TEHNIČKI POTENCIJAL I REGIONALNA RASPODJELA BIOMASE ZA ENERGETSKE POTREBE: ANALIZA SLUČAJA ZA HRVATSKU

TECHNICAL POTENTIAL AND GEOGRAPHIC DISTRIBUTION OF BIOMASS FOR ENERGY USE: A CASE STUDY OF CROATIA

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Sadržaj: U radu je predstavljena metodologija za određivanje regionalnog potencijala poljoprivrednih i šumskih ostataka te njihove cijene na lokacijama za elektranu. Predstavljena metodologija je primijenjena na Hrvatsku i njene županije, a potencijal je računat za slamu, kukuruzovinu i šumske ostatke (sitna granjevina i panjevi). Prilikom određivanja potencijala poljoprivredne biomase koriste se godišnji prinosi žitarica dok se kod šumske biomase potencijal određuje pomoću propisanoga etata za državne šume. Dobiveni rezultati pokazuju da u Hrvatskoj postoje velike količine biomase te da su one nedostatno iskorištene u energetske svrhe. Rezultati pokazuju da je maksimalni energetski potencijal slame oko 6.1 PJ, kukuruzovine 5.5 PJ, a šumskih ostataka 5.9 PJ.

Abstract: *This paper provides methodology for regional analysis of energy potential of different biomass types and methodology for assessing the cost of biomass at the power plant location considering transport distance of biomass, the transport cost and the size of the power plant. The methodology was applied on the case of Croatia. The energy potential of biomass in Croatian counties was calculated, using different methodologies, for wheat straw, corn stover and for forest residual, types of biomass considered economically viable at the moment. Methodology used for estimating removable residual from wheat straw was based on minimum requirements for soil protection, animal feeding and bedding. For estimating removable potential of corn assumption of 20% was used for calculating fraction on the field that goes uncollected and 50% for calculating amount of corn stover for soil protection. Methodology used for calculating potential of forest residual was based on assumption that 12% of the total mass of tree is forest residual which can be removed from forest and used in energy purpose. Results of this study indicate that the energy potential of wheat straw is 6.1 PJ, corn stover 5.5 PJ and for forest residual energy potential is 5.9 PJ.*

Key words: Biomass, forest residues, wheat straw, corn stover, energy potential

1. INTRODUCTION

In order to reduce greenhouse gas (GHG) emissions, increase domestic industry development, secure and diversify the supply of energy, biomass as a renewable energy *resource plays an important role for reaching these goals in industrial countries [1]. In regards to other renewable energy sources biomass has the ability to store feedstock and use it when it is required [2]. Furthermore, using biomass for production of energy can significantly contribute to the job creation and economic development of rural economies and slow down migrations from these areas to cities [3]. In terms of employment the largest impact comes from the investment into new power plants. According to [4], biomass power plant capacity of 25 MWe directly employs over 20 people but in the period of development, construction and operation this plant creates jobs of the order of 4000 man years, which is equivalent to around 160 full time positions over the lifetime of the plant.*

Nowadays biomass (e.g. wood) makes up only 7% of global fuel sources, with an estimated 15% of energy used in developing nations and only about 2% in developed nations [5]. In Croatia, production of primary energy from fuel wood in 2008 was 16.58 PJ or 8.7% of total country's energy production and for the period until 2030 the share of fuel wood and biomass should be 19.6% of primary energy production in Croatia [6]. To reach this goal, Croatia needs to increase quantities of residuals collected from the forests and agricultural fields. Unfortunately, the most common agricultural practice for these residuals is field burning, resulting in serious air pollution or in the spreading of large, uncontrolled fires.

This paper focuses on identification and quantification of the available biomass in the regions and analysis of the biomass cost at the power plant location. Firstly, methodology for assessment of regional biomass potential and cost of biomass at the plant location was developed. Secondly, the results, i.e., biomass potential from agricultural and forestry residues, the cost of the biomass at the power plant location in the Croatia are presented.

2. METHODOLOGY

In this section, the methodology for assessment of biomass potential is described. The selection of the biomass resources was based on the RenewIslands/ADEG methodology. Using this methodology three types of biomass were selected for further analysis, based on the region needs, its resources and the applicable technology.

2.1. Technical potential

Wheat straw is an agricultural residual that remains on the soil surface after grain harvest. The amount of residue produced on the field varies considerably with growing conditions and the amount of crop grown. Straw produced in regions should not all be removed from the fields. One part must be left on the field for the wind and water erosion control and one part of straw is used for bedding and feeding of livestock. Straw required for bedding and feeding of livestock varies from region to region and mainly depends on the duration of winter season and the number of cattle in particular region. Technical available potential of wheat straw in regions (expressed in t) will be obtained as:

$$E_{PW(i)} = (W_{P(i)} \times STGR_{W(i)}) - (SCP_{(i)} \times C_{A(i)}) - (SLP_{(i)} \times N_{C(i)}) \qquad (1)$$

Where $W_{P(i)}$ represents the wheat production in region i (t), $STGR_{W(i)}$ the wheat straw to grain ratio in region i, $SCP_{(i)}$ the straw cover required for soil protection in region i (t/ha), $C_{A(i)}$ the cultivated area of wheat in region i (ha), $SLP_{(i)}$ the straw used for livestock production in region i (t/cattle) and $N_{C(i)}$ the number of cattle in the region i.

