Brigham Young University
BYU ScholarsArchive

International Congress on Environmental Modelling and Software

1st International Congress on Environmental Modelling and Software - Lugano, Switzerland - June 2002

Jul 1st, 12:00 AM

Renewable energy: a decision support system for forest biomass exploitation

D. Freppaz

R. Minciardi

M. Robba

Roberto Sacile

A. Taramasso

Follow this and additional works at: https://scholarsarchive.byu.edu/iemssconference

Freppaz, D.; Minciardi, R.; Robba, M.; Sacile, Roberto; and Taramasso, A., "Renewable energy: a decision support system for forest biomass exploitation" (2002). *International Congress on Environmental Modelling and Software*. 215.
https://scholarsarchive.byu.edu/iemssconference/2002/all/215

This Event is brought to you for free and open access by the Civil and Environmental Engineering at BYU ScholarsArchive. It has been accepted for inclusion in International Congress on Environmental Modelling and Software by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

Renewable energy: a decision support system for forest biomass exploitation

D. Freppaz[b], R. Minciardi[a,b], M. Robba[a], R. Sacile[a,b], A. Taramasso[b]

[a]*DIST, Department of Communication, Computer and System Sciences*
University of Genova, Via Opera Pia 13, 16145 Genova – Italy.

[b]*CIMA, Center for Environmental Monitoring Research*
Via Cadorna 7, 17100 Savona – Italy

Abstract: A decision support system for forest biomass exploitation for energy supply is presented. In the proposed approach, geographic information system based techniques are integrated with mathematical programming methods yielding a comprehensive system, which allows formalizing the problem, taking decisions, and evaluating their effects. The aim of this work is to evaluate the possibility of biomass exploitation for both thermal and electric energy production in a provincial area. The decision support system is able to locate and size different kinds of plants on the territory (defining which kind of energy is convenient to produce for the specific area), take into account several aspects (such as economic, technical, normative, and social), offer a user-friendly interface, and decide how to plan biomass collection and harvesting. Biomasses are present in the territory in different locations. In this work, i parcels of different areas have been considered, each of them being characterized by a predominant biomass typology. Then, k possible locations for the plants have been taken into account.
The decisional variables to be determined reflect the main problems to be solved for the system; specifically they represent: the quantity of biomass i that must be harvested, the quantity of biomass i collected and transported to a specific plant k, the specific plant size, the quantity of thermal energy produced in a specific plant, and the quantity of electric energy to be produced by a specific plant. The cost function to be minimized takes into account installation, maintenance, transportation, collection, and energy distribution costs and possible benefits. The formulation of the problem includes constraints about the maximum quantity of biomass that can be exploited (established by normative or technical issues), technical aspects about the size of plants, and the need of thermal energy for the specific area. Finally, a case study is presented.

Keywords: *Decision support system, renewable energy, biomass, Geographic Information System, optimization*

1. INTRODUCTION

The conference of Kyoto (1997) defined the main issues concerning sustainable development. Energy is necessary for human life, but the actual production takes place with technologies that are considered not sustainable. The use of renewable energy sources is a fundamental factor for a responsible energy policy in the future. European Union indicates that the objective is to double, within year 2010, the contribution for energy production from renewable resources (from 6% of 1996 to 12% of 2010). Renewable biomass energy occupies an important position and plays a decisive role in the present world energy structure. According to statistics, one seventh of the total world energy consumption is from biomass. Quantitative analysis about strategies for renewable energy sources from biomass has been performed either evaluating the potential resources of bioenergy in different kind of countries (Hall and Scrase, 1998) or matching the woody biomass demand and supply by the forest industries in Europe (Kuiper et al., 1998).

Decision support systems (DSS's) have been proposed to help biomass management for energy supply at a regional level. Nagel has recently proposed a methodology (Nagel., 2000a), tested in the state of Brandenburg, Germany (Nagel., 2000b), to determine an economic energy supply structure based on biomass. The problem is formulated as a mixed-integer linear optimization using the dynamical evaluation of economic efficiency. Nagel's works focus on many aspects such as the user typology that can benefit from biomass use for energy supply, on the dimension and typology of heating plants, and on the sensitivity of the decision with respect to fuel costs. In addition, since biomass can help CO2 emissions, an economy effort should be dedicated to establish CO2 taxes or state subsidies for biomass-fired energy conversion plants.

