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Review

Analysis of the Possibilities for Using Renewable Energy Sources in the Autonomous Province of Vojvodina

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Abstract: The aim of this paper is to analyze renewable energy sources (primarily untapped biomass potentials) in the Autonomous Province of Vojvodina in the Republic of Serbia, which, when used for energy purposes, could significantly reduce energy dependence on fossil fuels. The idea of using biomass in Vojvodina emerged about ten years ago, but it is estimated that currently only 5% of total biomass potential, the most significant source of renewable energy in the region, is being used. This paper re-emphasizes the idea of focusing Vojvodina's energy policy on its own energy resources, which are readily available and renewable, but each year is either burned in the fields or left to rot. The paper will outline the total potential of raw materials, the form in which they are found, and the possible means of utilizing them. It will also provide an overview of energy in Vojvodina with a particular focus on the portion of renewable sources as a neglected potential within overall energy consumption. In addition to energy potential, this paper also points to the benefits for heating and the environment that would be created through increased use of biomass in the process of energy production.

Keywords: renewable energy; energy sources; energy potential; biomass potential

1. Introduction

As early as this current century, humanity will face significant challenges in providing the energy necessary for everyday life and the further development of the human population. Energy is an integral part of society and plays key roles in socio-economic development, improvement in living standards, and quality of life. Throughout history, humans have used various sources of energy, ranging from wood, coal, oil, and petroleum to nuclear power [1]. The overuse of fossil fuels has created an enormous imbalance in the amount of these resources that will be available in the future, and these fuels cannot be relied on beyond 2090. In addition to the depletion of fossil fuels, there is the generally accepted side effect of using fossil fuels, specifically the emission of carbon dioxide into the atmosphere, which results in the greenhouse effect and harmful climate change. As fossil fuels become depleted, prices and shortages will increase, causing serious energy crises and conflicts [2].

Clean energy is important for maintaining environmental standards, and by 2050 it should account for 50% of total energy consumption, while by 2100 total energy needs should be fulfilled exclusively through renewable, alternative, and clean energy sources [3]. In the Renewable Energy Directive 2009/28/EC, the European Union has prescribed for all member states that 20% of total consumption come from renewable energy [4]. Some countries, for example, Sweden, have already achieved a share of 50% renewable energy use, and Denmark is very close to achieving this goal. Currently, renewable energy sources (biomass, small hydro-power, geothermal, solar, wind) account for about 14% of global

energy consumption, of which 62% comes from biomass [5,6]. Thus, it is evident that of all forms of renewable energy sources, biomass is of the greatest importance. It is important to also note that, in comparison to fossil fuels, using biomass for energy purposes does not emit "new" carbon dioxide into the atmosphere [1].

Carbon dioxide is currently considered the greatest contributor to global warming, and the largest quantities are released into the atmosphere by burning fossil fuels or through the overproduction of large livestock for human consumption. Burning coal, oil, and gas causes 90% of global carbon dioxide emissions. For example, generating 10 kWh of primary energy by burning coal releases 3.3 kg of CO_2, 2.7 kg is released by burning oil, and 1.9 kg by burning natural gas. Biomass, on the other hand, is carbon neutral: Carbon dioxide is absorbed from the atmosphere during photosynthesis and plant growth, and then it returns to the atmosphere through natural decay or burning, which creates a balanced state [7].

Harvest residues are the largest biomass reserves in the world, and estimates are that 1.5 Gt of straw is generated worldwide [8]. By using palletization as a means of finalization, harvest residues can be used as raw material in their entirety, including stems and husks (wheat, rice, barley), corn cob and cornstalks, and plants cultivated for energy purposes (energy cane, green grass, hemp, poplar, willow, sugar cane) [9].

2. Potential for Raw Materialfor Biomassin Vojvodina

The Autonomous Province of Vojvodina is an integral part of the Republic of Serbia. Located in the north of the country, it is divided into seven districts and has a population of approximately 1.93 million [10]. Serbia as a region, of which Vojvodina is a part, uses very few renewable energy sources. In 2011, they comprised only 2% (i.e., 0.09 million tons of oil equivalent (Mtoe)) of overall energy sources [11].

According to estimates in 2011, energy consumption from renewable sources as a percentage of overall consumption was only 1.25% [12]. According to 2015 estimates by the World Bioenergy Association (WBA), the amount of renewable energy in primary consumption increased to 3.2% [7]. Such a small proportion of renewable energy sources as part of the total energy sources seems counterintuitive, considering the amount of biomass generated annually in Vojvodina. These statistics illustrate a catastrophic energy situation in Vojvodina, as they indicate incredibly high dependence on the import of fossil fuels for energy production. Data related to Vojvodina specifically is presented Table 1.

Table 1. Basic data of the Autonomous Province of Vojvodina.

