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Biomass and Bioenergy 26 (2004) 15–25

BIOMASS & BIOENERGY

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Optimizing forest biomass exploitation for energy supply at a regional level

Davide Freppaz[b], Riccardo Minciardi[a,b], Michela Robba[b,*], Mauro Rovatti[a,c], Roberto Sacile[a,b], Angela Taramasso[a,d]

[a]*CIMA, Interuniversity Center for Environmental Monitoring, Via Cadorna 7, 17100 Savona, Italy*
[b]*DIST, Department of Communication, Computer and System Sciences, University of Genova, Via Opera Pia 13, 16145 Genova, Italy*
[c]*DICHEP, Department of Chemical and Process Engineering, University of Genova, Via Opera Pia 15, 16145 Genova, Italy*
[d]*DIAM, Department of Environmental Engineering, University of Genova, Via Montallegro 1, 16145 Genova, Italy*

Received 3 July 2002; received in revised form 4 April 2003; accepted 25 April 2003

Abstract

A decision support system for forest biomass exploitation for energy production purposes is presented. In the proposed approach, geographic information system based techniques are integrated with mathematical programming methods to yield a comprehensive system that allows the formalisation of the problem, decision taking, and evaluation of effects. The aim of this work is to assess the possibility of biomass exploitation for both thermal and electric energy production in a given area, while relating this use to an efficient and sustainable management of the forests within the same territory. The decision support system allows for the locating of plants and the computing of their optimal sizing (defining which kind of energy is convenient to produce for the specific area), taking into account several aspects (economic, technical, regulatory, and social) and deciding how to plan biomass collection and harvesting. A case study applied to a small Italian mountain area is presented.

Keywords: Decision support systems; Renewable energy; Biomass exploitation; Geographic information system; Optimization; Regional energy planning

1. Introduction

Biomass exploitation plays an important role in the production of energy from renewable sources. There are reports in the literature on practical experiences of realizing this potential [1–5]. Quantitative analyses of strategies for utilizing biomass energy sources have been performed both evaluating the potential resources of bioenergy in different countries (forest-rich regions, nations with agricultural-land surplus) [6] or matching the woody biomass demand and supply with forestry industries in Europe [7]. The same works, however, fail to propose a systematic approach to define the actual availability of energy from biomass. At present, a comprehensive approach to biomass exploitation is required for regions where other kinds of energy are difficult to exploit or where the use of biomass could decrease environmental pollution and enhance regional welfare, e.g., by providing local employment opportunities or improving environmental preservation.

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* Corresponding author. Tel.: +39-010-353-2804 (2748); fax: +39-010-353-2154.
E-mail address: michela@dist.unige.it (M. Robba).

0961-9534/04/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0961-9534(03)00079-5

In this respect, decision support systems (DSS) have been proposed to assist in biomass management for energy supply at a regional level. Nagel recently proposed a methodology [8], tested in the state of Brandenburg, Germany [9], to determine an economic energy supply structure based on biomass. The problem was formulated as a mixed-integer linear optimization using a dynamical evaluation of economic efficiency, and with 1-0 conditions to solve the question whether or not to build a heating system, a heating plant or a co-generation plant. This work focused on many features, namely the kind of users that could benefit from biomass use for energy supply, the dimension and typology of heating plants, and the sensitivity of the decision with respect to fuel costs. The conclusions of these two papers [8,9] asserted that using biomass in individual plants is already economic for some consumers, although an attempt should be made to reduce biomass fuel prices. In addition, it was pointed out that since biomass can help to reduce CO_2 emissions, some economic measures and/or incentives should be adopted, such as CO_2 taxes, state subsidies for biomass-fired energy conversion plants, or reduced rates for electricity produced from biomass.

