



Production of Solid Biofuels in the Function of Development of Rural Areas

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ABSTRACT

Production of solid biofuels from renewable energy sources is not often offered as an option for the diversification of rural areas. With the aim of verifying the sustainability of such a solution in our own environment, we analyzed the effects of the possible introduction of energy plantations in the rural areas of the municipality of Kozarska Dubica in Bosnia and Herzegovina (B&H).

Short rotation coppices (SRC) of black locust (*Robinia pseudoacacia*), poplars (*Populus* spp.) and willows (*Salix* spp.), together with perennial energy grasses: switchgrass (*Panicum virgatum*) Chinese silver grass (*Miscanthus sinensis*) and miscanthus (*Miscanthus* × *giganteus*), based on the hitherto unused lands of this local community, are able to provide about 35,000 t of standard dry biomass every year, whose energy potentials are estimated at around 165,000 MWh, or 14,000 toe. At the same time, for the heating needs of the town of Kozarska Dubica, covering 2/3 of the residential and business premises, around 25,700 MWh should be provided in one season, which is significantly less than the estimated energy potentials.

By channeling the produced biomass into a district heating plant, the city of Kozarska Dubica would significantly improve the quality of life of its citizens, and create conditions for permanent and secure income for residents of rural areas.

Keywords: short rotation coppices, perennial energy grasses, solid biofuels, rural areas

INTRODUCTION

Diversification of the rural economy is often promoted as an effective means of improving the situation in rural areas of B&H, the Balkans and most of Europe. In doing so, various initiatives are found, which most often come down to food processing, recreation and tourism (Manić, 2014; Mitrović et Živković, 2018; Ward, 2006). Not so often, the sustainable development of rural entrepreneurship is linked to renewable energy sources, and if this is done, solar and wind energy is put in the foreground, where a participatory approach is often lacking and the rural population remains on the sidelines, without concrete influence on the initiative itself (Sommer et al., 2017; Tolnov Clausen et Rudolph, 2020).

In the environment from which we come, only in recent years has the production of solid biofuels found its place in the development strategies of rural areas. In practice, in the field, there are no commercial energy plantations, while the number of experimental plantations is very small.

Solid biofuels come from various sources. This paper focuses on two of their categories: SRC and artificially

established energy grass plantations. SRC are intensive plantations of fast-growing tree species, established on land that allows the use of mechanization, both in the planting phase and in the harvesting phase. Under certain conditions, abandoned land is considered, as well as land on which agricultural production is not profitable, and degraded land intended for recultivation (Dražić et al., 2005). These plantations have a high planting density, and are managed in the same way as a short rotation forests and SRC. They are intended to produce biomass that can be used to obtain energy (Serup et al., 2005). In the world and in our country, there is a large number of cultural (cultivated) species that can also be used for energy needs. A particularly interesting group are perennial herbaceous grasses, for several reasons. First of all, because they spend most of their life energy on the development of green biomass and roots and because they survive in the same place for several years, unlike annual grasses that must be renewed every year (Ljubojević, 2016).

In order to affirm the production of solid biofuels from renewable sources as a function of the development of the local rural area, we analyzed the possibilities and effects of introducing this activity in the municipality of Kozarska Dubica in B&H applying the case study method.

MATERIAL AND METHOD

Area of research

The municipality of Kozarska Dubica is located in the northwestern part of B&H, on the border with the Republic of Croatia, and covers an area of 499 km² with about 31,000 inhabitants, of which about 12,000 (38.7%) live in the city and about 19,000 (61.3%) in the countryside. The city of Kozarska Dubica is located along the Una river, at an altitude of about 100 m a.s.l. It is the administrative, political and cultural seat of the municipality. According to the latest census, 11,566 inhabitants live in the city area, distributed in 3,631 households (Anon., 2016). According to the same source, these families own 4,965 apartments, which means that the number of housing units is greater than the number of families, i.e. that some citizens own more than one apartment. According to the municipal cadastre, there are 644 business premises in the city.