Subject	Unit	Data
Population	-	1,932,000
Land area	ha	2,150,000
Arable land	ha	1,780,000
Forest land	ha	150,000
Cattle	Head	266,000
Pigs	Head	1,600,000

An analysis of the data in Table 1 shows that 83% of the land in Vojvodina is arable, while only 7% of the country is forested. This indicates that harvest residues are a primary form of biomass that could potentially be used for energy. Figure 1 illustrates the availability of this potential energy source in the region by showing the amount of harvest residues available in 43 municipalities in Vojvodina.

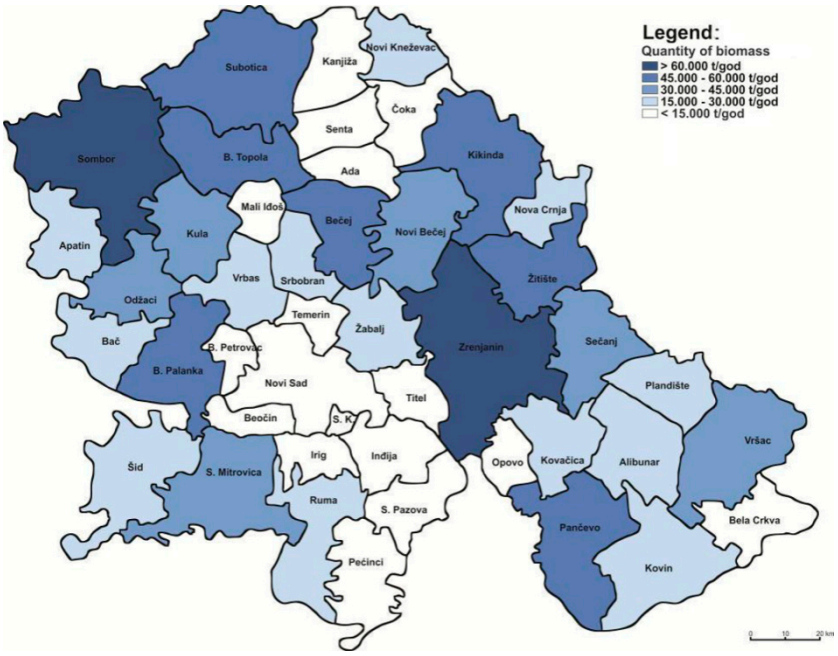


Figure 1. Density of available energy potential of harvest residues (agricultural biomass) in 43 municipalities in Vojvodina (Source adapted from Ref. [13]).

In Vojvodina, an average of 10 million tons of biomass are generated annually. If only 25% ofthebiomass available for energy purposes were utilized, the equivalent of about 1.3 million tons of oil (Diesel D2) would be replaced. This is approximately equivalent to all of the agricultural fuel consumption for the entire Republic of Serbia [14]. All available biomass can be divided into several types: wood biomass (trees, waste from the timber industry, fast-growing trees, etc.), non-wood biomass (harvest residues, fast-growing grasses, kernels or pits, plant husks, etc.), animal biomass, and biomass from municipal and industrial waste. Table 2 gives an overview of total biomass quantities by type in Vojvodina. In previous research on this topic, when presenting the quantities of biomass, averages for the period 2003-2007 have most often been used. Table 2 presents averages for 2009–2011.

Table 2. Total biomass quantities in the territory of Vojvodina [1].

Biomass Type	Tons per Year
Agro-biomass from crop production	6,245,000
Livestock manure	3,600,000
Forest biomass (residues)	351,000
Fruit and vine growing pruning	95,143
Municipal waste (organic)	393,000
Total	10,684,143

[1] Source adapted from Ref. [7].

Analysis of the data in Table 2 shows that, out of all forms of biomass available, harvest residues, which make up 58% of the total biomass, have the highest potential for energy use. A clearer picture of the energy potential in biomass emerges when examining the crops that yield the most harvest residues. These estimates are given in Table 3, which shows average cereal yields by type in the period 2009–2011.

Table 3. Agro biomass production of major energy crops [2].

Crop	Surface [ha]	Yield of Grain [t/ha]	Grain Mass [t/ha]	Ratio of Masses [t/t]	Yield of Straw [t/ha]	Mass of Straw [t/Year]
Wheat	262,900	3.7	972,730	1:1	3.7	972,730
Other cereals	62,800	3.0	188,400	1:1	3.0	188,400
Corn(stalk + corncob)	703,100	5.2	3,650,000	1:1	5.2	3,650,000
- Corncob	-	-	-	1:0.2	1.04	940,000
Sunflower(stalk + head)	153,000	2.0	306,000	1–2	4.0	612,000
- Shell	-	-	-	−1.0/-0.3	0.6	91,800
Soya	148,000	2.4	355,200	1–2	4.8	710,400
Oilseed rape	4204	2090	8786	1–2	4180	17,500
Tobacco(leaf: stem)	4321	1475 (leaf)	6373 (leaf)	1:0.35	0.516 (stem)	2230 (stem)
Total	1,338,325	4.25	5,487,489	1:1.2	4.76	6,245,060

[2] Source adapted from Ref. [7].