Another DSS for bioenergy applications, with special reference to harvesting wood for energy from conventional forestry and short rotation forestry, has recently been described [10]. In particular, the work addressed the calculation of delivery costs for wood fuel from conventional forest in the UK. Moreover, an exhaustive review of topics related to the problems of modelling bioenergy supply systems was provided. The same research group proposed other DSSs: the Coppice decision support system (CDSS), a spreadsheet model that can be used to model the costs of growing short rotation coppices under UK conditions [11], and the Coppice harvesting decision support system (CHDSS), which models the supply chain from the standing Coppice crop through harvesting, storage and transport [12]. These DSSs, as well as other models, have been linked together to produce BITES, now presented in an extended spread-sheet based format called bioenergy assessment model (BEAM) [10], which is a comprehensive biomass to electricity model.

Territorial evaluations, involving geographic [13,14], environmental [9] and socio-economic [15] characteristics of the region, are also very important aspects of the decision problem. In this respect, GIS-based approaches have recently been proposed.

Noon and Daly [13] proposed a GIS-based biomass resource assessment, Version One, called BRAVO, a computer-based decision support system to assist the Tennessee Valley Authority in estimating the costs for supplying wood fuel to any one of its 12 coal-fired power plants. The GIS platform in BRAVO allows for an efficient analysis of the transportation network, thus enabling accurate estimates of hauling distances and related costs. In a subsequent work, Graham et al. [14] extended several features of the previous approach, one of which was the estimation of the costs and the environmental implications of supplying specific amounts of energy crop feedstock across a state, taking into account where energy crops could be grown, the spatial variability in their yield, and transportation costs. More recently, a GIS DSS to estimate the potential for power production from agriculture residues was developed and applied to the island of Crete [16]. This DSS handles all possible restrictions, and candidate power plants are identified using an iterative procedure that locates bioenergy units and determines the cultivated area that is needed for biomass collection.

This paper presents a DSS approach to the regional exploitation of available biomass for energy supply conversion, with the objective of helping the planner in taking the following decisions:

- determining the optimal size of each plant in terms both of energy production and of feeding;
- defining the percentage of electrical energy with respect to the total energy produced;
- determining the quantity of biomass that must be collected;
- defining where to collect the biomass.

At the same time, the DSS takes into account several aspects, including:

- the available biomass in the region;
- the technological aspects regarding the plants;
- the economic effects, such as the cost of energy production, or the potential legislative benefits.

Specifically, in the proposed work, the available biomass present in the region is divided in parcels (of different areas) corresponding to the areas that are characterized by a predominant biomass type. This structure takes into account three main aspects of the problem:

- the need to determine not only the quantity of biomass that is convenient to collect, but also the parcels (and, consequently, their position on the territory) to be exploited;
- the need to control forest biomass exploitation to maintain a sustainable production;
- the heavy dependence of the costs of forest biomass collection on accessibility of each parcel and its distance from the plants.

The basic information needed for the approach proposed in this paper is relevant to the availability of biomass in the region under consideration, as well as to the needs of people living in that area (including industrial energy needs). A specific feature of this approach is that it takes into account all aspects that can influence, from an economic standpoint, the definition of the biomass exploitation plan in the considered area. Finally, for the case study presented herein, an environmental analysis focusing on NO_x, SO_2, CO_2, and dust emissions produced by the whole system has been carried out.

2. Formalization of the decision problem

2.1. Problem description

A regional authority requires support to evaluate the harvesting of forest biomass for purposes of energy production using combustion plants to be constructed over its small-medium region (less than 500 km^2), which is characterized mainly by mountainous territory covered by natural vegetation. This decision was prompted by the foreseen advantages stemming from autonomous energy production complemented by environmental and social benefits, namely improved regional control of forest fire risk, reduced CO_2 emission for energy production, and enhanced social and occupational activities. Different types of biomass are available in different locations. In this work, $i = 1,\ldots,N$ parcels of different areas have been considered, each of them being characterized by a predominant biomass type. These parcels also have different characteristics that are relevant, for example, to terrain and accessibility. In this region, $k = 1,\ldots,K$ locations for plants for energy conversion from biomass have been identified. The plants may produce both thermal and electrical energy. The main objective of this work is to define a DSS able to:

- size the various plants and determine the quantity of thermal and electric energy produced;
- determine the optimal biomass flows to plants, as well as the parcels to be exploited for energy production.

