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Research paper

GIS-based assessment of sustainable crop residue potentials in European regions

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ABSTRACT

In this paper a novel model based on a geographic information system (GIS) is presented for the assessment of sustainable crop residue potentials. The approach is applied to analyse the amount and the spatial distribution (1 km × 1 km grid cells) of cereal straw, root crop and oil plant residues for five European regions, considering spatially differentiated environmental sustainability issues, i.e. organic carbon content in topsoil, soil erodibility, and protected areas. The maximum sustainable residue potential varies strongly between the regions and residue types. In the scenarios Basis and Restrict, it accounts for 45–59% and 24–48% of the theoretical potential respectively without considering competing uses. Among the crop residues, cereal straw shows the highest energy potential in all regions under investigation. In terms of wet mass it accounts for 3.7 Mio. t_{wet}/a in North Rhine-Westphalia, 1.6 Mio. t_{wet}/a in Île-the-France, 1.2 Mio. t_{wet}/a in Wallonia, 0.9 Mio. t_{wet}/a in West Midlands, and 0.3 Mio. t_{wet}/a in South Netherlands (scenario Basis). Our survey shows that spatially differentiated potential estimations and the inclusion of crop residues other than cereal straw are urgently needed to improve the present rough estimations for crop residues which can be used in a sustainable way. The rather high spatial resolution of our analyses particularly allows for the support of regional stakeholders and prospective investors when it comes to questions of regional availability of biomass resources, transport distances to biomass conversion plants, and identification of suitable plant sites and sizes, respectively.

1. Introduction

Driven by the uncertainty whether energy cropping contributes to land use competition, reduction in food supply and increase in food prices, it is the objective of European politics and research to exploit the significant untapped potential of agricultural residues for energy conversion. In order to meet this objective, spatially high-resolution inventory assessments of agricultural crop residues, such as cereal straw, are required. Several assessment studies on the potentials of agricultural residues at different scales exist which apply a similar methodology to calculate the various types of potentials, but achieve varying results due to the lack of a common understanding on the theory, methodology and data. These uncertainties about the share and composition of agricultural crop residues which can be made available reliably, steadily and in a sustainable way currently limits the validity and use of potential studies for decision-making processes in politics and industry. Furthermore, high-resolution and regional potential studies are mainly carried out for distinct regions in one and the same country. Comparisons of regional residue potentials across borders and of different countries have therefore only limited validity because of differing underlying methods and assumptions, e.g. different terms and definitions of potentials such as theoretical, technical and sustainable potential. Another restriction of the existing assessment studies on agricultural residues is their lack in considering other crop residues than cereal straw such as residues from root crop and oil plant cultivation. Nevertheless, they may offer a noteworthy potential for bioenergy applications. Besides, criteria or indicators to measure what quantities of straw and other crop

Abbreviations: NUTS, Nomenclature of Units for Territorial Statistics; RPR, residue-to-product ratio; NRW, North Rhine-Westphalia; GADM, Global Administrative Areas; CDDA, Common Database on Designated Areas; EEA, European Environment Agency; EC, European Commission; CORINE, Coordination of Information on the Environment; CLC 2006, CORINE land cover 2006; EFSA, European Food Safety Authority; OSM, Open Street Map; CAPRI, Common Agricultural Policy Regionalized Impact Modelling System; EU, European Union; IUCN, International Union for Conservation of Nature; CHP, Combined Heat and Power Plant.

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residues can be removed from the field without negative impacts on the environment and soil fertility are missing.

Against this background it is the objective of this paper to present a novel GIS-based approach for the spatially differentiated assessment of sustainable biomass potentials. This advanced methodology has been developed within the EU-project BioenNW – Delivering local Bioenergy to North West Europe and assesses the potential of all common agricultural crop residues, i.e. residues from cereal, oil plant and root crop cultivation, and includes more sustainability restrictions than just the humus balance. In addition, potential estimations are carried out for a rather high spatial resolution, i.e. 1 km × 1 km grid cells and for different European regions in France, Germany, United Kingdom, Belgium and the Netherlands representing the areas under investigation of the BioenNW project.

2. State-of-the-Art

A number of resource-focused assessments have been made regarding the potential bioenergy supply including crop residues on an aggregated level, i.e. for large regions and countries [1–3] or at a global level [4]. However, in these studies crop residues as well as biomass potentials and corresponding estimation methods are not defined uniformly. Equally, studies estimating the bioenergy potential of crop residues in Europe and Germany or for European and German regions are differing due to

- the lack of a common definition of crop residues (they are mainly focusing on cereal straw neglecting other crop residues)
- the variability of the quantity and quality of residues available each year in different regions, as a result of climatic conditions and fluctuating crop yields
- varying assumptions on the ratio of residue to product and the share of residue recoverability
- different proportion of straw potentials being used for animal husbandry or other competing uses
- different terms and definitions of potentials such as theoretical, technical and sustainable potential
- different projection periods (current, 2020 or 2030 potential estimated).