The data in Table 3, and particularly the data on the quantities of harvest residues, indicate that maize has the greatest potential as a biomass, followed by wheat, soya, and sunflowers. Biomass from agriculture is used to produce a variety of products including humus and manure, animal feed, energy for heating, construction materials, furniture, alcohol, biogas, paper, packaging, decorative items, metal surface cleaners, cosmetics, etc.

When considering the quantities available, a question remains concerning the best way to use biomass from agriculture. There are large quantities of biomass renewed every year, but these are not used strategically, and unfortunately a large amount of them are still burned in the fields, despite laws prohibiting this.

The total amount of 6.2 million tons of available biomass from harvest residues is considerable, but due to limited capacity and lack of experience, only about 10% of this ends up being used for energy purposes. Realistically, utilization could be increased by up to 25%, which means that 1.5 million tons of harvested biomass is available for energy purposes. One specific limitation for such use of biomass is the field surface (yields per ha) in Vojvodina, which is much smaller than the average field surface in the EU. Figure 2 presents the distribution of arable fields in Vojvodina that are suitable for collecting straw through the use of presses for large bales, according to area and municipality.

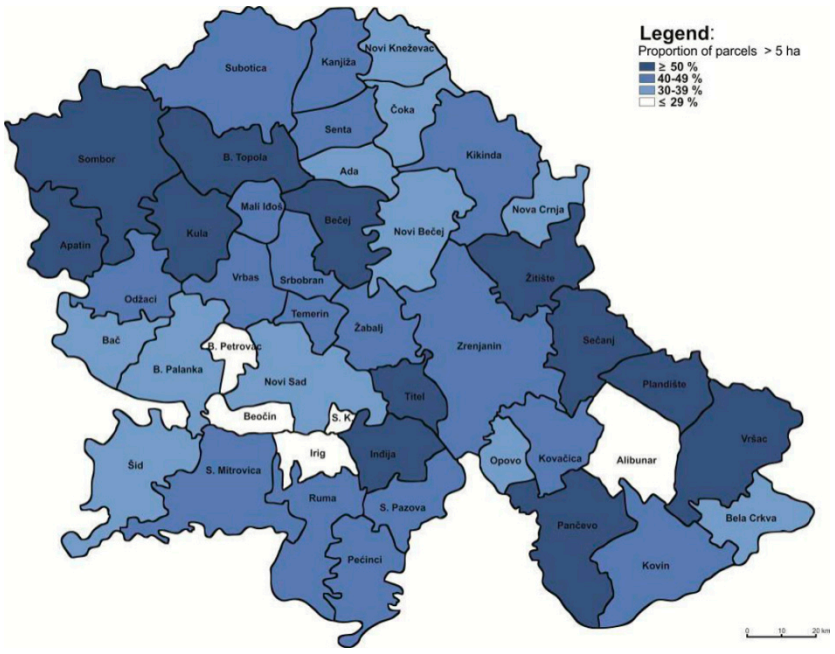


Figure 2. Proportion of parcels >5 ha in municipalities in Vojvodina with large baling presses suitable for collecting harvest residues (Sources adapted from Ref. [13]).

3. Energy Potential of Biomass and Its Current Share and Possible Potential in Total Final Energy Consumption in Vojvodina

The basic unit of energy is the joule (J), but in practice larger units are used (KJ or PJ). For large amounts of energy (e.g., annual government consumption), a common unit of measurement is the "oil equivalent"—toe (Ton of Oil Equivalent) and other units of measurement. Table 4 illustrates the relationship between energy units.

Table 4. Relationship between energy units.

	J	PJ	kWh	Toe
J	1	1×10^{-15}	2.78×10^{-7}	2.39×10^{-11}
PJ	1×10^{15}	1	2.78×10^{8}	2.39×10^{4}
kWh	3.60×10^{6}	3600×10^{-9}	1	8.60×10^{-5}
toe	4.19×10^{10}	4.19×10^{-5}	1.16×10^{4}	1

Energy consumption in Serbia is around 15 million tons of oil equivalent (Mtoe), while Serbia has 3.2 Mtoe in renewable energy sources and uses negligible quantities [15]. Ofthe3.2 Mtoe in renewable energy sources, biomass accounts for the largest share, with 2.6 Mtoe, of which 60% comes from agriculture (predominantly located in Vojvodina), and 40% comes from forest biomass [16]. In addition to harvest residues and forest biomass, the share of total available biomass is manure and biomass from organic waste. One of the most important indicators of fuel quality in general is its heat value. The thermal value of biomass depends on the type and structure of the biomass and, primarily, on the moisture content [17].