2.2. Decisional variables

The decisional variables necessary to describe the considered system and to define the objective function and the constraints are the following:

- u_i is the annual biomass quantity, in m^3/yr, harvested in the ith parcel;
- ϕ_{ik} is the biomass quantity, in m^3/yr, that is yearly sent to the kth plant from the ith parcel;
- CAP_k is the capacity, in MW, of a plant in the kth location;
- y_k represents the percentage of thermal energy produced by the kth plant;
- γ_k is a binary variable that is equal to 1 when the plant produces some amount of electric energy (i.e. when $y_k < 1$), 0 otherwise.

2.3. The objective function

The objective function takes into account the costs and benefits of the decision. Specifically, collection, transportation, harvesting and plant costs are considered, together with benefits from the sale of thermal and electrical energy. Five components contribute to the definition of the objective function to be minimized:

- G, i.e., the benefits deriving from the sale of the energy produced;
- C_P, i.e., the costs related to plant installation and maintenance;
- C_T, i.e., transportation costs;

- C_C, i.e., biomass harvesting costs;
- C_D, i.e., the costs related to energy distribution.

Thus, the overall objective to be minimized is:

$$O = -G + C_p + C_T + C_C + C_D$$

2.3.1. Energy production profits

Assuming that all plants have the same electrical and thermal efficiencies, the annual profit from energy production can be determined as

$$G = \sum_{i=1}^{N} \sum_{k=1}^{K} (y_k \eta_t C_t + (1 - y_k) C_e \eta_e) C_i u_i \tag{1}$$

being

$$C_i = \frac{1}{f} LHV_i MV_i$$

where LHV_i is the lower heating value of the biomass relevant to the ith parcel; in this work, LHV_i is assumed as a constant in all parcels and equal to 11.3 MJ/kg, supposing biomasses with 30–35% of humidity, η_t is the thermal efficiency, η_e is the electric efficiency, f is a conversion factor, whose value is 3.6 MJ/kWh, C_t is the unit price (€/kWh$_t$) for the sale of thermal energy, C_e is the unit price (€/kWh$_e$) for the sale of electric energy, and MV_i is the biomass density relevant to the ith parcel (kg/m^3).

2.3.2. Plant costs

Fixed and variable costs are related to installation and maintenance of a plant. Such costs have to be evaluated taking into account the estimated average life of the plants. Thus, the yearly overall plant cost may be expressed as

$$C_P = \sum_{k=1}^{K} [(CF_k + CV_k \mathrm{CAP}_k) + (\gamma_k CFE + CVE(1 - y_k)\mathrm{CAP}_k)], \tag{2}$$

where CF_k and CFE represent fixed costs, respectively, for the plant and for the machinery necessary to produce electrical energy; CV_k and CVE represent variable costs, respectively, for the plant and for the machinery necessary to produce electrical energy.

2.3.3. Transportation costs

The (yearly) transportation costs can be expressed as

$$C_T = \sum_{i=1}^{N} \sum_{k=1}^{K} C_{TR} \varphi_{ik} MV_i d_{ik}, \tag{3}$$

where C_{TR} is the unit cost for transport in €/kg^{-1}/km^{-1}, MV_i is biomass density, d_{ik} is the distance (km) from parcel i to location k, computed by the GIS module of the DSS.

2.3.4. Collection costs

Collection costs depend on different factors such as the difficulty of harvesting and the quantity of collected biomass. The (yearly) collection cost can be written as

$$C_C = \sum_{i=1}^{N} Cr_i MV_i u_i, \tag{4}$$

where Cr_i is the collection unit cost, in €/kg, for the ith parcel.