Thus, it is not surprising that there are also large differences in the estimated availability of crop residues which goes mainly back to varying assumptions on the primary uses of crop residues in agriculture for animal husbandry and for nutrient and carbon management of the soils.

European biomass potential analyses are often carried out on a national level [5] or for administrative units within one country according to the NUTS (Nomenclature of Units for Territorial Statistics)-classification [6]. Usually, the theoretical potential for cereal straw is estimated by applying an average relationship between straw yield and corn yield (residue-to-product-ratio). By considering the straw demand that is needed for animal husbandry and for maintaining the humus balance, the theoretical potential is commonly reduced to obtain the technical and sustainable potential, respectively. Concerning the studies on cereal straw potentials for energy usage in Germany, the humus balance is regarded as the most important parameter for assessing the share of straw which can be used in a sustainable manner. Weiser et al. [6] have calculated the German straw potential using a humus balance tool reflecting environmental constraints related to the conservation of the soil organic matter. With this methodology the technical straw potential of about 50% of the theoretical potential is reduced to a so-called sustainable potential which varies between 24 and 44% of the theoretical potential. According to Weiser et al. [6], the sustainable cereal straw potential in Germany ranges between approx. 8 to 13 Mio. t_{wet}/a if soil restrictions to maintain soil fertility and competing uses are considered. This coincides with the assessment of straw potentials in the German federal state of Baden-Wuerttemberg [7]. Gauder et al. [7] conclude that nearly one third of the total straw occurrence could be made available without endangering the supply of litter for animal husbandry and the long-term humus soil contents. These figures are supported by the estimates of the European Environment Agency resulting in a range between 33 and 37% to be available within a range of sustainability scenarios [8].

2.1. GIS-based potential assessment

For spatially high-resolution biomass potential analyses as well as for location and transport distance analyses, GIS-based approaches are commonly used [9–14]. GIS-based approaches permit the inclusion and combination of different types of spatial information via regional maps data on e.g. land use or soil conditions. In Voivontas et al. [9] the spatial distribution of the theoretical, available, technological and exploitable potential of agricultural residues is determined for the island of Crete using a GIS-based approach. Beccali [10] estimate the technical and economic potential for woody residues and energy crops for Sicily using a GIS-based methodology, including data on land cover, terrain elevation, climate and rain maps, geological, lithological and morphological maps. The local availability of forest biomass together with road network properties have been evaluated by Jäppinen & Korpinen [11] for two case studies in Finland. In Geijzendorffer et al. [12] a GIS is used to account for the spatial distribution of biomass resources in a logistical optimization model for two case studies in the Netherlands. As stated above, these high-resolution potential analyses are often carried for distinct regions within one country, for which reason a comparison of results of different studies and in between countries is in most cases not possible. The suitability of biofuel feedstock (woody lignocellulose plants, herbaceous lignocellulose plants, oil crops, starch crops, sugar crops) in Europe has been analysed by elaborating yield maps with a spatial resolution of 1 km^2 using climate, topography, soil and land use data [13]. Based thereon, land use scenarios have been elaborated taking into account agricultural residues as additional source for biofuel production [14]. However, the availability of agricultural residues for energy purposes considering agricultural sustainability is assumed to be uniformly 50% and spatially differentiated sustainability restrictions for residue removal from agricultural areas are not considered.

2.2. Residue-to-product-ratios for the assessment of crop residues

In order to estimate the total amount of crop residues, i.e. the theoretical potential, average crop areas and crop yields together with average residue-to-product-ratios (RPRs) are widely used as a starting point. In most studies, the availability of crop residues for energy purposes is based on rough estimations, taking into account e.g. requirements for soils and harvest losses but without considering local conditions. With the objective to estimate the energy potential, moisture content and heating value of the residues are important parameters. Tables 1–3 give a literature overview of average RPRs, water contents, and heating values of residues as well as the estimated residue availabilities for most common European cereals (wheat, rye, barley), root crops (potatoes, sugar beets), and oil plants (rapeseed, sunflower, linseed).

The literature overview is focussing on European surveys and references are listed by countries/regions. It can be noticed that especially the assumptions about the residue-to-product-ratios are