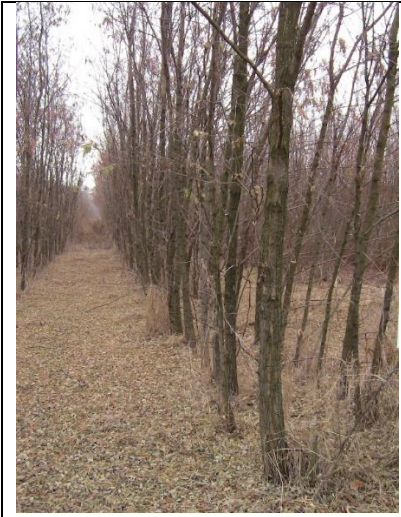
Assessment of available land areas and their structure

The analysis of available land areas and their structure, i.e. field conditions that determine the choice of the optimal set of species and optimal production lines, was carried out in the following way. When creating the land use plan for a part of the municipality of Kozarska Dubica with an area of 30x15 km, i.e. 45,000 ha, IRS 2005 Fusion and Ikonos 2009 satellite images with a spatial resolution of 5 m were used (Anon., 2005; Anon. 2009), as well as high-resolution satellite images that can be viewed on the ArcGIS 10 (or newer) platform (Anon., 2016/1). In this way, the existing CORINE Land Cover classification of land, created in 2006 for most of Europe, including the territory of B&H, was completed (Anon. 2006). The thematic map of land use was created in the ESRI ArcGIS v. 10.1 software package, using tools for classification, i.e. extracting information from raster images, which belong to the group of tools for spatial analysis. The analysis was done for two defined zones: 1. the suburban zone, whose longer axis of the ellipse is 5 km and covers an area of 3,878 ha, and 2. the rural zone, which covers an area of 31,851 ha. The process of extracting areas of different, predefined categories of use was carried out by applying a supervised classification of a raster image, by previously creating an ASCII signature file, so that a part of the surface that represents one of the categories of use of the space (e.g. forest areas in private ownership) is separated by an interactive method using polygons, after which it receives the code of the classification unit to which it belongs. In this phase, the classification units separated in this way have the character of a sample. Such a procedure was carried out for each of the 11 classification units related to different uses of space (Map 1), which had to be separated when creating the thematic map, except state-owned forests, for which digital maps of the forest management units were used. Surface classification on the total analyzed area, was performed using the Maximum Likelihood Classification tool, based on already defined classification units, i.e. their samples contained in the signature file (Anon., 2024).

Selection of the optimal set of plant species, their yield and energy potentials

A greater number of tree and shrub species are suitable for biomass production in SRC, however, only a small

number of them have been introduced into regular production in large industrial plantations. In Europe, these are: black locust (*Robinia pseudoacacia*), poplars (*Populus* spp.) and willows (*Salix* spp.), (Fig. 1-3). Considering this fact, these species were also our choice. The yield possibilities of black locust and willows are approximated by the lower interval values from the literature, while the yield possibilities of poplars are calculated as average interval values (Tab. 2). After consulting a large number of relevant sources, we came to the conclusion that black locust would be best suited to bright/warm positions on southern exposures, poplars would be best suited to moderately bright/moderately warm positions on flat terrain, and eastern and western exposures, while willows would be best suited not only to dark/cold positions on northern exposures, but also to positions that are also suitable for poplars. When designing the optimal solution, willows were positioned only on dark/cold exposures, while moderately bright/moderately warm positions were reserved for poplars, because they achieve a higher average yield of useful biomass per unit area, all other conditions being equal.

		
Figure 1: SRC of black locust	Figure 2: SRC of poplars	Figure 3: SRC of wilows
Photos were taken in the large experimental plantations at the Tass Puszta site, Hungary (S. Ljubojević)		

There are at least thirty grass species in the world that can potentially be used as energy crops. On the basis of extensive research carried out in Europe and the USA, five species are recommended for European areas, namely: for the Mediterranean area - giant reed (*Arundo donax*), for the area of southern and central Europe – switchgrass (*Panicum virgatum*), giant miscanthus (*Miscanthus x giganteus*) and Amur silver grass (*Miscanthus saccharifolius*) and for the area of central and northern Europe - Chinese silver grass (*Miscanthus sinensis*) and red canary grass (*Phalaris arundunaceae*), (Ljubojević, 2016). In this case, three species were chosen: switchgrass, giant miscanthus and Chinese silver grass. Red canary grass is intended for the eventual formation of plantations on wet, coastal zones. The yield possibilities of Chinese silver grass are approximated as 35%, of switchgrass as 40% and of giant miscanthus as 50% of the above values from the literature (Tab. 2). After consulting a large number of relevant sources, we came to the conclusion that dark/cold and moderately bright/moderately warm positions would be most suitable for switchgrass. Moderately bright/moderately warm positions and bright/warm positions would be most suitable for giant miscanthus, while dark/cold and moderately bright/moderately warm positions would be most suitable for Chinese silver grass. When specifying the optimal solution, Chinese silver grass was positioned in dark/cold positions because it gives a higher yield of useful biomass than switchgrass. Giant miscanthus was positioned in moderately bright/moderately warm and bright/warm positions because it gives the highest yield of useful biomass. Switchgrass is directed only to the belts under power lines, as the least demanding species.

