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Cost-benefit Analysis with GIS: An Open Source Module for the Forest Bioenergy Sector

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Abstract

This paper introduces a novel methodology for the optimal use of forest biomass for energy purposes, by means of GIS procedures. The method allows the identification of the most suitable area for a power plant, starting from the energy demand and the local availability of wood resources. After the site identification, the procedure conducts a cost-benefit analysis, including financial and environmental flows. The described methodology has been automatized in GRASS GIS, which is a free and open source GIS software, and now constitutes a downloadable add-on. In this contribution, we tested such procedure in a case study in Italy, the alpine valleys of Gesso and Vermenagna in Piedmont region (North-West of Italy).

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Keywords: cost-benefit analysis; energy power plant; environmental values; renewable energy

1. Introduction

One of the major concerns, when planning the creation of a power plant fueled with biomass, is the economic feasibility of the investment. The energy potential of the local biomass is highly uncertain, as well as the local energy demand. For this reason, an accurate planning of the activities and analysis of the available data is crucial for a successful development of a new power plant. Starting from these consideration, the present contribution proposes

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a novel methodology for estimating the economic feasibility of a new power plant. The procedure takes into account local forest and environmental data to estimate the energy potential harvestable from a certain area. Based on local geographical data and energy consumption density, the positioning and size of the power plant could be further assessed. Finally, a cost-benefit analysis (CBA) is implemented, allowing a comprehensive exploration of the economic convenience of a potential investment, by calculating the net present value of the investment (NPV). CBA may be implemented in several ways and may include social and environmental externalities, which are useful in particular when the potential investor is a public institution [1,2]. In the literature it is possible to find DSS for the estimation of biomass potential [3,4], however most of them do not consider the economic feasibility of the power plant. Our procedure attempts to fill this gap by introducing new tools for CBA. The procedure is part of a set of decision support system (DSS) for energy planning, called "r.green", realized ad add-ons for GRASS GIS. The procedure has been tested in a case study in the Italian Alps, the Gesso and Vermenagna valleys. We propose three scenarios. In the first one, the hypothetical investor is a private entrepreneurship, thus only financial flows are considered. In the second and third scenario the investor is supposed to be a public institution, which is interested not only to financial aspects but also to social and environmental concerns. In the second scenario we add a measure of the social benefit of a new power plant, which is given by people´s willingness to pay (WTP) for renewable energy. The third scenario adds to the second the environmental impacts, thus even the expected variation of the forest capital is included

2. Materials and methods

r.green is a set of DSS created for the estimation of energy potential from different renewable sources. At the present stage of development, *r.green* includes solar energy, hydropower and forest biomass [5]. The model for the estimation of the forest biomass potential is called *r.green.biomassfor*. The structures of the models are very similar and are organized in several modules. In particular *r.green.biomassfor* has 4 main modules (called theoretical, legal, recommended and economic potential), this paper describes a fifth module (which is called r.green.biomassfor.plant), useful for siting the power plant and for CBA. Each module adds some form of constrains and take into account several environmental data in order to refine the estimation [6]. The interested reader may find more information about this suite of GRASS add-ons in [5, 7-10]. The procedure for *r.green.biomassfor.plant* is conducted in two stages. The first step involves the computation of forest and environmental data for estimating the energy potential of the local forested area, the size and siting of the power plant [11, 12]. The second step is the economic analysis.

Estimating the energy potential. The environmental analysis involves processing forest data, in order to estimate the energy potential of the considered forest. This part of the analysis is conducted by calling the functions of other *r.green.biomassfor* modules, previously introduced [13].

Siting power plant. This part of the analysis is conducted with the new module, "r.green.plant", and it represent the main novelty of this contribution. Positioning of the power plant is based on the energy demand. The module tries to accomplish the energy demand of a given area by means of a forest biomass power plant. In particular, a raster map with the present level of energy consumption is required. The procedure identifies the pixel with the highest energy demand then, from this point, additional pixel are added to enlarge the area to be served by the plant. The program calculates the average energy demand of the extended area and if it is above a given threshold it continues adding neighboring pixels. The process stops when energy demand is below the threshold, because the investment is considered not feasible. The threshold is set by default at 400 Mwh/ha per year, but it can be modified by the user. Once the area is identified, the size of the power plant is hypothesized, based on the total energy demand of the identified area and the forest biomass availability. In particular, the module computes the total energy demanded by the area and the total potential that may be extracted from the forest. In order to avoid oversizing, the minimum value between energy demand and forest biomass availability is considered. The idea is that the maximum quantity of local forest biomass should be exploited, so the power plant should be as big as possible (until the local demand is satisfied) but not so much to have the need to import biomass from outside.