The territorial evaluation, involving geographical, environmental and socio-economic characteristics of the region are also very important aspect in the decision modeling of biomass management. In this respect, Geographic Information Systems (GIS) based approaches have been recently proposed. Noon and Daly (1996), have proposed a GIS-based Biomass Resource Assessment, Version One, called BRAVO. Such a system was defined as a computer-based DSS to assist the Tennessee Valley Authority in estimating the costs for supplying wood fuel to any one of its 12 coal-fired power plants. In BRAVO, the GIS platform allows for the efficient analysis of transportation networks, so that accurate estimates of hauling distances and costs can be determined.

The aim of this work is to evaluate the possibility of biomass exploitation for both thermal and electric energy production in a provincial area. The decision support system is able to locate and size different kinds of plants on the territory (defining which kind of energy is convenient to produce for the specific area), take into account several aspects (such as economic, technical, normative, and social), offer a user-friendly interface, and decide how to plan biomass collection and harvesting. Specifically, the system is modelled taking into account the available quantities of the various biomasses present on the territory and the location of plants for energy production. A cost function, to be minimized, and several constraints have been formulated. The available data and results can be displayed in a GIS, through which it is also possible to add and modify data from the map.

2. THE DECISION PROBLEM

A regional authority wants to evaluate the harvesting of forest biomass for energy production using combustion plants in a small medium territory (less than 1500 Km^2) mainly characterized by mountainous territory covered by spontaneous vegetation. The motivation of this decision is to join advantages given by an autonomous energy production, and environmental and social advantages, such as an improvement of the territory control that should be related to a reduction of forest fire risk, a reduction of CO2 emission for energy production and an improvement of social and work activities in rural areas. Biomasses are present in the territory in different locations. In this work, $i=1,...,N$ parcels of different areas have been considered, each of them being characterized by a predominant biomass typology. These parcels have also different characteristics, that are, for example, different slope variability and human accessibility. In this territory, k=1,...,K locations for plants for energy conversion from biomasses have been identified. These plants may produce both electric and thermal energy. The main objective of this work is to define a decision support system able to:

- verify that the chosen locations for plants are convenient
- size the various plants and determine the quantity of thermal and electric energy to produce
- find the optimal biomass flows to plants and the parcels to be exploited for energy production

2.1 Decisional variables

The decisional variables necessary to describe the physical reality and to define the objective function and the constraints are:

- $\mathbf{u_i}$: the annual biomass quantity, in m^3, harvested in the *i-th* parcel;
- $\boldsymbol{\varphi_{ik}}$: the biomass quantity, in m^3, that is yearly sent to the *k-th* plant from *i-th* parcel;
- $\mathbf{CAP_k}$ is plant capacity, in MW, of a plant in the k-th location;

- $\mathbf{y_k}$ represents the percentage of thermal energy produced by the *k-th* plant ,
- $\boldsymbol{\gamma}_{\mathbf{k}}$ is a binary variable that is equal to 1 when the plant produces electric energy, 0 otherwise.

2.2 The objective function

The objective function takes into account all costs and benefits in the system. Specifically, collection, transportation, harvesting and plant costs are considered, together with benefits from the selling of thermal and electric energy. The objective function to be minimized is composed by the following five terms:

- **G**: benefits deriving from the selling of energy produced
- $\mathbf{C_P}$: plant costs related to installation and maintenance of plants
- $\mathbf{C_T}$: transportation costs
- $\mathbf{C_C}$: the biomass harvesting costs
- $\mathbf{C_D}$: costs due to the distribution of energy

2.2.1 Energy production profits

Assuming that all plants have the same efficiency, the profit from energy production is given by:

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

being

$$C_i = \frac{1}{f} \cdot PCI \cdot MV_i$$

where

- PCI is heating value, assumed constant for biomasses with 30-35% of humidity, and is equal to 11,3 MJ/Kg**;**
- η_t is thermal efficiency for the plant considered;
- η_e is electric efficiency for the kind of plant considered;
- f is a conversion factor, whose value is 3,6 MJ/kWh**;**
- C_t is unit benefit (€/kWht) for the selling of thermal energy;
- C_e is unit benefit (€/kWhe) for the selling of electric energy;
- MV_i is biomass density (Kg/m^3)

2.2.2 Plant costs

Plant costs are related to installation and maintenance of a plant. There are both fixed and variable costs, namely:

$$\mathbf{C_P} = \sum_{k=1}^{K} \begin{bmatrix} (CF_k + CV_k \mathbf{CAP_k}) + \\ (CFE \cdot \boldsymbol{\gamma}_{\mathbf{k}} + CVE(1 - \mathbf{y_k})\mathbf{CAP_k}) \end{bmatrix} \tag{2}$$

where

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

2.2.3 Transportation costs

Transportation costs can be expressed as:

$$\mathbf{C_T} = \sum_{i=1}^{N} \sum_{k=1}^{K} C_{TR} \cdot \boldsymbol{\varphi}_{\mathbf{ik}} \cdot MV_i d_{ik} \tag{3}$$

where:

- C_{TR} is unit cost for transport in €Kg^{-1}Km^{-1};
- MV_i is biomass density;
- d_{ik} is distance, in Km, from parcel *i* to location *k.*

2.2.4 Collection costs

Collection costs depend on different factors such as difficulty of harvesting and quantity of collected biomass. They can be written as:

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

where Cr_i is collection unit cost, in €/Kg, for *i-th* parcel.

2.2.5 Costs for the distribution of energy

Energy distribution costs are expressed by.

$$\mathbf{C_D} = \boldsymbol{\gamma}_\mathbf{k} \sum_{k=1}^{K} \sum_{j=1}^{z} \left(C_{de} L_{kj} + C_{cab} \right) \qquad \textbf{(5)}$$

where:

- C_{de} is unit cost, in €/Km, of electric energy distribution (15 KV);
- L_{kj} is distance, in Km, between plant in the k-th location and the j-th user;
- C_{cab} is fixed cost for distribution of electric energy.

2.2.6 The overall cost function

The overall cost function to be minimized is given by:

$$\mathbf{C} = -\mathbf{G} + \mathbf{C_P} + \mathbf{C_T} + \mathbf{C_C} + \mathbf{C_D} \qquad \textbf{(6)}$$

2.3 The constraints

The formalization of the overall problem can be obtained by introducing the following set of constraints, which have to be taken into account in the minimization of **(6)**.

Restrictions on forest biomass collection
For each cell, the overall quantity of biomass that can be collected is supposed to be limited, in relation to the biomass quantity x_i, by the following constraint.

$$0 \le \mathbf{u_i} \le \alpha_i x_i \qquad i=1,...,N \qquad \textbf{(7)}$$

where α_i is the maximum percentage of biomass that can be collected in parcel *i*, and x_i is quantity actually present on the territory. Obviously, α_i must be set to a value which, 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.

Mass balance
The biomass flow coming out from a parcel (i=1,...,N) and that is sent to different plants (in location k, k=1,...,K) must be equal to the overall biomass collected in the parcel, that is

$$\sum_{k=1}^{K} \boldsymbol{\varphi}_\mathbf{ik} = \mathbf{u_i} \qquad i=1,...,N \qquad \textbf{(8)}$$

Biomass flow constraints
The biomass quantity entering a specific plant must be equal to the plant capacity. This can be represented by the following constraint:

$$\frac{1}{31536000} \cdot \sum_{i=1}^{N} \boldsymbol{\varphi}_\mathbf{ik} \cdot PCI \cdot MV_i = \left(\frac{\mathbf{CAP_k y_k}}{\eta_t} + \frac{\mathbf{CAP_k}\left(1-\mathbf{y_k}\right)}{\eta_e} \right) \qquad \textbf{(9)}$$

$k=1,...,K$

Production plant constraints
The plants are supposed to operate under a maximum and minimum production threshold constraint. This can be expressed imposing that each plant must produce at least CAPmin (in MW), and at most CAPmax (in MW).