The expected heating power of biomass of selected plant species, i.e. their energy potentials, are given in Table2. The conversion of values from MJ/kg_{atro} to kWh/kg_{atro} was performed using the form /1/, while the form /2/ is used to convert MWh to toe (tons of oil equivalent):

1 MJ = 0,277777778 kWh, adopted 0,2778 /1/

1 toe = 11,63 MWh /2/

In practice, the weight of biofuel with a moisture content of 0% is often called atro weight and is expressed in atro tons (t_{atro}). The name of this conditional unit comes from the abbreviation of the German term “absolut trocken” – absolutely dry (Kulušić, 1977). Biofuel with a higher atro weight has a higher degree of utilization and therefore a higher value.

Table 1: Expected aboveground biomass yield of selected energy species

Energy species	Average biomass yield $t_{atro}/ha/year$	Country/region	Source
Black locust	7.1 - 9.7	Hungary	Redei et Veperdi, 2009
Poplars	14-Oct	Slovenia	Čebul et al., 2012
Wilows	20-Jul	Austria	Jauschnegg et. al., 2009
Switchgrass	5 – 26.6	Mediterranean region	Alexopoulou et al., 2000
Chinese silver grass	36.56	Slovakia	Porvaz et al., 2008
Giant miscanthus	May-44	Europe	Angelini et al., 2009

Table 2: Expected biomass heating power by energy species

Energy species	MJ/kg $_{atro}$	kWh/kg $_{atro}$	kWh/t $_{atro}$
Black locust	18.95	5.26	5,260
Poplars	17.26	4.79	4,790
Wilows	17.69	4.91	4,910
Switchgrass	17	4.71	4,720
Chinese silver grass	17.72	4.92	4,920
Giant miscanthus	17	4.72	4,720

Notes: The expected energy values of black locust, poplars and willows biomass are adopted according to Horvat (1980), in doing so, the value for willows is calculated as the middle between the values for white (*S. alba* L.) and gray willow (*S. cinerea* L.). The expected energy value of switchgrass biomass was adopted according to Lewandowski et al. (2003, 2003/1), Chinese silver grass according to Porvaz et al. (2012) and giant miscanthus according to Jureková et Dražić (2011).

Current importance of SRC and energy grass plantations for the rural development of B&H

The importance of SRC and energy grass plantations for the rural development of B&H was observed from two angles – strategic and production. From a strategic point of view, all relevant documents adopted at the level of the state and its constituent entities were analyzed. From the production aspect, all energy plantations recorded so far on the soil of B&H were taken into account.