Economic Analysis. This stage is also quite new, because most of the studies in the literature focuses on estimating the energy potential of a given area, with few considerations about new power plants [6,14]. Cost-benefit Analysis (CBA) is an applied economic tool for valuing the economic convenience of a new project. In particular, this procedure considers all the direct and indirect costs and benefits that may be related to a particular project. In the environmental field, such tool is particular effective for including non-market effects connected with a project. Future costs and benefits are discounted in order to identify the net present value of the project; if the NPV is positive then the project is said to be welfare-increasing, according to the Kaldor-Hicks criterion [15]. The CBA formula is the following:

$$NPV = C_0 + \sum_{i=1}^{I}\sum_{j=1}^{J}(1+r)^{-t} * (B_i - C_j)$$

Where C_0 is the initial investment cost, which is not discounted because it occurs in the first year. B_i and C_j are, respectively, the benefits and costs in each t-th year of the project lengths, actualized with a discount rate r. Discount rate and lifetime period may be set by the user, the default are 3.5% and 20 years, respectively. Expected costs and benefits have to be set by the user, with no default. If such data are not included, the financial analysis is not carried out and only a hypothesis about the power plant site is given. Costs and benefits may include financial, social and environmental figures.

3. Application: case study

In order to illustrate the described methodology, we present the preliminary results of a case study in Italy. The area is composed by two alpine valleys, Gesso and Vermenagna, located in the Piedmont region. The land area of the two valleys is approximately 51,500 ha of which about 32,000 ha are situated in protected areas. The main land uses are forests (42%) and pastures (33%). Currently, among RE sources, only water is exploited through some small and large hydropower plants. The extraction of forest residues for energy is currently 10-15% of the potential, even if there are no energy production plants in the area. Energy demand, forest and other environmental data were provided by the local public administration. Financial, social and environmental costs and benefits were estimated by the authors. A detailed description of social benefits and environmental externalities may be found in [16-22].

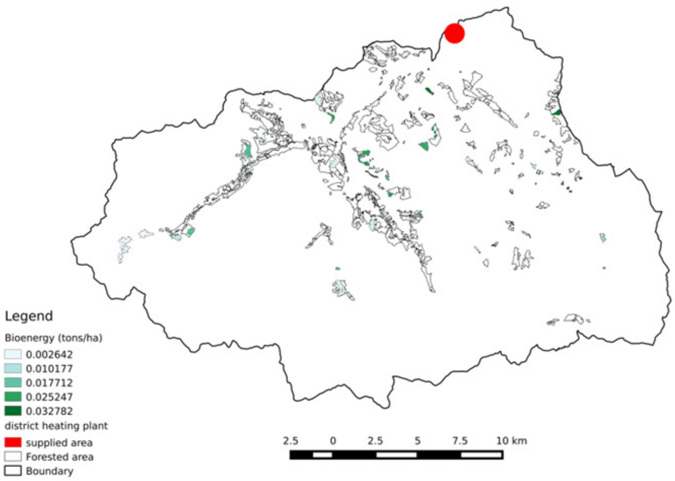

Fig. 1. Supplied area of the dhp and locally available bioenergy

4. Results and discussion

The positioning of the district heating plant is visible in Fig. 1. It was estimated that the power plant may cover an area of approximately 600 m of radius, in which the energy demand density is adequate and the global energy demand is about 19300 Mwh per year. Considering a yearly functioning of 4500 hours (slightly more than 6 month, which is reasonable for an alpine community), a power plant of about 4 Mw would be able to cover the entire energy demand of the area. On the other hand, the analysis of the forest biomass energy potential returned a local availability of around 1300 tons of wood biomass that could be used for fueling the power plant. The local biomass availability is lower than the energy demand and the power plant is set to accomplish this criterion. The size of the power plant is set to 1.2 Mw, because it is the maximum size for using the entire biomass supply of the local forested area.

