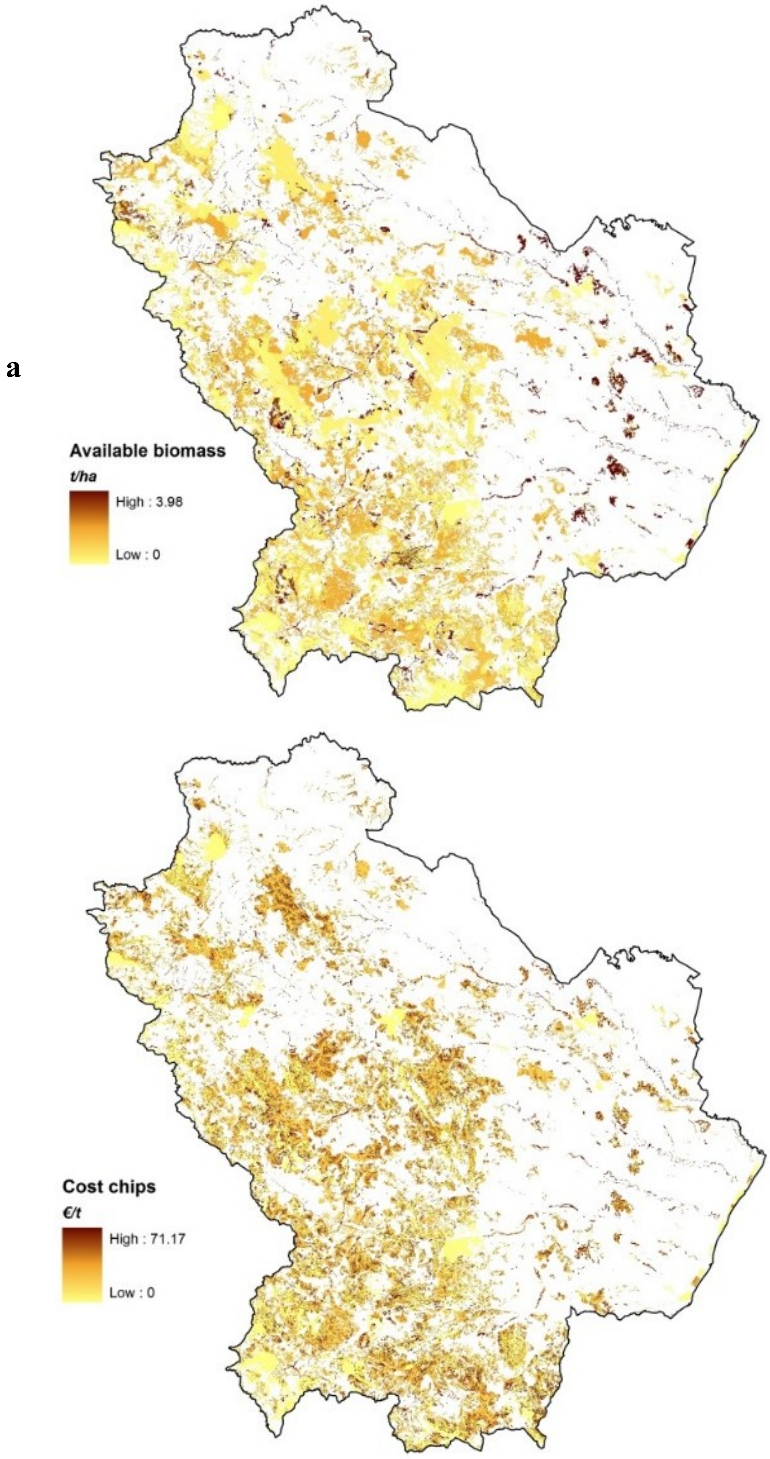
Materials Hauled	Slope (%)	Wood Hauling Technique	Equation of Wood Hauling Cost (€/m^3)
Wood-Coppice forest	0–20	Agricultural basket/trailer	$0.0486 \times D$ * $+ 3.413$
Wood-Coppice forest	21–40	Transport trawl	$0.0319 \times D + 14.818$
Wood-High forest	0–20	Agricultural basket or transport trawl	$0.0982 \times D - 2.261$
Wood-High forest	21–40	Transport trawl	$0.1136 \times D + 2.577$
Forest residues	0–20	Agricultural basket/trailer	$0.0019 \times D + 6.609$
Forest residues	21–40	Transport trawl	$0.0343 \times D + 20.698$

* Distance from the road network.