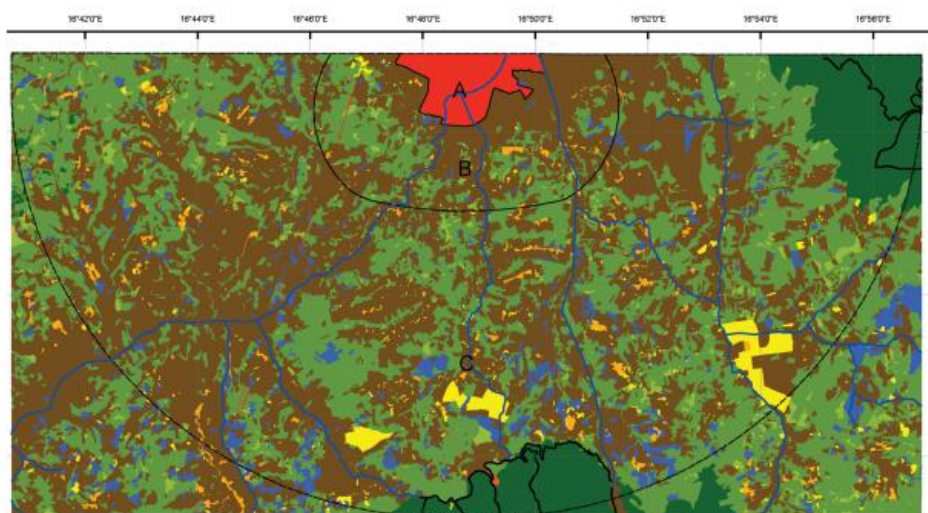
RESULTS

B&H, as a decentralized state, has the privilege of having four rural development strategies simultaneously. One at the umbrella level, two at the entity level and one at the Brčko District level. In the Strategic plan for rural development of B&H (2023-2027), none of the 12 strategic measures, foreseen for the realization of six strategic goals, refer to the production of solid biofuels from renewable sources (Anon., 2024/1). The same is with the Strategy of agriculture and rural development of the Federation of B&H (Anon., 2022), in which, the production of biofuels from dedicated energy plantations is not explicitly mentioned anywhere. The strategic framework of Republika Srpska, in one of five strategic goals (under the title: “Nature protection and sustainable use of natural resources”), in addition to crop residues and enzymes from domestic animals (bio-gas), includes energy plants as renewable energy sources (Anon., 2021/1). The Brčko District has not adopted a separate rural development strategy, but rather it has been incorporated into the overall development strategy under priority: „Development of agriculture and rural areas“. This priority does not envisage measures that can be linked to the production of renewable energy sources, i.e. solid biofuels. There are no such measures under priority: „Efficient use of energy“ (Anon., 2021).

No SRC, either experimental or production, has yet been built in B&H. The Faculty of agriculture and food from Sarajevo set up three trial plots of miscanthus in Sarajevo, Rogatica and Tuzla. The experimental plantation in Tuzla is located on the landfill of the local mine and thermal power plant (Čustović et al., 2016). The Faculty of Ecology of the Independent University in Banja Luka established a small demonstrative miscanthus plantation at the location of the "INCEL" industrial zone. Within the framework of the project "Biomass cultivation on coal mine tailings dumps in the Federation of B&H, a certain number of miscanthus rhizomes were planted at the Vrtlište surface mine, Kakanj Mine and thermal power plant.

Available areas and their structure

The gravity area, where the energy plantations would be established, consists of two zones: rural and suburban (Map 1). The surface of the suburban zone is approximated by an ellipse, the longer axis of which is 5 km (which is also the transport distance in the E - W direction) and the shorter axis is 2.7 km (which is also the transport distance in the N - N direction). The surface of the rural zone is approximated by a semicircle with a radius of 15 km, which is also the maximum transport distance for the entire observed area. In particular, the rural and suburban areas of the municipality of Kozarska Dubica occupy an area of 35,728.90 ha (Tab. 3). From Table 3, we see that 2,193 ha of land is not brought to its intended purpose, that is, it is not used. In this, uncultivated agricultural land participates with 63.7% (1,396.08 ha), forest land in private ownership with 33.5% (734.48 ha), belts under power lines with 2.3% (51.5 ha) and forest land owned by the state with 0.5% (10.94 ha), (Map 1). Globally, 92% of unused land is in the rural zone and only 8% in the suburban zone.



Map 1: Surface structure by categories and zones: A – urban, B – suburban, C – rural



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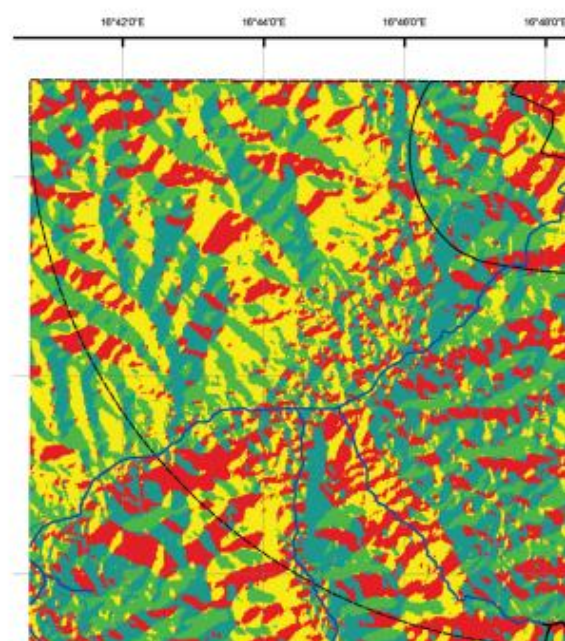
1-urban zone, 2 – industrial zone, 3 – areas under power lines, 4 – other areas, 5 – bare agricultural land, 6 – agricultural land under annual crops, 7- agricultural land under perennial crops, 8 – privately owned forest land, 9 – private forests, 10 – state-owned forest land, 11 – state forests

