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Location problem of lignocellulosic bioethanol plant - Case study of Serbia

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A B S T R A C T

Lignocellulosic bioethanol (LCB) is a biofuel produced from the nonfood feedstock, with the great potential of greenhouse gases (GHG) emissions savings. Crop residues are considered to be suitable feedstock for its production, however, the amount of the feedstock needed for a production is large, making the supply of the plant rather complex and expensive. Therefore, selection of an optimal LCB plant location plays an important role in reducing supply costs and GHG emissions.

The main objective of this study was to define the adequate approach for determining the location of LCB plant. As an appropriate basis, the p median mathematical model was selected and further adapted. The general objective of the model is minimization of both internal and external biomass transport costs. The necessary input for the model testing is selection of biomass and mapping of its potentials. The model was tested for the problem of LCB plant location in Serbia, considering both road and inland waterway transport of biomass. Novi Sad was selected as the optimal macro location of the plant in Serbia. The comparative analysis pointed out that, in the case of Serbia, depending on the selected location and transport mode, the biomass transport costs can range from 7 €/t to 18 €/t and have a share from 13.5% to 30% in the plant supply costs. Additionally, the costs savings in the case of applying multimodal instead of road transport can be from 1 €/t up to 9 €/t of biomass, respectively 5 €/t up to 45 €/t of produced bioethanol. Based on the results, effectiveness of the defined approach for the selection of LCB plant location can be verified. The results directly pointed out the importance of the transport costs analysis at the selection of a LCB plant location and the positive effects of using inland waterways for the biomass transportation.

Obtained results can be further used for detailed analysis of environmental impacts, first of all GHG emissions saving.

1. Introduction

Introduction of renewable energy sources, as well as sustainability criteria for their production and utilization, are defined in European Union Directive 2009/28/EC (in the text RED – *Renewable Energy Directive*), Directive 2009/30/EC, as well as in relevant communication C 160/8 (EU-Commission, 2010). The most challenging demand is to obtain share of 10% of biofuels in transportation till 2020, especially due to clear request to fulfill criterion to achieve minimal savings of 60% of Greenhouse Gases (GHG) emissions, with respect to fossil comparator that rates 94 g CO_{2eq}/MJ (EU-Commission, 2016). As a consequence, to the reaction of the society, utilization of food and feed as a feedstock is unstimulated by, so called, ILUC (*Indirect Land Use Change*) Directive (EU-Commission, 2015). It is stated that the share of energy from biofuels produced from cereal and other starch-rich crops, sugars and oil crops and from crops grown as main crops primarily for energy purposes on agricultural land shall be less than 7% of the final consumption of energy in transport till 2020. In the same document, share of biofuels produced from non food/feed feedstock (listed in Annex IX) shall be doubled. It is related to lignocellulosic materials.

In recent EU documents (EU-Commission, 2016), are presented amendment of RED and RED annexes. For biofuels and bioliquids production facilities getting into operation after 2021 proposed

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increase of minimal GHG emissions requires saving to 70%. In annexes are presented default values of GHG savings for diverse biofuels. They are 40, 47 and 57%, for corn ethanol, rape seed biodiesel and pure vegetable oil from rape seed, respectively. Obviously, for these biofuels, defined GHG emissions saving cannot be obtained. The only exception is sugar cane ethanol with saving 70%. In the same document is given default value of GHG emissions saving for wheat straw ethanol, lignocellulosic bioethanol (LCB), 83%, and thereby is this biofuel acceptable.

Serbia, as a contracting member of Energy Community, since 2005, accepted obligation to follow EU energy policy, what includes policy related to renewable energy sources. As well as in other European countries, the most challenging demand for Serbia is to obtain required share of transportation fuels. As a country with an intensive agriculture, Serbia can be potential producer of LCB, using crop residues. However, production of LCB requires big amounts of feedstock whose supply to the plant is rather expensive and also causes GHG emissions. Both the transport costs and the GHG emissions depend, among others, on supply transport distance and applied modes of transportation.

In order to make the LCB production in Serbia effective and sustainable, a strategic approach to the location problem of the plant that will enable the lowest possible costs and the lowest negative influences on the society and environment is required. Therefore, within this paper, case study of locating an LCB plant with the optimal feedstock supply is presented. Within the study, two modes of transport (road and inland waterway transport) and their internal and external transport costs were considered. Internal transport costs consider the direct costs of transport service, while external costs cover the indirect costs: pollution, noise and accidents. Including the external transport costs in the analysis enables comparison of transport modes based also on their economic impact on society and not only on their competitive advantages in the particular supply chain.