Based on the calculated potential biomass and the equation of wood hauling costs, the space-based hauling cost was obtained with reference to the unit area. As expected, wood hauling costs increased proportionately with the distance from the landing. Accordingly, forest utilization and hauling was not economically viable for all wooded areas. Hence, the areas with extraction costs greater than 50 €/m^3 were considered as unsuitable and were excluded from the evaluation.

Wood chipping costs, based on field experiences conducted in the regional area, subsequently integrated and compared with data obtained in other regions, were estimated to be 10 €/t [54]. Further cost items were included, such as the expenses for administration, watch and management, taken as percent values (15%) on extraction, cutting and preparation costs. Thanks to the data obtained, each *pixel/hectare* was associated with the total cost for the use-harvesting-chipping process. The results show a potential biomass harvest rate per hectare varying between 0 and 3.98 t/ha and a variable cost between 0 and 71.17 €/t of chipped wood (Figure 3).

Figure 3. Available biomass (**a**) and utilization costs (**b**).



2.4. Siting of Processing Centers

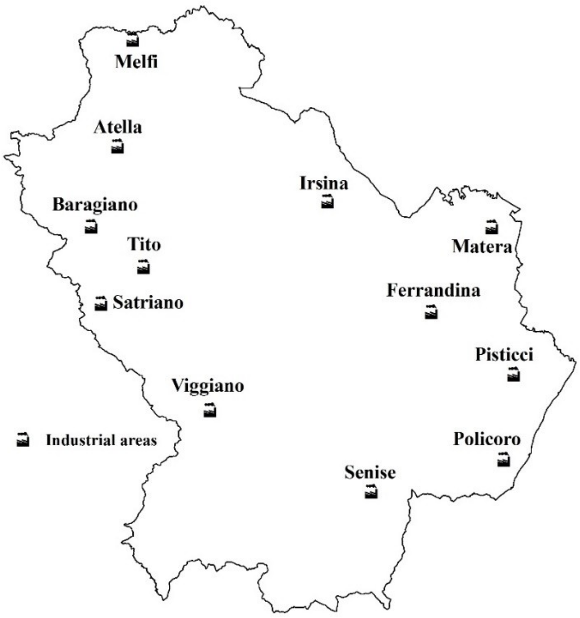
The optimal siting of processing centers has been studied in the literature using different methods. Most of them identify the optimal siting of the plant through the optimization of target functions [55,56], whereas other authors have addressed the problem by the use of GIS [57–59]. Whatever method is applied, the proper siting of the processing center should take into account different aspects that may be grouped into three main categories: energetic, environmental and economic factors [26].

Furthermore it would be desirable to site plants: (*i*) close to built-up areas, with a sufficiently high number of users and with such a housing density as to prevent the building of a large, expensive and poorly performing district heating system; (*ii*) in the neighborhood of industrial areas that require large amounts of thermal power for their production cycle; or (*iii*) close to public infrastructures such as hospitals, schools, covered sports facilities, *etc.* It is desirable to site the plant close to the road system (so as to easily supply the plant) and to the biomass supply area, to minimize transportation costs and transport-borne emissions.(Please confirm this should be “or”)

From the landscape point of view, it would be useful to site the plant in urbanized areas, with similar facilities so as to prevent the siting in areas typically characterized by agricultural and forestry elements. Based on the above considerations, for the siting of conversion plants we opted to use the existing industrial areas in the regional territory. This would enable an easy power distributing of both electrical energy, due to the *in-loco* presence of the national electric network, and of the thermal power produced. The latter could supply the energy (thermal) demand of the existing industrial establishments. A further advantage is the possibility of using production facilities that are no longer in use, which reduces the implementation costs of the processing center.

Based on the data supplied by the *Basilicata Region*, there are 15 industrial facilities across the regional territory. Three of these sites have been excluded from the evaluation, as they are spatially close to other sites (Figure 4).

