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Identification of potential energy wood terminal locations using a spatial multicriteria decision analysis

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ABSTRACT

The utilization of fuel wood from forests contributes to the European Energy Strategies but requires a collection system that normally consists of road/railroad infrastructure and storage sites. While a transport network usually already exists, custom-built terminals are often not available. A reliable identification of potential energy wood terminal (EWT) locations requires the consideration of spatial information and the preferences of stakeholders. To meet these requirements, a spatial multicriteria decision analysis model was developed.

The model framework consists of three steps. (1) An exclusion analysis eliminates unsuitable areas. (2) The performance of suitable areas is evaluated by applying fuzzy set theory and by involving experts who assign their preferences via the Analytical Hierarchy Process. The combination of spatial data and the preferences of users results in a Suitability Index map. (3) A pre-defined grid transforms the suitable areas into potential EWT points. Planned terminals were evaluated if they meet the pre-defined threshold values. For all spatial analyses, geographic information systems technology was used.

The model was demonstrated in Styria (Austria). Infrastructure and phytosanitary risks have been identified as the most important evaluation criteria for selecting EWTs, whereas land use and nature protection have been identified as negligible. Only 18% of Styria, or almost 300,000 ha, were classified as potential storage areas. In particular, coniferous forests and alpine areas with steep terrain and high snow cover duration reduced the original study area dramatically. Therefore, more than 50% of the land is potentially suitable only in the most southeastern part of the province. In this region, hilly terrain and broadleaved forests dominate, which are not excluded from storing fuel wood because of phytosanitary risks. The application of a pre-defined grid achieved 82 potential EWT points for the total area of Styria.

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1. Introduction

As the European Union searches for new energy solutions to decrease its dependence on imported fossil fuels, cost-efficient and renewable biomass sources will be needed for domestically produced biofuels to make a significant contribution to the European Energy 2020 strategy [1]. Forestry products are one potential biomass source. They are the largest component of the current biomass supply in Europe, totaling approximately 770 TWh of primary energy per year. Approximately half consists of by-products from the industry (such as black liquor, sawdust, and bark), 360 TWh (70 Mt) is roundwood and 30 TWh (6 Mt) is from forest residues (branches, tops, and stumps). The largest bioenergy growth opportunity in forestry is to increase the capture of forest residues. This would result in a growth of 170 TWh from forest residues [2].

The utilization of fuel wood from forests requires a collection system that allows the supply of the woody biomass from the forests, storing at central landings and transportation to the biomass plant. The collection system is normally composed of: (1) a vehicle and truck-transportation network, (2) a railroad network, (3) interactions between roads and railroads, and (4) storage areas [3]. The relevance of implementing storage areas within the biomass supply chain [4] has been emphasized in terms of (1) increasing the chipping efficiency up to 40%, (2) reducing the capacity bottlenecks because of the availability of all-season safety stock, (3) reducing the phytosanitary risks due to storing the woody material outside of the forests, (4) and improving the drying efficiency because of storing the material in sunny and windy open land sites [5].

While road and railroad networks usually already exist, custom-built terminals are often not available. Especially in Alpine regions, biomass recovery is limited because of the long snow cover duration and the low soil bearing capacity after snow melting and heavy rainfalls [6]. To overcome these shortcomings and to balance the supply, all-season storage terminals should be used [7].

There have been several studies focusing on the processes that occur during energy wood storage, such as the drying performance [5,8–11], the greenhouse gas (GHG) emissions [12,13], the dry matter losses [11] and the fuel quality changes [14], but there is still a lack of knowledge for identifying suitable areas and locations for energy wood storage.

To identify potential locations for EWTs, geographic information systems (GIS) are one of the most suitable technologies. This analysis tool allows the elaboration of site suitability modeling to examine the geographic variation of spatial layers associated with pre-defined economic, environmental and social criteria. Site suitability modeling is broadly used in a variety of fields because it helps to capture geographic variation for different purposes [3]. It allows the measurement of associations between locations and different spatial layers in a way that individual effects can be evaluated and used to infer their relative influences on the final model [15]. GIS is also often used in the context of bioenergy, especially for the evaluation of biomass potential [16–20]. There have also been many studies concerning the site selection of biomass power plants [21–27], but there is still a lack of methods and models for identifying potential locations for storage sites. Existing studies for selecting optimal EWTs are based on location-allocation modeling approaches [4,28]. In this case, linear optimization models calculate the optimum locations from a preselected number of potential storage places. This paper, however, will focus on the pre-selection process which is fundamental for the optimization of models and further, related analyses.

A decision about locating EWTs based only on economics may not comply with local environmental regulations or other social criteria [29]. The quality of the decision is also influenced by the membership functions of the evaluation criteria. The membership of elements in a set may be assessed either in binary terms (an element either belongs or does not belong to the set) or in fuzzy sets (with degrees of membership). Fuzzy set theory should especially be used in a wide range of domains in which information is incomplete or imprecise [30]. Another critical aspect is that many stakeholders in biomass projects have diverse and often conflicting perspectives, and therefore, a transparent and participatory process is required to find a balance between the preferences of the various stakeholders. Understanding the interdependency of these factors is essential because the failure of one factor can lead to the failure of the entire project [31,32]. The use of multicriteria decision analysis (MCDA) facilitates the participation process and has an important role in the successful uptake of policy and management strategies and long-term planning [33]. The MCDA method is widely used in energy planning to achieve solutions that are near the maximum productivity potential and have the minimum environmental and social costs [34,35].

Spatial multicriteria decision analysis (SMCDA) assembles geographical data and the preferences of decision makers in a way that the outcomes can be weighted and/or ranked, facilitating the final decisions [3]. Sultana and Kumar [29] used this methodology to determine suitable locations for biomass plants. Van Dael et al. [36] developed a screening model to evaluate the suitability of several communities in Belgium for energy production plant locations. However, these studies neither focused on EWTs, which have specific requirements, nor included fuzzy sets for criteria with moderate suitability. Therefore, in our study, we developed a new approach by including these two important factors.

The aim of this research was to generate a GIS model to locate EWTs through the integration of economic and environmental constraints. After defining the criteria and analyzing the stakeholder preferences, a GIS model was developed to integrate the various spatial layers and to calculate the suitability for every layer and for the entire case study region. Finally, recommendations were given for potential locations for energy wood storage sites based on an SMCDA ranking.

2. Material and methods

2.1. Study framework

The central elements of the study framework (Fig. 1) are data collection and geodatabase generation, using the exclusion analysis followed by a suitability analysis to identify candidate sites for energy wood storage. Strict exclusion criteria define regions that are in no case suitable for the storage of