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Estimation of surplus biomass potential in southern and central Poland using GIS applications

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ABSTRACT

Poland has considerable agro-biomass potential that could pave the way toward sustainable development and achieve the country's renewable energy targets by substituting the excessive use of fossil fuels, particularly coal and lignite. To develop biomass cost supply curves, biomass recourse assessment is required and socio-economic factors and environmental constraints must be considered. Surplus biomass potential is the proportion of biomass that can be used for energy generation and economic development with minimum risk. Two provinces were selected in this study to estimate forest and agricultural biomass resources. In central Poland, Kujawsko-Pomorskie province was selected due to the high density of renewable energy installations there, while Upper Silesia in the south of the country was selected because of its large coal deposits and higher forest cover. We used GIS applications, secondary data from official sources, and data from a field survey with 210 farmers to produce land use and GIS maps for surplus forest and agricultural biomass. Surplus residues from all crops in Upper Silesia and in Kujawsko-Pomorskie were estimated at 0.60 t/ha over a 12-month period. These figures correspond to approximately 57,000 and 178,000 t/year in both provinces, respectively. These maps are a useful tool in optimizing the locations of future investments in biomass-based power plants in the study regions.

1. Introduction

Bioenergy is expected to increasingly contribute to the ambitious Paris Agreement on Climate Change and to the United Nations' Sustainable Development Goals. Bioenergy, biofuels, and biochemicals in solid, liquid, and gaseous forms can substantially boost clean energy generation via co-generation and/or hybrid energy systems. Numerous employment opportunities could also be created along the bioenergy production chain compared to other traditional or modern energy generation systems. For example, it is estimated that the bioenergy sector currently provides 38% of jobs (2.9 million) in the renewable energy industry [1]. As such, numerous studies have sought to estimate the biomass/bioenergy potential across the globe, although these estimates appear inconsistent and vary considerably [2,3]. These inconsistencies and variations may have stemmed from the different types of biomass considered, and/or the different types of approaches and methodologies implemented in the bioenergy assessment studies [2,3]. An increase in the use of bioenergy would require that a number of social, economic, and environmental factors (macro and micro) are taken into account in order to provide robust data for policymakers, investors, and biomass-based industries [4]. Biomass refers to agriculture, forests, and waste (Municipal Solid/liquid Waste), and under the agriculture category, for example, first, second, and third generation biofuels (bioethanol, biodiesel) are usually distinguished [4]. Other studies focus primarily on post-harvesting agricultural residues, such as straw or corn stover to calculate the bioenergy potential [5–8]. These studies have also sought to calculate the residual removal rate. For example, 30% of agricultural residues in India could be used for energy generation after the existing uses of biomass at the household level are considered [8,9]. In the US, a 33% removal rate of corn stover provided farmers with sufficient additional profit to encourage a shift to more continuous corn production [7]. Some studies suggest a general residue removal factor of 50% [10], while other studies recommend a removal rate based on crop type or a country-specific value (determined from a literature review or from expert guidance). For example, a 40% removal rate has been estimated for cereals and 50% for corn, rice, and

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sunflower [11], while [12] assumed an approximate removal rate of 33% for Germany and Hungary and up to 50% for France. In Poland, the share of crop residues that can be delivered to the market (30%) was estimated based on a survey of farmers, after deducting the proportion of biomass used by the farmers for heating, cooking, animal feed and bedding [13].

An equally important consideration in bioenergy resource assessment embraces the need to offset greenhouse gas emissions, and avoid both biodiversity loss and deforestation [2,4]. Furthermore, issues exist in regard to the cost of transport of “low energy density” feedstock, and the environmentally acceptable level of residual removal [4,14]. Indeed, transportation costs may account for 31% of the total cost of straw at the plant gate [15], and 24% of cross-border transportation, e.g. from Russian Karelia to Finland [16]. This suggests that biomass price largely influences the quantities of biomass available for energy generation. The types of biomass potential generally consist of a “theoretical” potential, which is the maximum biomass quantity that can be recovered from within certain physical boundaries while accounting for the limitations associated with changes in weather conditions [2]. The “technical” biomass potential is the proportion of the biomass deducted from the theoretical potential, after accounting for food, feed, and fiber demand [2]. The “economic” potential is the fraction of the technical potential that can be delivered to the market based on economic aspects, such as biomass price, market demand, and fossil fuel prices [2]. The “implementation” biomass potential fraction is calculated in order to incorporate de-risking policies, such as financial/fiscal incentives, guarantee public acceptance and support, and ultimately establish an acceptable sustainability threshold [2]. In developing countries, however, non-incentivized biomass is often produced by rural farmers and is thus mainly associated with traditional uses, such as animal feed and bedding, cooking, and thatching. In this regard, “surplus” biomass potential is posited as a newly defined biomass potential. In order to calculate the surplus biomass potential, an exploration of the domestic use of biomass is required to determine the share of biomass that can be recovered for energy generation [17]. Moreover, the surplus biomass potential must also account for an “ecological” share that is needed to maintain soil fertility. Different methodologies have been adopted to estimate the bioenergy potential [2,18], for example, statistical analysis that utilizes accessible datasets (FAOSTAT, EUROSTAT), spatially explicit analysis that combines spatially explicit data on land use, literature reviews, and partial equilibrium, biophysical processes, and integrated assessment models [18]. However, these methodologies have some disadvantages; they are not fully able to account for some environmental or social constraints, they can be labor intensive and thus the results cannot always be reproduced, and they also are subject to high uncertainties [2].