Figure 4. Identification of used processing centers.



2.5. Assessment of Transportation Costs

Once the potential sites for plants were identified and the amounts of potential biomass harvested from each pixel defined, a model for the analysis of biomass transportation costs was implemented. The model developed is based on the travel time on the road network (function of the average velocity of transportation means) as the value of impedance to identify the minimum-cost path from the supply areas to the processing centers [60,61].

In the first step the road system was classified according to the type, the driving velocity of trucks (as provided for in the national legislation relative to car driving and penalties) and the morphology, for the characterization of slopes. According to the road slope and the speed limits prescribed by the national legislation for heavy vehicles, the final driving speeds were estimated as proposed in Table 4.

Table 4. Speed-Slope ratio.

Road Speed *(km/h)*	**Slope** *%*	**Final Speed** *(km/h)*
80	<10	80
80	10–25	70
80	25–50	60
80	>50	50
70	<10	70
70	10–25	60
70	25–50	50
70	>50	40
50	<10	50
50	10–25	45
50	25–50	40
50	>50	30

Source: data processed by the Research Unit.

Afterwards, transportation costs were evaluated using functions of raster spatial analysis. The applied functions included:

- *Cost Distance Function*: this incremental function calculates the travel time between two neighboring cells as the product of the linear distance between cell centroids and cell mean impedance. It has the location of the plant and the raster of travel velocity along the road graph as inputs, and it produces a raster of cumulative travel time along the road network in seconds (cumulative travel time) (Figure 5a).
- *Euclidean Allocation Function*: this function instead enables to obtain a continuous surface of travel time values. It is used to extend the cost distance function into the forest areas adjoining the roads (Figure 5b).

Based on the above maps the supply areas for each of the identified plants was marked out on the basis of the road distance and the time taken to reach the plant. Therefore, whether a portion of the surface is adjacent or not to a plant or to another has been defined by the following function:

$$S_i = \min(tI_1; tI_2; \dots tI_n) \tag{1}$$

where:

S_i: indicates the i-th portion of the area;

t: biomass transportation time;

I_1; I_2;... I_n: indicates the conversion plant.

Once the supply basins for each plant were marked out (Figure 5), the biomass transportation costs were assessed. The transportation cost from a forest site to the plant was defined by the following relation:

$$CT = ((t_p \times 2) + t_t) \times C_{mt}/P_{mt} \tag{2}$$

where:

CT: transportation cost;

t_p: raster of travel times (to and fro) in minutes (obtained by the *Euclidean Allocation Function*);

t_t: time for the loading and unloading of truck, in minutes;

C_{mt}: hourly cost of the means of transport (€/min);

P_{mt}: maximum allowable load of the truck, in tons;

Based on the above, and on survey data from logging enterprises and companies working in the road transport [62], the following values were used to calculate the transportation cost:

t_t: twenty-five minutes including 15 for the loading and 10 for the unloading (for loading and unloading time we assumed the use of dump trucks; hence, the calculated times, assuming two trucks used alternatively and continuously hooked into the same tractor, refer only to the time for hooking, loading and unhooking);

C_{mt}: one point zero eight Euros per minute corresponding to €65 per hour;

P_{mt}: twelve tons of woodchips (for the maximum allowable load of the means we assumed the use of trucks with a volume of 36 m^3. Considering a ratio of m^3/t of woodchips equal to 1/3, we found that the maximum allowable load of the truck was 12 t). A continuous surface area of transportation costs (€/ton) follows for all identified conversion plants (Figure 6).

The results clearly show that the local and regional accessibility of the resource influences the transportation costs. By comparing Figures 5a and 6 it can be seen that minor costs are obtained in the areas close to the biomass transformation plant, following the road routes.