Corn stover is an agricultural residue defined as the portions of the corn plant aside from corn kernels that remain on the soil surface following grain harvest. It is not possible to collect all the corn stover from the field because of losses which are generated during the process of harvesting and collecting. These losses mainly depend on the mechanization used in the harvesting and collecting process. Corn stover residues which are left on the field *protect soil from water and wind erosion and increase soil organic carbon (SOC) dynamics. For higher corn yield and lover soil erosion, greater presence of stover is needed. Technical available potential of corn stover is obtained after subtracting the quantities of stover needed for soil protection and losses due to collecting and harvesting process from the total production of corn stover in region. Technical available potential of corn stover in region i (expressed in t) will be obtained as:*

$$E_{PC(i)} = (C_{P(i)} \times STGR_{C(i)}) - (T_{CS(i)} \times M_L) - (T_{CS(i)} \times S_{PP(i)}) \quad (2)$$

Where $C_{P(i)}$ represents the corn production in the region i (t), $STGR_{C(i)}$ the corn stover to grain ratio, $T_{CS(i)}$ the total potential of corn stover which is produced on the field in the region i (t) and M_L the mechanisation losses (%), $T_{CS(i)}$ the total amount of corn stover produced on the field in region i (t) and $S_{PP(i)}$ the soil protection factor in the region i (%).

Forest residues usable for energy purpose are produced during silvicultural operations aimed at producing firewood and industrial wood and from sustainable sawlog harvest. The methodology followed is based on the current national yearly felling and biomass fraction, but only for tree branches smaller than 7 cm in diameter. Technical available potential of forest residues in the region i (expressed in m^3) will be obtained as:

$$E_{PF(i)=} = Y_{F(i)} \times F_R \quad (3)$$

Where $Y_{F(i)}$ represents the yearly felling of the forest in the region i (m^3) and F_R the forest residues factor (%).

2.2. Energy potential

The assessment of biomass energy potential is based on the technical potential of the biomass and the respective lower heating value of each biomass available for energy purposes. The lower heating value is different for each type of biomass and this value depends on chemical structure of biomass, contents of moisture in the biomass and content of the hydrogen in the biomass. Energy potential for different types of biomass (expressed in GJ) will be obtained as:

$$B_{ep(n)} = E_{p(n)} \times LHV_{(n)} \quad (4)$$

Where $E_{p(n)}$ represents the technical available potential of biomass type n (expressed in tons) and $LHV_{(n)}$ the lower heating value of biomass (expressed in GJ/ton).

2.3. The cost of the biomass at the power plant location

The cost of the biomass at the power plant location depends on the cost of the biomass at the forest road or agricultural field, the transportation cost, the distance between the biomass location and the plant location and on the size of the power plant. The main impact on the cost of biomass has a radius of collecting biomass which mainly depends on the size of the power plant and on the available biomass in the areas located closest to the plant location. The cost of the biomass at the power plant location (expressed in €/tons) will be obtained as:

$$G_C = \sum_{i=1}^{n} \frac{\left[C_B + \left(T_P \times U_i\right)\right] \times K_{Bi}}{P_B} \quad (5)$$

Where G_C represents the average price of the biomass at the plant location (€/ton), C_B the price of the biomass (€/ton), T_P the biomass transport cost (€/ton/km), U_i the distance between center of the region and the plant location (km), K_{Bi} the total amount of biomass delivered from region i (ton) and P_B the annual fuel consumption of power plant (ton).

3. CASE STUDY DESCRIPTION

Land surface of the Republic of Croatia spreads over a total of 56,542 km^2, out of which 42% is under forests, 19% is available for cultivation, 19% is limitedly suitable for cultivation, and 14% is not available for cultivation and can be used for cultivation of energy crops [7]. Republic of Croatia is divided into counties, primary territorial subdivisions. There are total 21 counties, counting in the City of Zagreb which has status equal to a county. Croatia produces more than 2.7 Mt of wheat and corn grain annually and cuts over 4.5 million cubic meters of state owned forest [8]. In the Croatian state owned forest Annual Allowable Cut (AAC) in the period of 2006 – 2015 is around 5.8 million cubic meters of tree and growth is 7.96 million cubic meters [9]. Parameters of the Croatian cereals production are presented in Table 1.

Table 1. Croatian cereals parameters for a period of 4 years (2002-2006) [8]

		Wheat production			Corn production		
		Area, ha	Production, t	Yield, t/ha	Area, ha	Production, t	Yield, t/ha
Croatia	Avg	190,382	750,946	3.97	357,278	2,053,043	5.86
	Max	233,611	988,175	4.58	407,455	2,501,774	6.92
	Min	146,411	601,748	2.96	296,521	1,569,150	3.86

4. RESULTS

4.1. Technical potential of biomass in Croatia

The availability of biomass from the forest and main crops in Croatia has been evaluated. The potential of biomass in Croatia was calculated by using appropriate value from Table 2.