2.3.5. Connection costs to the national network for electrical energy distribution

The (yearly) overall cost to connect the plants producing electricity to the national network can be expressed as

$$C_D = \gamma_k \sum_{k=1}^{K} (C_{ed} L_k + C_{conn}) \tag{5}$$

where C_{ed} is the unit cost, in €/km, of a connection for electrical energy distribution, L_k is the distance, in km, between the plant in the kth location and the nearest connection point to the electrical network, C_{conn} is a fixed cost, independent of the length of the connection link.

Note that the term $\sum_{k=1}^{K} (C_{ed} L_k + C_{conn})$ is a constant for the statement of the optimization problem.

2.4. The constraints

The following constraints have been introduced in the formalization of the problem.

2.4.1. Restrictions on forest biomass collection

For each cell, an upper bound is defined for the overall quantity of biomass that can be collected. This upper bound is presumed to be related to the annual average biomass quantity x_i on that cell, which is assumed to be constant and known. Thus, the constraints can be written as

$$0 \leqslant u_i \leqslant \alpha_i x_i, \quad i = 1, \ldots, N, \tag{6}$$

where α_i is the maximum percentage of biomass that can be collected in parcel i. Obviously, α_i must be set to a value that, on the basis of the biomass dynamics of the forest, makes the biomass exploitation environmentally sustainable and avoids the risk of extinction. The definition of proper values for such parameters is generally left to Forest Exploitation Plans, which are generally prepared by forest experts.

2.4.2. *Biomass flow constraints*

The biomass flow coming out of a parcel ($i = 1, \ldots, N$) that is sent to the different plants (in location k, $k = 1, \ldots, K$) must be equal to the overall biomass collected in the parcel, that is

$$\sum_{k=1}^{K} \phi_{ik} = u_i, \quad i = 1, \ldots, N. \tag{7}$$

2.4.3. *Mass conservation in the plant*

The biomass quantity entering a specific plant must be sufficient to saturate the plant capacity, as plants with excess capacity are to be avoided. Thus, the following constraints have to be fulfilled:

$$\frac{1}{\Pi} \sum_{i=1}^{N} \phi_{ik} LHV_i MV_i = \left(\frac{\mathrm{CAP}_k y_k}{\eta_\mathrm{t}} + \frac{\mathrm{CAP}_k (1 - y_k)}{\eta_\mathrm{e}} \right), \quad k = 1, \ldots, K, \tag{8}$$

where $\Pi = 31{,}536{,}000$ is the number of seconds in a year.

2.4.4. *Production plant constraints*

The plants are presumed to operate within maximum and minimum production threshold constraints. This can be expressed by imposing that each plant produces at least $\mathrm{CAP}_{\min}$ (in MW), and at most $\mathrm{CAP}_{\max}$ (in MW), namely

$$\mathrm{CAP}_{\min} \leqslant \mathrm{CAP}_k \leqslant \mathrm{CAP}_{\max}, \quad k = 1, \ldots, K. \tag{9}$$

2.4.5. *Minimum energy recovery*

A constraint has to be set to impose that the quantity of the energy produced in the area through renewable sources must be at least equal to a fixed percentage of the energy required by that area. Such a constraint may be written as:

$$\sum_{k=1}^{K} \mathrm{CAP}_k \geqslant \chi E_{\mathrm{TOT}}, \tag{10}$$

where E_{TOT} is the overall power (in MW) required in the area, and χ is the minimum percentage that makes the use of biomass worthwhile.

2.4.6. *Constraints over the thermal energy produced*

Accurate analysis in the region of interest allows the establishment, in connection to each possible plant, of the potential catchment area, i.e., the set of users (houses, small industries, public services) that can satisfy their thermal energy needs and can technically receive thermal energy coming from that plant. Such a set can be identified on the basis of the distances of users from the plant, and/or of technical features of the various users. In any case, in the proposed model no user-to-plant assignment problem is considered, since the possibility of having a user that can alternatively receive thermal energy from two different plants is unrealistic. This is also due to the fact that, in this model, the existence of plants for thermal energy production is not a matter of discussion, as is for their sizing.