2.6. Choice of the Conversion Technology and Plant Sizing

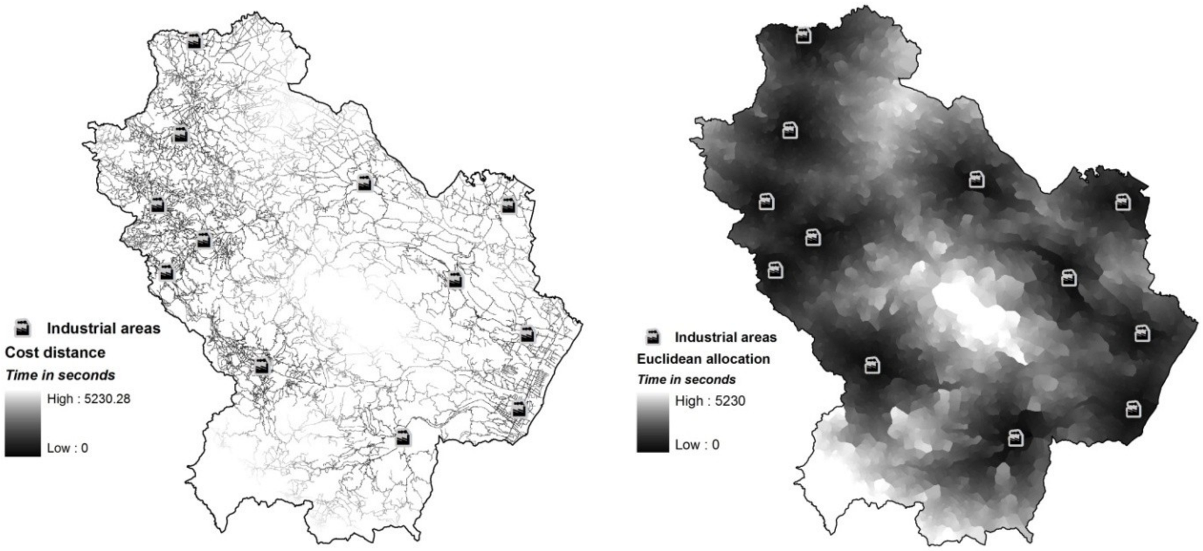
The choice of the conversion technology is influenced by the chemical (carbon/nitrogen ratio) and physical (moisture) properties of the fuel. More specifically, there are two conversion types [63,64]:

- thermochemical processes;
- biochemical processes.

For wood, the best process is thermochemical because of a moisture content lower than 30% and a C/N ratio greater than 30.

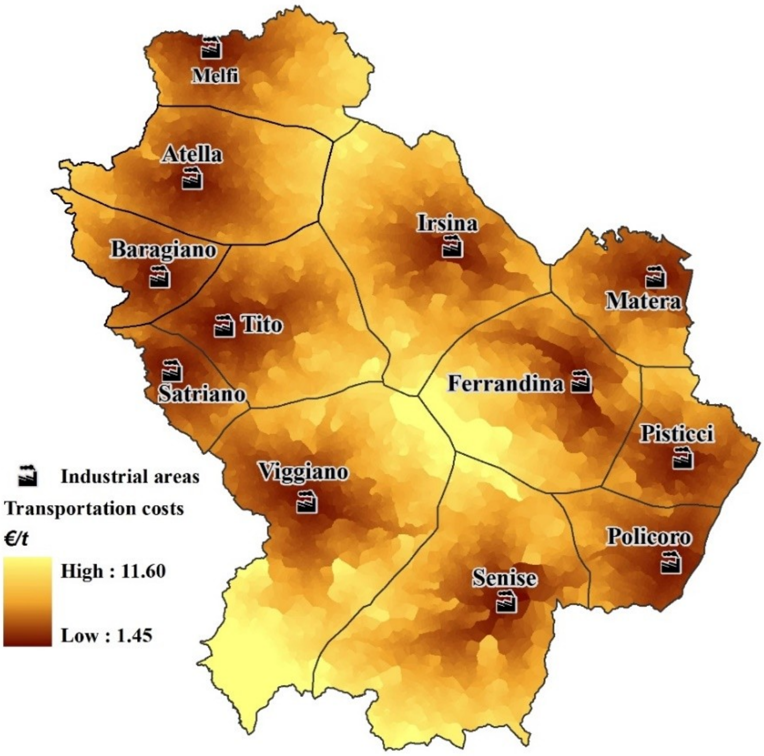
In the present work the ORC (Organic Ranking Cycle) technology with organic fluid for power co-generation was applied. This technology is particularly suitable for the use of forest biomass as starting fuel both for its high energy yields and low emission levels.