Table 2. Characteristics of different types of biomass in Croatia [10]

	Straw to grain ratio [-]	Soil protection [t/ha]	Livestock production [t/cattle]	Mech. losses [%]	Soil protection factor [%]	LHV of biomass [GJ/t]	Forest residue factor, [%]
Wheat straw	1.6	1.5	0.6	-	-	13.74	-
Corn Stover	0.8	-	-	20	50	14.7	-
Forest Residues	-	-	-	-	-	8.5	12

Agricultural biomass has been identified and calculated for two categories, wheat straw and corn stover. To calculate technical available potential of wheat straw, number of cattle in Croatia has been used in the equation. Maximal technical available potential of wheat straw in Croatia is over 900 kt year^{-1} and corn stover over 600 kt year^{-1}. Calculated potential of forest residual in Croatia is over 700,000 cubic meters. Technical potential of wheat straw and corn stover is presented in Table 3.

Table 3. Technical potential of wheat straw and corn stover in Croatia

		Technical available potential of wheat straw, t	Technical available potential of corn stover, t
Total Croatia	Avg	622,752	492,730
	Max	937,476	600,426
	Min	449,993	376,596

4.2. Energy potential of biomass in Croatia

The energy potential of biomass in Croatia was estimated by using LHV for different types of biomass. Characteristics of several biomass types have been reported in Table 2. The total energy potential of biomass was estimated for all counties in Croatia. The maximum energy potential was observed in the east part of Croatia, while the minimum potential have counties in the south part of Croatia so it can be disregarded. Energy potential of agricultural and forest residues in Croatia is presented in Table 4.

Table 4. Energy potential of agricultural and forest residues in Croatia [9-11]

		Energy potential of corn stover, 1000 GJ	Energy potential of wheat straw, 1000 GJ	Energy potential of forest residues, 1000 GJ
Total Croatia	Avg	7,243	8,557	-
	Max	8,826	12,881	-
	Min	5,536	6,183	5,909

4.3. The cost of the biomass at the power plant location

The cost of the biomass at the location of the power plant has been calculated based on the input data from section 4.1 and expression (5). The transport cost of the biomass of 0.1 €/t/km [12] and the cost of the biomass of 35 €/t [10] have been used in the calculation of the biomass cost. Also, the cost of the biomass has been calculated for the power plant capacity of 300,000 t. The results are presented in Fig. 1. The comparison of the calculated biomass cost shows that the cost generally increases with the increase of the plant capacity. The illustration also shows that selected locations Osijek and Vukovar have lower calculated price of biomass compared to Slavonski Brod. For the location Osijek and biomass power plant capacity of 300,000 t/year, calculated price of biomass ranges between 39.50 €/t and 46,72 €/t.

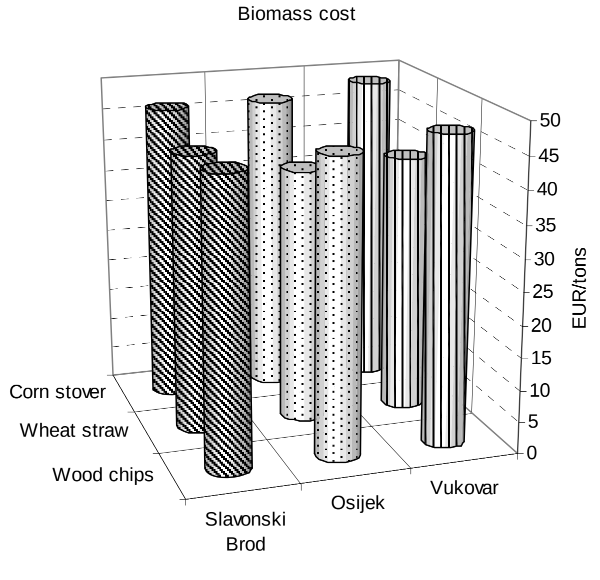

Fig. 1. The cost of the biomass at the selected location for the power plants with the capacity of 300,000 t/year and biomass transport cost of 0.1 €/t/km

5. CONCLUSION

In this work, a methodology for technical evaluation of the biomass potential and cost of biomass at plant location has been presented. The methodology has been applied to Croatia. From the biomass statistical data it was possible to estimate the technical and energy potential for each type of biomass. The results show that there is a high potential of the biomass for the energy purpose. Average quantities of wheat straw which can be removed from the field is 600 kt and corn stover 490 kt. Available potential of forest residues calculated in this study is 690,000 cubic meters. Energy potential of forest residual is 5.9 PJ, wheat straw is 6.1 PJ and energy potential of corn stover is 5.5 PJ. An analysis performed in Croatia, for three different locations, plant capacity and different types of biomass, shows that the biomass cost ranges between 39.5 €/t and 46.7 €/t. The methodology applied for the estimation of the biomass cost didn't take into consideration competing uses of biomass with other sectors and therefore, future studies should be focused on that issue.

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