Thus, it is reasonable to suppose that the produced thermal energy is less or equal to the potential demand, but greater than a minimum percentage of such a demand. This constraint can be formalized as

$$\beta \cdot E^k \leqslant \mathrm{CAP}_k \eta_\mathrm{t} y_k \leqslant E^k, \quad k = 1, \ldots, K, \tag{11}$$

where E^k is the need, in MW, of thermal power, as regards the catchment area relevant to the kth plant, and β is the minimum percentage of thermal power that is necessary to guarantee.

2.4.7. *Constraints defining binary variable γ_k*

Finally, the following constraints are introduced in order to impose that $\gamma_k = 1$ whenever $y_k < 1$

(i.e., whenever plant k produces electric energy).

$$q\gamma_k - (1 - y_k) \geqslant 0, \quad k = 1,\ldots,K, \tag{12}$$

where q is a very large number compared to the possible values of y_k.

3. System implementation

A system has been implemented according to the optimization model described above which allows experts to plan biomass exploitation in a region. To support the decision, the DSS is based on three modules:

- the GIS-based interface for the characterization of the problem and for the computation of the parameters involved in the problem formulation;
- the database where data characterizing the problem are stored;
- the optimization module.

To define the problem from a geographical standpoint, the experts can view the region in a GIS-oriented interface. The territory is divided into parcels, characterized by an associated prevalent type of biomass.

As a first step, the experts can customize their problem, planning both forests eligible for biomass collection and sites to locate the energy conversion plants. By default, the system appoints all the parcels as eligible. However, the experts are allowed to exclude those parcels that they do not intend to consider for harvesting in any case (for example, because they are inaccessible, or are protected), or to add other biomass collection sites, such as biomass derived from agriculture/industrial production. In addition, the experts can define the eligible sites where a plant has to be built.

As a second step, some important characteristics of the system are computed. More specifically,

- the average biomass quantity x_i associated to each parcel can be manually entered in the system or computed as a function of the area of the parcel and its features, such as the mean and the standard deviation of the slope and the prevalent kind of biomass;
- the travel costs between each eligible parcel and each eligible plant are computed using GIS functionalities.

As a third step, the optimization procedure is performed. When this has been carried out, the output of the system is shown on the map, and displays the parcels on which harvesting is most convenient.

The GIS module has been implemented in Visual Basic 6.0, using ESRI MapObject2.1 and Microsoft Mappoint 2002 facilities. For a suitable management of the information, the data planned in the GIS module and the results deriving from the optimization module are stored in a relational database. The database is implemented in MS Access 2000.

The optimization module has been developed according to the model described in the previous sections. The optimization module has been defined using Lingo 6.0, by Lindo System. Communication with the database is managed by a proper ODBC (Open DataBase Connectivity) interface, while the optimization module is realized by a specific Lingo component. The system has been preliminarly applied to the Savona district of the Liguria region (Italy).

4. Application to a case study

The system was applied to the consortium of municipalities in the mountain region of Val Bormida (Savona district, Italy). This region counts 42,000 inhabitants, and the overall energy demand (including industrial activities) is 105 $\mathrm{MW_t}$ and 136 $\mathrm{MW_e}$/year. The area of Val Bormida (about 500 km^2) is covered nearly entirely by natural forest vegetation (mostly homogeneous hardwood forest).

To model the optimization problem, the area was divided into 370 parcels characterized by one of four main types of biomass (beech, oak, chestnut, conifer) located in various parts of the region. In addition, the biomass waste coming from ten industrial sites was taken into account.

The local authority aims to install six biomass-to-energy plants (see Table 1). The number of plants is due to the specific interests of six municipalities, each of which had identified a site where to build a thermal energy plant.

The decision on the energy production technology (biomass combustion) had also been fixed. These plants—and consequently the installation and electrical and thermal energy distribution costs—were evaluated to last for an average life span of 20 years.