Figure 5. (**a**) Map of the Cost Distance Function. (**b**) Map of the Euclidean Allocation Function.



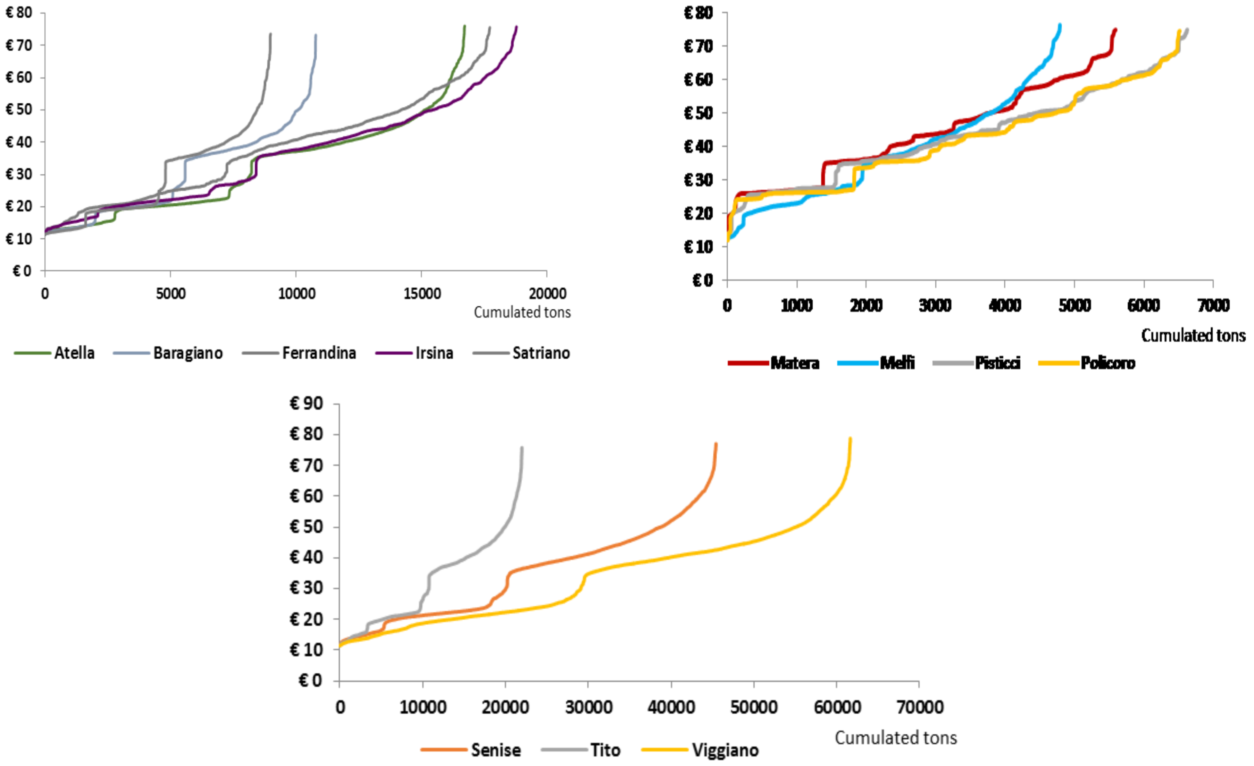
(**a**) (**b**)

Figure 6. Transportation costs and supply area.



The amount of biomass available at a plant location determines the size of the conversion plant, so we need to look at supply at each location. Based on the zonal statistics using GIS, the cost-supply curves were built to assess the amounts of available biomass at different costs [65]. The data used for this purpose involved the raster map of total costs and the map of the spatial distribution of annual available biomass. The results show, for each cell, the biomass content and its cost (Figure 7).

Figure 7. Cost supply curves of supply area.