1.1. Lignocellulosic bioethanol technology

Biofuels produced from non food/feed feedstock are commonly called second generation biofuels, 2G, and LCB belongs to them. Due to lower indirect energy input for lignocellulosic feedstock, wood and crop residues etc., GHG emissions of generation and supply are lower. The LCB production and use, environment and sustainability issues are tackled in many publications. Wiloso et al. (2012) presented literature review of LCA studies for the second generation bioethanol. It was concluded that, regarding two studied impact categories, net energy output and global warming, second generation bioethanol performances are much better than of fossil fuels. Next, GHG emissions saving of LCB from corn stover and wheat straw are in the range between 82 and 91%. In Sheehan et al. (2003) is presented a model developed to determine environmental impact of substituting of gasoline with corn stover based LCB, that includes the impact of collecting the stover on soil, considering soil erosion and soil organic matter.

Banerjee et al. (2010) provided an overview of the LCB technology and made list of issues that have to be addressed in order to make commercial LCB production economically viable. In this research it is stated that possible measures are: use of cheaper substrates, appliance of cost-effective pre-treatment approaches; overproducing and recombinant strains for maximized ethanol tolerance and yields; improved recovery processes; efficient bioprocess integration; economic exploitation of side products; energy and waste minimization. Analysis on competitiveness of second generation biofuels with first generation and opportunities for cost reduction is given in Stephen et al. (2012). They suggested that producers of LCB should not compare with the current production costs of the first generation bioethanol, but with the future, reduced cost (which is generally decreasing). Festel et al. (2014) compared the production costs of different biofuels with the fossil fuels, showing that, in mid to long term, the 2nd generation biofuels are most likely to achieve competitive production costs.

LCB technology clearly has a great potential but is now in early commercial maturity phase. Schwab et al. (2016) reported about twelve plants in the USA, of which three use crop residues, corn stover. In Europe is in operation the only one, Proesa™, in Crescentino. More investments and further development of LCB technology is expected in coming years, after several years of operation of existing facilities, when environmental effects, optimal feedstock pre-treatment, reliability and cost-effectiveness of longer term operation will be proven. Already at this stage, feedstock procurement is identified as major problem, and location of LCB plant plays important role in this regard, as well.

1.2. Feedstock supply for LCB

Feedstock supply of a LCB plant includes procurement of biomass on primary storage and logistic activities such as biomass loading, transport, transshipment, unloading, storing. In the same way, supply costs consist of biomass price on primary storage and logistic costs. Logistic costs are highly dependent on the plant location, and have big influence on supply costs, GHG emissions and supply security, particularly the transport costs. LCB plant storage should provide enough feedstock for about two weeks of operation. That means, the supply should be performed continuously all year round.

Biomass is, after collection, stored on primary storages, in the vicinity of fields and farms, at the micro location connected to roads. Price of biomass on primary storages depends on many factors. Some authors (Thompson and Tyner, 2011; Archer et al., 2014) gave relatively wide range of them, for different regions. In study of Martinov ed. (2015), performed for region of Vojvodina, price of corn stover dry mater, was assessed to be between 42 and 45 €/t. In the same publication, the logistic costs were between 11.1 and 14.0 €/t, or over 20% of supply costs.

The issue of feedstock supply has been elaborated in numerous articles in which an assessment of the existing feedstock potentials was one of the first steps. Bhutto et al. (2015) analyzed the perspectives of the ethanol from lignocellulosic feedstock production in Pakistan. This study forecasts the annual yield of five lignocellulosic feedstocks i.e. cotton stalks, sugarcane tops, rice straw, maize stalks and wheat straw from 2013 to 2030 in Pakistan. Based on the availability of biomass feedstock, the study forecasts the maximum theoretical potential for production of bio ethanol from these crop residues up to 2030. Assessment of bioenergy and location problem of the power plant in Pakistan was further performed by Biberacher et al. (2015). The assessment was performed in two steps. In a first step, annual biomass growth is calculated with the BETHY/DLR model on a spatial resolution of 1 km^2. In a second step, the ASECO model is utilized to identify optimal plant locations with related biomass supply areas, determined by biomass growth rates and available road infrastructure.

The studies proved necessity of mapping feedstock potentials before discussing possibility to locate a plant. Further, researchers demonstrated the significant cost effects of adequate selection of plant location and capacity. Kocoloski et al. (2011) investigated impacts of facility size and location decisions regarding cellulosic ethanol production cost, concluding that the decisions can contribute substantially, up to 15–25% of the total costs.

Starting from the high share in the total costs, many researchers developed models for optimization of transport or supply chain costs of biomass. Gold and Seuring (2011) provided review of the