Table 1
Results of the optimization problem with $\chi = 10\%$

k	Plant site	γ_k	y_k	CAP_k
1	Altare	0	1	3.03
2	Cairo Montenotte	0	1	17.35
3	Calizzano	0	1	2.02
4	Carcare	0	1	7.04
5	Mallare	1	0.25	4.89
6	Millesimo	0	1	3.96

For several reasons (environmental, social, political, etc.), a target of the local authority was to ensure that the overall energy need in that area is satisfied at a minimum percentage of 10% by biomass exploitation.

On the other hand, decision makers do not have a clear idea about several aspects of the problem:

- the definition of the optimal size, in terms of energy production, of each plant;
- the definition of the optimal quantity of thermal and electric energy to be produced in each plant;
- the definition of an optimal exploitation plan of the parcels.

Thus, the DSS presented here can be used to assist them in their decisions. In the following subsections, the results achieved by the optimization problem for several parameter specifications are presented. In all problems, $CAP_{min} = 0$ MW, $CAP_{max} = 36$ MW, and α_i was set to either 5% or 1% according to the regulations for the specific type of biomass present in parcel *i*. In Section 4.1, the optimal solution for $\chi = 10\%$ is presented (i.e., when the minimum percentage that makes the use of biomass energy worthwhile is assumed to be 10%), whereas Section 4.2 reports the sensitivity analysis with respect to parameter χ. A further sensitivity analysis was carried out on parameters E_k (i.e., the need for thermal power, as regards the catchment area relevant to the *k*th plant). Finally, an evaluation of the environmental impact of the installations is reported.

4.1. Optimal planning with $\chi = 10\%$

Table 1 reports the optimal values of the decisional variables obtained by solving the optimization problem for $\chi = 10\%$. The optimal value of the objective function is in this case about 621,000 €/year. It turns out that only 1.9% of the total biomass quantity present in Val Bormida is actually exploited, providing an overall energy production which amounts to about 14% of the whole energy demand.

In the optimal solution, electric energy is produced in only one of the plants, namely the one located near the town of Mallare. This is due to the fact that a low thermal energy requirement is specified for the Mallare municipality. Thus, since in the proposed formulation the installation of a plant in that municipality is imposed, electric energy production becomes convenient.

4.2. Sensitivity analysis with respect to parameter χ

In the proposed approach, not only is the optimal solution determined: it is also possible to perform a sensitivity analysis of the optimal solution with respect to the various parameters characterizing the problem statement. In this connection, several tests have been carried out. First of all, the sensitivity analysis was performed on the value of parameter χ, which represents the minimum percentage of the overall energy required by the region that must be guaranteed using biomass. In this respect, the convenience to increase the lower bound on the energy production, i.e., to increase the value of χ, was examined. Fig. 1 shows that for small values of χ (up to 16%), the optimum value of the objective function is nearly constant, but for higher values, costs increase exponentially. This results from a marked increase in the biomass needed, and, consequently, from an increase of the transportation and collection costs to exploit poorly accessible parcels. It is worth noting that for values greater than 22%, there is insufficient available biomass—according to current regional regulations (see constraints (6))—for the production of the required energy. On the basis of these results it can be affirmed that a reasonable choice for the value of parameter χ is 16%.

4.3. Sensitivity analysis with respect to parameters E_k

A second sensitivity analysis was carried out on the values of parameters E_k (appearing in constraints (11)).