Poland is a European Union (EU) country with a high potential for bioenergy production from agro-biomass; arable land (AL) area per capita is 0.41 ha compared to the EU average of 0.19 ha. In 2010, agricultural land for energy production amounted to 1.68 million hectares (Mha) (i.e. 11.5% of AL) [19]. The share of agricultural land that could be allocated for energy purposes (after satisfying staple food needs) may reach 2.54 Mha by 2020 (i.e. 17.7% of AL), and 3.38 Mha (i.e. 24% of AL) in 2030. These estimates will largely depend on (a) the types of agricultural products utilized, (b) the staple food market in Poland, the EU and globally, (c) lifestyle choices and food consumption behaviors in Poland, and (d) the suitability of set-aside land for bioenergy production [20]. A number of studies have estimated the biomass potential in Poland. In 2006, Nilsson et al. [21] provided an estimate of 150 PJ/year for straw and 55–65 PJ/year for forestry residues (based on a calorific value between 14.3 and 15.2 MJ/kg). In 2011, it was estimated that 5.8 million tonnes (Mt) of dry straw would be required to meet the national renewable energy targets, although the potential of straw could be approximately 9.1MtDM [22]. In the same year, Iglinski et al., [23,24] estimated that Poland produces approximately 23 million tonnes of straw per year with the assumption that 1.5 kg of straw is equivalent to about 1 kg of coal. Fabar [25] suggested that in order to meet the targets set in the National Action Plan for 2020, Poland would need 2.5 million tonnes of biomass for electricity generation and about 9 million tonnes for heating and cooling. Pochitonow et al., [26] defined three types of agro-biomass potential in the Administrative District of Gorlice located in the south-eastern part of Małopolska Voivodship. Assuming a potential 1.5 t/ha of straw and a 15MJ/kg calorific value, the theoretical potential would be about 193 TJ/year, and with a 80% conversion rate from chemical to thermal energy, the technical potential would be 154TJ/year. Depending on farm size, technology, volume of residual straw, and domestic biomass use, the economic potential would be only 5% of the technical potential i.e. 8TJ/year. In 2013, the technical potential of straw was estimated at 6.7–8.9 Mt, and is expected to stabilize at 8.63 Mt in 2020 [27–29].

The aforementioned studies used simple statistical analysis or energy–economic models based on public datasets of agricultural areas and production to estimate bioenergy potential. Therefore, these estimates are rough estimates, subject to considerable uncertainty and do not integrate the various socio-economic and ecological factors. To our knowledge, no studies have used an integrated resource assessment that combines geodata, such as land use/land cover (LULC) maps, and data obtained from geographical information systems (GIS). Furthermore, this integrated methodological approach also incorporates social factors related to biomass use at the household level [17]. Therefore, the aim of this study is to conduct a biomass resource assessment using an integrated and spatially explicit analysis in order to generate LULC maps and GIS-based biomass potential from the forest and agricultural sectors in selected locations in central and southern Poland.

2. Materials and methods

The study follows the methodological approach developed by Natarajan et al. [17] to generate the GIS and land cover maps. It combines survey data from farmers and secondary data on agricultural and forest cover. The following sub-sections provide a step- by step explanation towards the final stage of map production.

2.1. Study areas

The study was concentrated in two provinces of interest; Silesia in southern Poland, and Kujawsko-Pomorskie (Kuyavia-Pomerania) in central Poland (Fig. 1). Kujawsko-Pomorskie is approximately 18,000 km^2 and Silesia approximately 12,000 km^2 in area. The study covers two out of 16 provinces in Poland. In the selected provinces, the main locations are the city of Torun and the surrounding areas in Kujawsko-Pomorskie, and Upper Silesia in Silesia. Torun represents a region with a high density of renewable energy installations (wind energy, biogas, pelleting industry, and dedicated energy crops) [15,16], while Upper Silesia represents a region with large coal and lignite deposits and a higher forest cover [30]. Upper Silesia is also home to the largest coal-power plants in Poland.

2.2. Biomass data

2.2.1. Survey data

The survey-based data was collected by developing a questionnaire and approaching farmers in the selected provinces. Field surveys with the farmers were carried out between July and August 2015. The survey tool (in English) was developed by a team of researchers at the University of Eastern Finland (UEF). Thereafter, the draft questionnaire was sent to colleagues in Poland for translation into the Polish language. The questionnaire consisted of several sub-sections. The first part was devoted to identifying biographical information, which included farm type and size, farming equipment, domestic energy sources, biomass use at the farm level, and the perceived value of farming (source of income or cultural heritage). These variables were