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Economic evaluation of forest biomass production in central Italy: A scenario assessment based on spatial analysis tool

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ABSTRACT

A spatial analysis tool, a Decision Support (DS) model able to support decision-making processes related to forestry energy planning has been developed using ecological and economic parameters. In this paper, the relative performance of different forest energy chains were compared by using metrics such as net revenue from forest processes, break-even prices of wood fuels, and the price elasticity of the bioenergy supply. Working with different scenarios at a spatial level, the DS model can evaluate innovative technologies and traditional forest harvest and logistical chains across a range of products, such as firewood and woodchips. The spatial analysis lends itself easily to an analysis of the political and administrative constraints with respect to levels of administration and regional variables.

As expected, applying the tool to the Tuscany region in Italy shows that local characteristics and the species composition of an area influence the economic outcome of different harvest and logistical chains. In particular, mixed species Mediterranean forests appear to be suitable for the implementation of innovative bioenergy production processes, such as Whole Tree Chipping.

1. Introduction

Interest in innovative biofuels in Europe has grown in recent decades with the importance of the twin goals of reducing greenhouse gas emissions and mitigating climate change. The use of this type of energy requires consideration of a set of variables and relationships between socio-economic and environmental factors to implement sustainable bioenergy chains and avoid depletion of natural resources. Natural resource based policies and management decisions are essential to reach these goals [1] and [2].

The “Status of Biomass Resource Assessments” [3] shows an array of methodologies that have been developed to provide in-depth insight into state-of-the-art biomass resource assessments for European forests; the authors of this work analysed the heterogeneity of the results, methodologies and data sources used. These authors also offer an analysis of the relevant literature that depicts the main parameters of the evaluation and includes the following:

- type of biomass potential (ecological, technical, economical, and sustainable);
- approach (demand-driven and resource-focused);
- biomass sources (stem wood, logging residues, early thinning, and stumps);
- geographical coverage (global, national, local, etc.); and
- time frame.

Many papers focus on the quantification of biomass by spatial analysis methodology and Geographic Information

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System (GIS)). The optimal resource allocation considers logistical parameters (resource accessibility and supply chain facilities), bioenergy demand saturation, economic optimisation and carbon dioxide minimisation.

Methodologies that define the bioenergy supply/demand ratio at different administrative levels were proposed by the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) approach [4] and by the Scale approach [5].

Moller and Nielsen [6] evaluated the optimal allocation of woodchips by minimizing transportation costs from forest areas to end-users. Panichelli and Gnansounou [7] developed an analytical methodology to allocate forest biomass in a gasification plant that implemented the BIOAL algorithm. A similar approach can be found in Frombo et al. [8], who developed a mixed non-linear programming methodology able to introduce environmental constraints in the chain evaluation of forest residues. Other economic evaluations of the production process were performed by spatial analysis and scenario assessment [9] [10], and [11]. The minimisation of the carbon footprint in the agroenergy sector was considered in Lam et al. [12] and [13] by utilizing a P-graph algorithm.

The effect of biomass extraction on forest multifunctionality was introduced to assess how it affects social perception [14] and to consider the ecological, technical and socio-economic constraints in different mobilisation scenarios [15].

In the forestry sector, the potential conflict that can be established between biomass used for energy or directed for other uses may be observed in production related to sawmill residue. Depending on the typology of the residue and the market, residues used to produce bioenergy may create a conflict with conventional uses, such as production of panels [16], [17], and [18].

Although several studies have analysed forest biomass availability, only a limited number of studies have considered the potential trade-offs in the production of different wood-energy assortments in the forestry sector. Manley and Richardson [19] investigated and reported on forest management systems in Canada, Sweden, the United Kingdom, and Switzerland. These systems included conventional organisations for managing softwood and mixed wood forests for multiple products and hardwood-oriented systems with an emphasis on the production of biomass for energy.

In this framework, this paper aims to define the potential trade-offs in a forest bioenergy production system by calculating biomass availability and economic indices.

Section 2 presents the methodological approach, the scenario assessment and spatial analysis model characteristics. In section 3, the main results of the study are presented and explained. Finally, section 4 reports conclusions and potential future studies.

2. Methodology

2.1. Study area and dataset

The model was developed and tested in Tuscany, in central Italy. Data from the recent National Forest Inventory [20] highlight that the total regional forest surface is approximately 1,151,000 ha (50.1% of the total surface). Tuscany forests are characterised by strong variations in terms of geomorphology and species composition. The main formations are deciduous broadleaved forests (79%, mainly composed by turkey oak – *Quercus cerris* L., chestnut – *Castanea sativa* Mill., and pubescens oak – *Quercus pubescens* Willd.), followed by evergreen broadleaved forests (13% composed of holm oak – *Quercus ilex* L. – and cork oak – *Quercus suber* L.) and conifers (8%) (Fig. 1). Of these forests, 80% belong to private owners. The regional forests are generally managed as coppice (63% of total and 79% of private surfaces) and are normally harvested for the production of firewood [21].

The first phase of the work was the implementation of a Territorial Informative System that includes the following themes:

- Administrative boundaries (regional and municipality boundaries);
- Corine Land Cover 2006;
- Digital Terrain Model (DTM);
- Main and forest roads;
- Tuscany Forest Inventory; and
- Municipality county seat.

The model is based on a raster analysis with a spatial resolution of 75 m per square pixel.

2.2. Scenario assessment and methodological approach

The study was based on a medium- to long-term time frame and utilised a resource-focused approach. In accordance with the issues described in chapter 1, different case studies were evaluated for the following purposes: i) estimating the total potential biomass from Tuscany forests, ii) evaluating the economic efficiency of forest processes, and iii) analysing the trade-offs between the different scenarios.

In particular, the model provided three scenarios (each a SC).

SC1 analyses forest chain organisations utilizing current technology level and without woodchip production. The hypothesis is that processing operations, such as delimbing and crosscutting, are undertaken in the forest. Extraction is provided by tractor and winch or by cable crane.

A medium-high technological level with respect to current standards will be introduced in SC2 and SC3. A Whole Tree extraction system was utilised and ground-based extraction was undertaken by skidder. Trees are processed at landing and residues (tops and branches) are chipped. When there is thinning from high forests (in SC2) and for SC3 generally, the model applies the WTC system. Furthermore, SC3 focuses only on forest stands currently used for firewood production (coppices of oak, beech – *Fagus sylvatica*, hophornbeam – *Ostrya carpinifolia* Scop., etc.).

The spatial model considers ecological biomass availability, and this amount was subsequently refined by the introduction of technical and economic constraints.

2.3. Spatial model implementation

2.3.1. Ecological biomass availability

Biomass availability may be defined as a function of the periodic annual increment of forest. This value refers to the stock of natural capital and a sustainable yield [22].