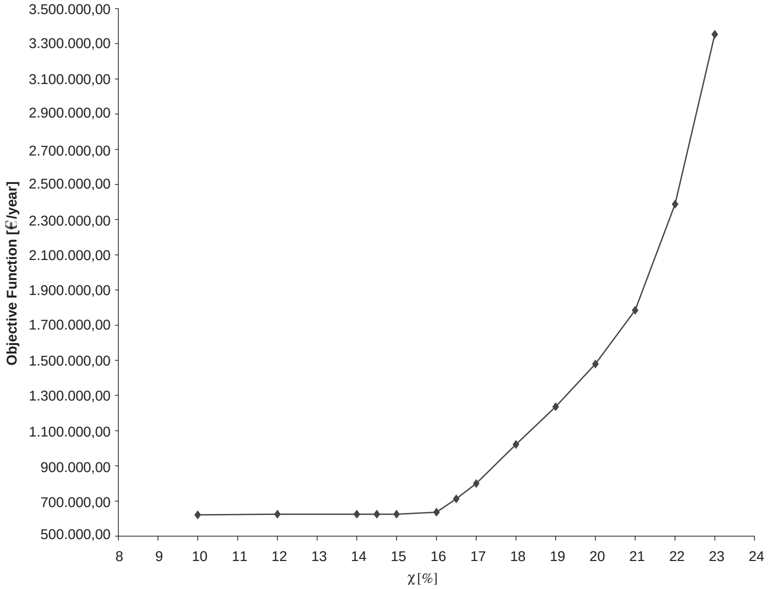

Fig. 1. Overall costs versus percentage of energy produced by biomass.

In this analysis, parameter χ is imposed to be equal to 16%. In constraints (11), the decisional variables y_k, that represent the percentage of thermal energy to be produced, are all set to one, i.e., no production of electrical energy is allowed in any plant. In addition, E_k is imposed to be the same for all plants, increasing it in the sensitivity analysis from 5 to 25 MW. The parameter β is set to 0 in order to avoid lower bounds to the CAP_k decisional variables that are more restrictive than those given by constraints (9). This sensitivity analysis has the purpose of evaluating the plants that are better positioned in relation to the biomass flows from the various parcels. Although this analysis was performed only with reference to thermal energy request, its results can be extended to more general plants for energy production. In fact, the quality of the location of each plant is evaluated, as is its optimal size, only from the viewpoint of the ease of feeding it with the biomass available in the region.

Fig. 2 summarizes the results obtained. For lower thermal demands (less than 13 MW), the capacity of each plant was equal to the thermal energy demand; in this case, each plant satisfies the energy demand through the use of biomass coming from parcels where harvesting is cheaper. For thermal demands greater than 13 MW, the biomass coming both from harvesting and from the waste of local production activities is not able to feed the overall demand of the plants. So, depending on their positions, the sizes of the various plants in the optimal solution become different: the plants that are most suitable for the transportation cost of biomass turn out to have capacities corresponding to the maximum thermal energy request, while others whose positioning is less favourable, turn out to have a lower size. For the specific case study, the Altare and Mallare sites seemed to be the most convenient, while Cairo Montenotte provided the least fitting location.

4.4. Environmental considerations

The solution obtained in the optimal case also allowed deriving additional information, for instance, on how to deal with environmental externalities. The solution of the optimization problem reported in Section 4.1 shows that 621,000 €/year must be spent for an energy production of 14% from forest biomass resources. Considering that the cost for receiving this amount of energy is presently about 236,000 €/year, an extra contribution of 385,000 €/year would allow energy production from renewable resources. This fact must be evaluated along with the environmental impact of the proposed solution. More specifically,

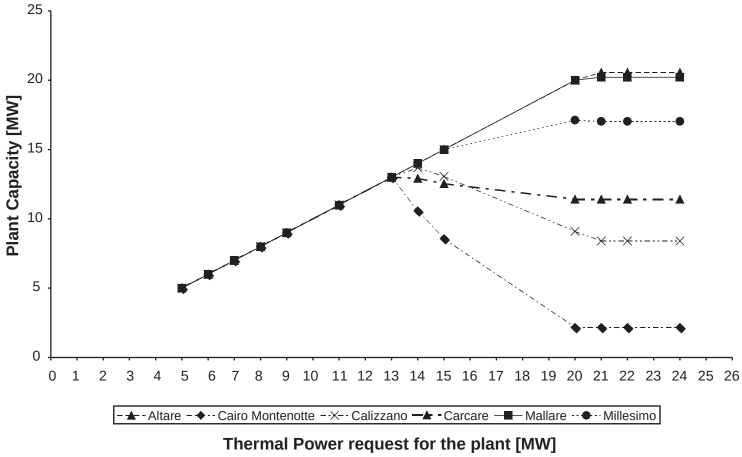

Fig. 2. Plant capacities versus thermal power request for each of the plants.