Table 3: Surface structure by categories and zones

	Category	Suburban zone (B)	Rural zone (C)	Total (B+C)
		(ha)		
1	State forests	-	2,637.54	2,637.54
2	State-owned forest lands	-	10.94	10.94
3	Private forests	1,114.58	10,872.38	11,986.96
4	Privately owned forest lands	94.77	639.71	734.48
5	Agricultural lands under perennial crops	36.04	791.27	827.31
6	Agricultural lands under seasonal crops	2,490.04	15,097.18	17,587.22
7	Uncultivated agricultural lands	68.01	1,328.07	1,396.08
8	Other lands	63.69	421.83	485.52
9	Belts under power lines	10.51	40.99	51.50
10	Industrial zone	-	11.35	11.35
	Total	3,877.64	31,851.26	35,728.90
	Total	173.29	2,019.71	2,193.00

Note: Surfaces that are not brought to purpose are shaded.

On the areas that are currently not used for their intended purpose, the most represented are northern positions (N) - 29.8% (652.66 ha). Western exposures (W) have slightly lower frequencies – 26.1% (572.34 ha), then eastern exposures (E) – 24.5% (538.21 ha), followed by southern exposures – 18.2% (399.95 ha), while flat positions have the lowest frequency (Ø) – 1.4% (29.84 ha), (Map 2).

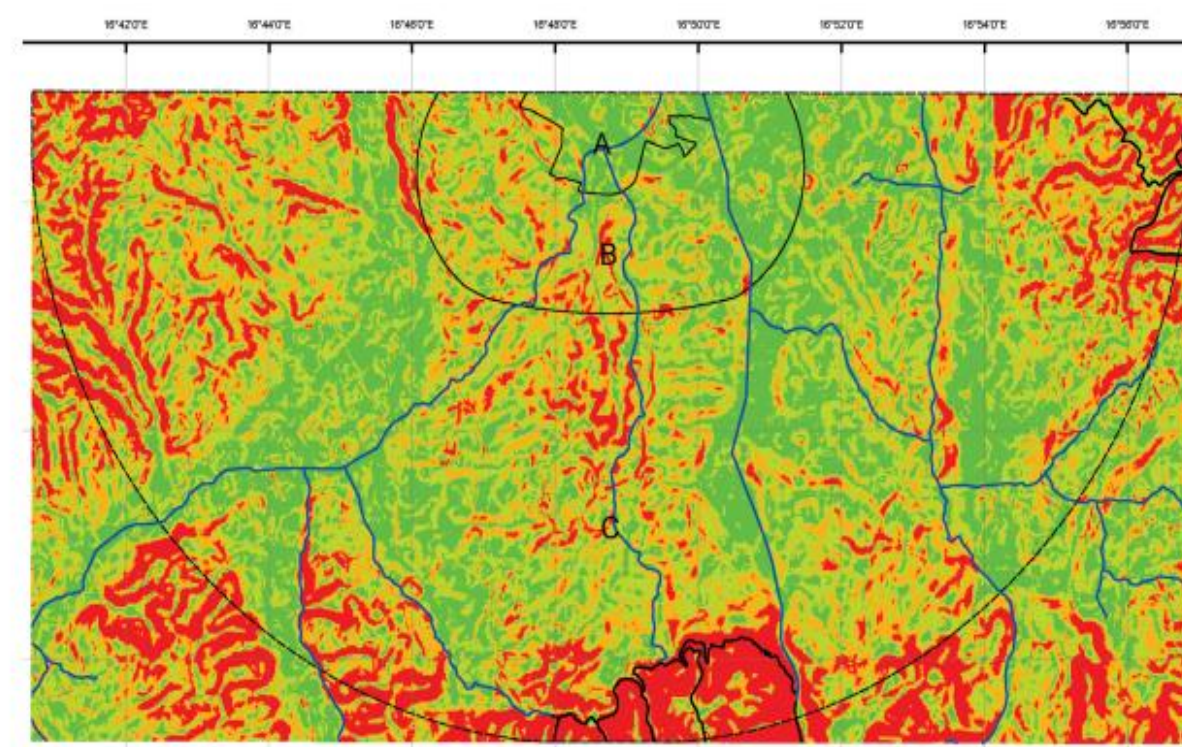


Map 2: Distribution of surfaces according to exposures



Ø N E S W

If we consider the terrain exposures in the context of the inflow of direct solar radiation, then we can talk about the following distribution: the largest part of the observed areas falls into the category of moderately bright/moderately warm exposures (E,W Ø) - 50.6% (1110.55 ha), while dark/cold (N) and bright/warm positions (E) are evenly represented - 29.8% each (652.66 ha each). When it comes to terrain slope, the most common are terrains with moderate slopes (6-15%) with a frequency of 59.5% (1,306.32 ha). They are followed by flat terrains (0-5%) - 24.9% (545.67 ha) and finally terrains with large slopes/steep terrains (>15%) - 15.6% (341.01 ha), (Map 3). The relatively small participation of steep terrain allows a wide variety of technological lines, from planting (sowing) to felling (harvesting) and further to the processing plant or the final consumer.