The curves obtained for each area indicate the available biomass at a given price level and show how the availability is mainly influenced by the increase in transportation costs and forest processing costs. All curves show a quick change in gradient at the same point of the ordinate axis (≅ €30). This change is due to the fact that the curves actually highlight two distinct phenomena: under €30 are the amounts of forest-derived biomasses (Mediterranean pine forests, mountain pine forests and hygrophilous formations) that are totally utilized (trunk and wood prunings), whereas above €30 the amounts of biomass derive from the "wastes" of the other formations (Figure 2). In fact, in the first case the higher labor productivity results in lower unit forest processing costs.

After the cost supply curves were identified for each supply basin, the limit value for the total cost was fixed to €50/t [66]. For the purpose of this work we considered the amounts of biomass falling below that cost threshold (Table 5).

Based on the amounts of biomass shown in Table 5, the previously identified, potential processing plant for each basin was designed. The power of each plant was calculated using the following formula:

$$P = Energy / time \tag{3}$$

where:

p: plant power to be installed in each area (MW);

Energy [67,68]: biomass energy assuming a WC of 25% and a calorific value of 3700 KWht;

Time: average annual operating hours of facilities.

Table 5. Tons of available and utilized woodchips.

Biomass Supply Basin	**Available Fresh Woodchips**	**Available Fresh Woodchips**	**Difference**
	Total	*<€50/t*	*t*
Atella	16,710.85	15,130.61	−1580.24
Baragiano	10,778.47	10,071.49	−706.98
Ferrandina	17,711.64	14,168.30	−3543.33
Irsina	18,774.10	15,424.36	−3349.75
Matera	5,589.70	3,777.51	−1812.20
Melfi	4,793.48	3,766.93	−1026.55
Pisticci	6,628.96	4,443.04	−2185.92
Policoro	6,512.80	4,701.06	−1811.75
Satriano	8,981.85	8,442.12	−539.73
Senise	45,417.95	38,760.07	−6657.88
Tito	21,985.47	19,918.72	−2066.75
Viggiano	61,636.66	55,075.86	−6560.79

For estimating the amounts of potential energy, we assumed 7920 annual operating hours and a plant yield of 18% for the production of electrical energy and 4320 running hours (in winter) and 76% yield for thermal power. The heat power produced during the rest of the year could be used to dry out woodchips or be supplied to the neighboring industrial sites for particular needs of their production cycle.

The results show plant powers ranging from a minimum of 1.32 MW to a maximum of 19.30 MW (Table 6) and amounts of energy between 1881.58 MWhe and 19,360.65 MWhe and from 4333.34 MWht to 44,588.17 MWht.

Table 6. Estimated power plant size for each supply area.

Biomass Supply Basin	**Available Chips (<€50/t)**	**ORC Power Plant**	**Electric Energy**	**Thermal Energy**
	t (WC = 25%)	*MW*	*MWhe–7920 h*	*MWht–4320 h*
Atella	11,347.96	5.30	7,557.74	17,405.70
Baragiano	7553.62	3.53	5,030.71	11,585.87
Ferrandina	10,626.23	4.96	7,077.07	16,298.70
Irsina	11,568.27	5.40	7,704.47	17,743.62
Matera	2,833.13	1.32	1,886.86	4,345.50
Melfi	2,825.20	1.32	1,881.58	4,333.34
Pisticci	3,332.28	1.56	2,219.30	5,111.11
Policoro	3,525.79	1.65	2,348.18	5,407.92
Satriano	6,331.59	2.96	4,216.84	9,711.51
Senise	29,070.05	13.58	19,360.65	44,588.17
Tito	14,939.04	6.98	9,949.40	22,913.77
Viggiano	41,306.90	19.30	27,510.39	63,357.27

3. Results and Discussion

In order to find the cost effectiveness of the investment, we carried out the economic analysis of the potential forest energy chain in each designated area. To this end, we applied the most representative economic indicators used to evaluate investment projects:

$$NPV = \sum_{k=0}^{n} \frac{FC_k}{(1+r)^k} \tag{4}$$

FC_k: flux at year k obtained from the benefits at year k minus the costs at year k;
k: project length in years;
r: cost of capital.
IRR expressed by the formula:

$$NPV = \sum_{k=0}^{n} \left[\frac{R_k - C_k}{(1+r)^k}\right] = 0 \tag{5}$$

R_k: benefits at year k;
C_k: costs at year k;
r: cost of capital;
k: project length.