Table 2
Emissions when different combustibles are used to produce 14% of the energy in Val Bormida

	Comparisons			
Combustible	SO_2 (g)	NO_x (g)	Dust (g)	CO_2 (g)
Coal	78,856,810	78,868,314	19,702,699	8,875E + 10
Natural gas	111,651,504	76,690,309	0	3,827E + 10
Oil	111,651,504	84,560,652	38,968,263	8,001E + 10
Biomass	220,485	46,972,814	5,751,773	1,256E + 09

again considering an energy production of 14% from forest biomass, CO_2 emissions deriving from the full production of biomass based energy (including transportation and collection) are about 1250 t/year [17], while they amount to nearly 69,000 t/year using current sources.

A further environmental analysis was carried out, evaluating all emissions in case other combustibles were used to produce the same quantity of energy. Table 2, also obtained taking into account literature data [17], compares SO_2, CO_2, NO_x, and dust emissions when biomass, oil, natural gas, and coal, respectively, are used for the 14% energy production target.

5. Conclusions and future research directions

National and European laws dealing with forest wealth management recommend that, in case a municipality wishes to manage its wooded area even with minimal interventions, a twenty-year management plan of the area has to be presented. These plans are frequently autonomously designed, without any coordination among neighbouring municipalities.

This work presented the problem of defining an optimal exploitation plan of the biomass for a consortium of municipalities in an Italian mountain region. The main innovation proposed regards the definition of a comprehensive quantitative approach, based on a DSS that can suggest actions and policies to boost biomass utilization. Specifically, with this approach it is possible to plan biomass exploitation in a region, sizing the plants and verifying the performance of the overall system. This tool could be used to suggest how to obtain energy from biomass not only where biomass surplus or residuals are produced or purposely harvested, but also where they are naturally available. More specifically, in this work the available biomass present on the territory is divided into parcels (of different areas) that correspond to the areas that are characterized by a predominant biomass type. This structure allows determining the parcels to be exploited, thereby ensuring that such exploitation is sustainable for the ecosystem, as well as correctly evaluating the costs of forest biomass collection. As a result, it is possible to take into account the energy needs of the studied area, the commitment to using renewable resources, and the necessity of controlling the forest ecosystem.

A further innovative feature of this approach lies in the application of mathematical optimization technologies integrated with a GIS and a database, whose information has to be gathered through experimental tests and interaction with experts. The proposed approach is quite general, as it can be extended to different regional situations.

The results obtained on a small Italian mountain territory show that only a relatively small fraction (16%) of the energy need in the area can be satisfied at a reasonable cost by biomass combustion energy. In addition, this production mainly satisfies local thermal energy demands, while electric energy is produced only when the demand to a certain plant is low. It is important to note that environmental externalities, such as enhanced control of the territory due to wood collection, should be taken into account.

Many issues must still be explored, namely, the influence of local energy production policies based on renewable sources on global world pollution reduction, the need for an accurate evaluation of government contributions to local activities for direct and indirect environmental protection, and the specific need for technologies that improve the efficiency of energy production by diminishing costs and the environmental impact.

Future work entails the development of a DSS that can support the definition of biomass exploitation plans (plant site definition, plant size definition, collection scheduling, etc.) different for each year. Specifically, the development and the calibration of an accurate model to represent biomass growth dynamics is being studied and, in this case, the application of dynamic optimization approaches should replace an approach based only on the application of mathematical programming. Finally, the possibility of using different types of conversion plants, with special attention to technologies applying a higher efficiency such as gasification plants [18], will be also examined.

Acknowledgements

The authors are grateful to the Savona District Council (Italy) for their collaboration in the development of the decision model and in its application to the case study.

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