Map 3: Distribution of surfaces by slope



Energy potential of land not converted to biological production

Based on the expected biomass yield and its known heating capacity, the total energy potentials of the suburban zone and rural zone were calculated and summarized in Table 4.

Table 4: Energy potential of land not converted to biological production

Zone	Area (ha)	Expected biomass yield (t_{atro})	Expected energy reserves	
			MWh	toe
Suburban	173,6	2.352,98	8.752	752,4
Rural	2.019,7	32.689,84	156.304	13.439,9
Total	2.193,3	35.051,82	165.056	14.192,3



It is known that only a part of households use central heating (in the EU on average 12.4%; Safa, 2013). Since this is an urban area of a small settlement, 2/3 or 66.7% of the city's population was taken as the basis for the calculation. If we consider that the average area of a residential unit of a household in BiH is 73 m² (Anon., 2016) and of a business unit in Kozarska Dubica is 58 m² (pilot survey based on 30 business premises in the city), we arrive at the data that it is necessary to heat 201,610 m² of residential and business premises. The expected average energy consumption for heating is 127.5 kWh/m²/year, which gives a total consumption of 25,705,275 kWh (201,610 m² x 127.5 kWh/m²) = 25,705.3 MWh; according to EU statistics, the average energy consumption in EU countries with standard residential buildings (excluding energy neutral and passive buildings) is between 90-140 kWh/m²/year (Anon., 2024/2). By choosing the upper quartile of the above range as acceptable for the area of B&H, we arrived at an expected value of 127.5 kWh/m²/year.

In the observed region, the heating season lasts seven months (from September 15 to April 15), or 5,040 hours, which means that the required power of the district heating plant is 5.1 MW (25,705 : 5,040).

We see that the energy potential of the land that has not been brought to biological production (165,056 MWh) exceeds the energy needs of the planned city heating plant (25,705.3 MWh). In order to reduce the cost of transportation, the priority in raw material supply would be the suburban zone, from which all available biomass would be used (2,353 tons equivalent to 8,752 MWh). In order to reduce production costs, this biomass would be delivered in the form of coarse wood chips (hog fuel) and without additional drying. 14% of biomass would be supplied from the rural zone and directed to the city's heating plant (4,541 tons of biomass equivalent to 21,709 MWh). The remaining quantities of biomass from the rural zone would be directed to the collection and logistics centers for biomass.

The biomass collection and logistics center (BCLC) is a regional service station for solid biofuels of guaranteed quality. The sale of biofuels through the BCLC creates additional value for all participants in the reproduction chain. Biomass producers are enabled to enter the market together, regardless of the size of their holdings and the technical equipment of their work. Biomass consumers are ensured the delivery of quality biofuel from local sources throughout the year. For this reason, households and businesses can choose this financially advantageous and environmentally friendly method of heating without any fear. BCLC contribute to the creation of new "green jobs" and secure existing jobs in related sectors in the long term (Loibnegger et al., 2010).

CONCLUSIONS

Land that is located within 15 km radius around the town of Kozarska Dubica, and that has not yet been converted to biological production, covers an area of 2,183 ha. In this, uncultivated agricultural lands participate with 63.7%, forest lands in private ownership with 33.5%, belts under transmission lines with 2.3%, and forest lands owned by the state with 0.5%. Globally, 92% of unused land is in the rural zone and only 8% in the suburban zone.

If energy crops were established on these areas, they would be able to provide about 35,000 t of standard dry biomass every year, whose energy potentials are estimated at around 165,000 MWh, or 14,000 toe.

For the heating needs of the city of Kozarska Dubica, with coverage of 2/3 of residential and business premises, in one season, it is necessary to provide about 25,700 MWh, which is significantly less than the estimated energy potential.

By channeling the produced biomass into a central heating plant with a capacity of 5.1 MW, the city of Kozarska Dubica would significantly improve the quality of life of its citizens, and create conditions for permanent and secure income for residents of rural areas.

The offered solution is not the exclusivity of the municipality of Kozarska Dubica. It could be applied in a similar way in many other local communities and thus contribute to better energy security in the whole B&H.

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