$$\text{Payback Period} = \frac{\text{Initial investment}}{\text{Annual return (net benefits)}} \tag{6}$$

The cost items needed to estimate indicators were derived from surveys carried out among enterprises working in renewable energies, with special reference to biomasses [69]; those data were then averaged so as to obtain the unit costs. As to the benefits, the potential amounts of electric and thermal energy were evaluated respectively at a price of €60.37/MWhe, taken as an average of the values recorded in the national electricity market in the first months of 2013, and at €60/MWht, a price relatively lower compared to traditional fossil fuels (methane gas), with a view to supplying final consumers with a cheaper price of heat energy (Table 7).

Table 7. Unit costs.

Plant Cost *€/KWe*	**Annual Running Cost** *€/KWe*	**District Heating Network Cost [70]** *€/m*	**Selling Price of Electricity** *€/MWhe*	**Selling Price of Heat Energy** *€/MWht*
4500	220	190	60.37	60

For covering installation and distribution costs, a seven-year loan was chosen at a real interest rate of 4.2% and a discount rate of 5.5%, while the plant lifetime was assumed to be 20 years. The results show NPV figures ranging between €297,561 and M€8.05, IRR values between 10.66% and 19.10% and Payback periods from 8 to 10 years (Table 8). In terms of employment, the implementation of biomass energy chains in the regional territory would create about 150 new (seasonal + permanent) jobs, to be employed in the whole production process for about 14,000 total annual working days.

Table 8. Net present value (NPV), internal rate of return (IRR) and Payback Period (*Million €*).

Biomass Supply Basins	**Total Cost** *M€*	**Income from Energy Sales** *M€*	**NPV** *M€*	**IRR** *%*	**PbP** *Years*
Atella	4.58	1.50	2.02	16.87	8.6
Baragiano	3.14	1.00	1.25	15.55	8.8
Ferrandina	4.31	1.41	1.87	15.84	8.6
Irsina	4.66	1.53	2.06	16.92	8.6
Matera	1.36	0.37	0.30	10.68	10.2
Melfi	1.35	0.37	0.30	10.66	10.2
Pisticci	1.55	0.44	0.40	11.66	9.9
Policoro	1.62	0.47	0.44	11.98	9.8
Satriano	2.68	0.84	1.00	14.86	9.0
Senise	11.29	3.84	5.59	18.71	8.2
Tito	5.94	1.98	2.74	17.56	8.4
Viggiano	15.92	5.46	8.05	19.10	8.2

4. Conclusions

This paper seeks to offer a new methodological approach to the production of energy from forestry biomass by proposing a detailed analysis of the whole forest energy chain and suggesting for each step a given assessment methodology. In fact, the proposed model addresses the main problems associated with the use of biomasses: available amounts, supply basins, costs for biomass transportation and dispatch of produced energy. All these factors have been related to each other by the combined use of GIS and the main indicators of cost effectiveness. A number of possible additions and improvements may be developed by this paper. The proposed methodology could be extended to other geographical areas, within or outside the forestry sector, by assessing the specific guiding policies and incentive measures in the field of bioenergy.

More specifically, the analysis is focused on the use of the residues resulting from forest applications and on the types of woods whose commercial utilization is not cost effective due to the absence of local market for timber. Clearly, in the estimate of residues, marginal forest areas are excluded together with those that, for their specific morphology, necessitate a higher level of mechanization and higher costs. For all examined basins we have consistently found positive economic indicators and return periods of less than 10 years, namely half of the entire lifetime of power plants. Further benefits associated with the building of energy chains result from new job creations (in this specific case about 150 new jobs) that would generate some added value both in social terms and for the economic and environmental benefits, derived from the use of biomasses.

Even more ambitious results could be achieved by setting up integrated forest-energy districts, where different implementing actors could join to form a single entity. In view of the fact that a significant portion of woodland is state-owned, the above opportunity might hopefully involve the public authority that should provide guarantees on investments.

The results obtained are promising, considering that the analysis did not take into account the incentives provided by the national government for renewable energy production. Their inclusion in the economic evaluation would produce much more profitable results.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

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