$$\text{CAPmin} \le \mathbf{CAP_k} \le \text{CAPmax} \qquad k=1,...,K \qquad \textbf{(10)}$$

Minimum energy recovery
A constraint imposing that the quantity of energy produced through renewable sources must be at least equal to a fixed percentage of the power required by the considered area. Specifically, the constraint is:

$$\frac{1}{31536000} \cdot \sum_{i=1}^{N} \sum_{k=1}^{K} \boldsymbol{\varphi}_\mathbf{ik} \cdot PCI \cdot MV_i \ge \chi \cdot E_{TOT} \qquad \textbf{(11)}$$

where E_{TOT} is the total energetic need for the studied area, and χ is the minimum percentage that makes the intervention relevant.

Constraints over the thermal energy produced
A precise analysis on the studied area allows to establish the number of users (houses, small industries, public services) interested in satisfying their need of thermal energy. The produced thermal energy must be less or equal to the demand, but greater than a minimum percentage of this demand to justify the construction of the plants. This constraint can be formalized as follows:

$$\beta \cdot E^k \le \mathbf{CAP_k}\eta_t \mathbf{y_k} \le E^k \quad k=1,\ldots,K \qquad \textbf{(12)}$$

where E^k is the need, in MW, of thermal energy for the k-th plant and β is the percentage of thermal energy that it is necessary to guarantee.

Constraint defining binary variable γ_k
The following constraint is introduced in order to impose that $\gamma_k = 1$ whenever $\mathbf{y}_k < 1$ (i.e., whenever in plant *k* electric energy is produced).

$$q\gamma_\mathbf{k} - (1 - \mathbf{y_k}) \ge 0 \qquad k=1,\ldots,K \qquad \textbf{(13)}$$

where q is a big number respect to the possible values of $\mathbf{y_k}$.

2.3 Problem structure and software implementation

The overall problem defined in the previous subsections turns out to be a nonlinear mixed problem (i.e., characterized by the presence of continuous and binary variables).
A system allowing experts to plan the biomass exploitation in a region according to the previous optimization model has been implemented. To support the decision, the EDSS is based on three modules:

– the GIS based interface for the characterization of the problem and for the computation of the relevant parameters;
– the database;
– the optimization module.

To define the problem from a geographical point of view, the experts can view the territory by a GIS oriented interface (figure 1). The territory is divided in parcels, each of them being characterized by a prevalent kind of biomass.

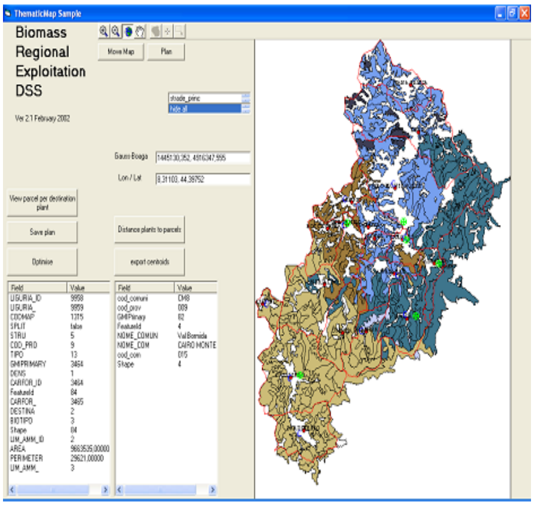

Figure 1. The GIS application interface. The region shown in the picture is the Savona district.

3. APPLICATION TO A CASE STUDY

The system has been applied to the consortium of municipalities in the mountain region of Val Bormida (Savona district). This region is covered for almost all its area (about 500 Kmq) by natural forest vegetation (mostly homogeneous hardwood forest). In this preliminary approach, this area has been divided in 370 parcels and five typologies. Six sites for biomass-to-energy conversion plants have been taken into account.