Scenario 1. The first scenario is related to the standard economic analysis, which might be carried out by a private investor. Investment costs consider the average costs of buildings, machineries, grid connection costs and administrative costs for a power plant of that dimension. For a power plant of 1.2 Mw, we consider a level of investment cost of 1.5 mln €. O&M costs are assessed to be 220.000 € per year consider conversely costs for workers (it is assumed the need of 3 full-employed workers), hashes waste management, insurances, planned and extraordinary maintenance. Fuelwood costs are estimated separately from the model. Considering an average price for woodchip of 75 €/ton and a requirement of about 1300 tons of wood biomass, fuelwood costs are assessed to be 97500 €/year. Economic benefits, given that the power plant is higher than 1 Mw, are estimated to be 18 €cent/Mwh (7 cent for the energy and 11 as incentive from green certificates). Considering a self-consumption of energy for about 800 Mwh, the energy sold is 4600 Mw. According to these figures, the NPV is assessed to be 5.8 mln €. The NPV is positive, thus considering just the financial flows the investment seems to be convenient.

Scenario 2. The second scenario just add WTP in the count of benefit, which should return a higher NPV than the Scenario 1. This may be considered the point of view of a public administration that wants to understand the welfare effect of a new power plant for the community. In this case, WTP represent the perceived benefit of the local inhabitants to enlarge the share of RE production. People reported a WTP 0f 5.2 € per month as an increment of the energy bill, thus 62.4 € per year. Considering 10,000 inhabitants and an average household of 2.5 people, we would have around 4000 users that would buy RE at a higher price, leading to additional 249,600 € of annual benefit. In this case, the NPV is about 9.3 mln €.

Scenario 3. This is the situation in which a public administration not only is the investor of the power plant but also the owner of the forest. In this case, it might be interesting to understand the effect of a power plant project on the entire public asset, i.e. the variation of natural capital value. In this case the expected NPV decreases, because the environmental impact is negative (on average, it was obtained a negative externality of about 50 €/ha). The NPV is positive but lower than the previous scenario, at about 9.1 mln €.

5. Conclusion

The present paper has shown the functioning of a new GRASS GIS add-on, for CBA in the forest bioenergy sector. The module considers a large number of environmental and economic data in order to support planning of new power plants. The procedure has been applied to a case study in the Italian Alps, the Gesso and Vermenagna valleys, to show the functioning. In this case study, the NPV has been proved to be positive in all scenarios, although with some differences. In particular, the scenario with only financial flows shows the lowest NPV, while the higher is given by scenario number 2. This means that local inhabitants have a strong positive opinion of RE and perceive an increase in production as a benefit. When including environmental impacts, NPV is somehow in the middle of the two, still positive but lower than in scenario 2. This is an evidence that the impact on the environment is negative. In all cases, a project of a new power plant can be considered as welfare-increasing, according to the Kaldor-Hicks criterion. The novel aspects of this new procedure are related to its capability to simultaneously consider forest biomass availability, energy demand data, environmental data and financial and non-market figures. In the literature, there are only few studies considering so many variables at the same time and, to the best of the authors´ knowledge, none of them are focused on the implementation of the power plant. This new procedure tries to fill this gap and provide a new and user-friendly methodology. Some drawbacks of the described methodology are related to the huge amount of data required for the implementation. A good detail of forest data, as well as energy demand, is not always available. Further development of the model is planned and, at present, two additional options are expected to be added. One is related to the possibility of automatically reiterating the procedure, so that the user may set more than one plant if necessary. This option may be useful if transportation costs for forest biomass are too high to bring all the available biomass in only one stocking point or the local energy demand is scattered into the considered policy site. The second option will be an additional procedure to run a stochastic sensitivity analysis to the CBA results, by assuming a random distribution of costs and benefits, in order to understand how the NPV changes due to random disturbances on the foreseen figures.

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