Table1 : results of the optimization problem

Plant	Y	CAP (MW)	CAPtherm	CAPelectr
Altare	1	3,03	3,03	0
Cairo Montenotte	1	17,35	17,35	0
Calizzano	1	2,02	2,02	0
Carcare	1	7,04	7,04	0
Mallare	0,30	5,33	1,62	3,71
Millesimo	1	3,96	3,96	0

The mathematical problem is non linear with 2672 continuous and 6 binary variables. The optimization problem has been solved by use of the optimization software Lingo 6.0 requiring less then one minute of computation. The optimal value of the objective function is about 636000 €. It represents the yearly amount of money to be spent to produce the required amount of energy in Val Bormida from renewable sources. Table 1 reports optimal value of the decisional variables obtained by solving the optimization problem. Parcels that must be exploited for the optimal planning of the system are highlighted in Figure 2. Figure 2 graphically highlights the parcels whose biomass is exploited in the optimal solution.

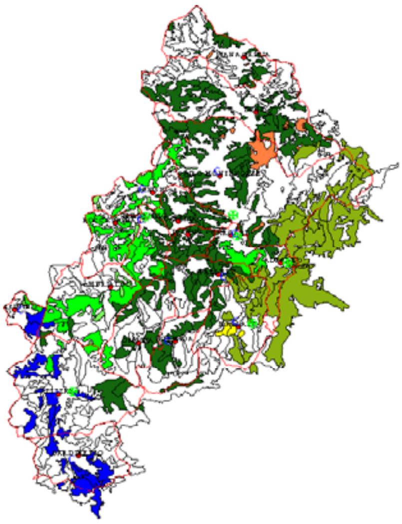

Figure 2: parcels exploited in the optimal solution

Finally, a sensitivity analysis has been performed with respect to the value of parameter χ, which represents the percentage of the overall energy required by the area that must be satisfied using biomass as combustible. Figure 3 reports the results of this sensitivity analysis. At first, only thermal energy is produced and costs are the same. When producing electric energy too, costs arise exponentially with the percentage of total energy required. Around $\chi = 22\%$ there is no sufficient quantity of biomass in Val Bormida to produce more energy.

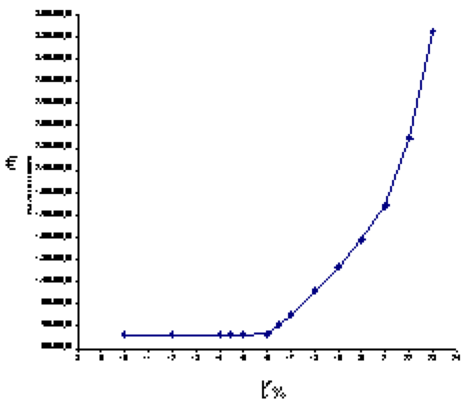

Figure 3: overall costs versus percentage of energy produced by biomass

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

In the proposed DSS, geographic information system based techniques are integrated with mathematical programming methods yielding a comprehensive system, which allows formalizing the problem, taking decisions, and evaluating their effects. Specifically, it is possible to plan biomass exploitation, to size the plants and to verify the location of a specific plant. Further research on this topic will be devoted to the development and the calibration of an accurate model of the biomass dynamics growth. In such a case, the application of optimal control approaches should replace an approach based on the application of mathematical programming.
Finally, the possibility of using different typologies of plants, such as gasification plants, can be taken into account.

5. ACKNOWLEDGENENTS

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

6. REFERENCES

Hall, D.O., and J.I. Scrase, Will biomass be the environmentally friendly fuel of the future? *Biomass and Bioenergy*, 15(6), 451-456, 1998.

Kuiper, L.C., and R.J.A.N Sikkema Stolp, Establishment needs for short rotation forestry in the EU to meet the goals of the Commission's White Paper on renewable energy, *Biomass and Bioenergy*, 15(4-5), 375-367. 1998.

Nagel, J., Determination of an economic energy supply structure based on biomass using a mixed-integer linear optimisation model, *Ecological Engineering*, 16 S91-S102, 2000a.

Nagel, J., Biomass in energy supply, especially in the state of Brandeburg, Germany, *Ecological Engineering*, 16 S103-S110, 2000b.

Noon, C.E., and M.J. Daly, GIS-based resource assessment with BRAVO, *Biomass and Bioenergy*, 10 (4-5), 101-109, 199