As the moisture content in the structure of the biomass increases, its thermal value decreases. Table 5 shows estimates from Brkic and Janic [18] of approximate biomass heating values (for an equilibrium moisture content of 14%).

Table 5. Net biomass heat values for equilibrium moisture content [3].

Biomass Type	Net Calorific Value [MJ/kg]
Wheat straw	14.00
Barley straw	14.20
Oat straw	14.50
Rye straw	14.00
Corn stover	13.50
Corn stover from seed corn	13.85
Corn cobs	14.70
Sunflower stalks	14.50
Sunflower husk	17.55
Soy straw	15.70
Rapeseed straw	17.40
Tobacco stalks	13.85
Fruit growingpruning	14.15
Vine growingpruning	14.00

[3] Source adapted from Ref. [18].

Table 6 provides an overview of the primary energy that can be produced from the biomass available in Vojvodina, broken down by biomass type. The total primary energy from biomass is 71 PJ, and when the primary energy from imported wood, fast-growing trees, and crops for transport fuels is included, the total primary energy reaches 98 PJ [7].

Table 6. Net heat value of wood depending on moisture content [4].

	Tons/Year	Average Energy Content per Ton [kWh]	Primary Energy [GWh]	Primary Energy [PJ]	Primary Energy [Mtoe]
Agro biomass as byproduct	6,245,060	3200	19,984,615	61.5	1469
Agro biomass for 70 Mio Liter biofuels [5]	58,000	8900	516	1.9	0.045
Livestock manure	3,600,000	130	480	1.7	0.040
Forest biomass	351,000	3400	1190	4.3	0.103
Fruit and vine growing pruning	95,143	3400	323	1.16	0.027
Municipal waste	393,000	550	216	0.8	0.019
Sum of By-Products and Biofuels				71.36	1.695
Firewood import	250,000	3900	900	3.2	0.076
In addition, 100,000 ha of short rotation forest	1,200,000 (dry matter)	5000	6000	21.6	0.516
Crops for transport fuels	52,000	11,000	572	2.0	0.048
Total	11,044,203			98.16	2.335

[4] Source adapted from Ref. [7]. [5] Half ethanol, half biodiesel.

The total primary biomass energy from Table 6 is significantly different from the previously published data in the paper [1]. This difference is due to the analysis of new data about structural changes and the extent of planting, as well as the inclusion of previously missing data for biomass of animal origin, biomass derived from organic waste, and biomass used for biofuels, along with new data for imported wood, fast growing forests, and crops for transport fuels.

It is important to note that the stated potential in biomass available for energy purposes is different from the real potential that can be exploited. Often, when evaluating potential, a maximalist approach is applied, and the potential for total yield (i.e., the total amount of harvest residues above ground) is calculated. When defining the real energy potential of biomass, the potential is divided into the following categories:

1. Theoretical potential: total above-ground residuals;
2. Technical potential: quantities of residues that can be harvested with available techniques and selected processes. In most cases this is 22–65% of the theoretical potential, which depends on type of plant, animal species, and the structure of waste;
3. Sustainable potential: quantities of residues that can be harvested without consequences for preserving soil fertility. Determining this is complex and depends on a number of factors including soil condition, agro-climate conditions, plant species, crop rotation, etc;
4. Energy potential: obtained when the quantities used for other purposes (bedding, animal feed production, mushroom cultivation, the pottery industry, production of construction material, etc.) are subtracted from sustainable potential [18].

How sustainability, and thus energy potential, is defined is also influenced by how the land is tilled. In addition to conventional tilling with rollover plows, more often large areas, especially in areas with lower rainfall, are treated without rollover. If all or most of the harvest residues are left on the surface during such cultivation, then this can be considered conservationist land cultivation. This type of cultivation would suggest that, by the time crops are sowed, about 30% of the surface is covered with plant residues (most often harvest residues, although there may be remains of fertilizer among the crops, including solid manure). However, for certain types of plants, even with harvesting half of the crop residues on the fields, enough mass is left behind to meet the requirements defined for conservation cultivation [18].

It would be realistic to estimate that 25% of harvest residues could be used for energy purposes, and the rest could be used for other purposes. A small percentage of fruit and viticulture biomass is mainly used for heating household buildings, and its potential for use in energy purposes through

the use of appropriate technology could be up to 50%. Livestock biomass can be used to produce biogas, and estimates are that up to 30% of this biomass could be utilized. Biomass from forests and the timber industry could be used to produce briquettes and pellets, and approximately up to 50% of this biomass could be utilized. Municipal waste is not currently used for energy purposes. However, since municipal waste contains up to 60% organic material, one part could be used for biogas production, another for compost, and a third to generate heat. Approximately, up to 50% of this municipal waste could be used for energy purposes. The actual biomass potential in Vojvodina can be obtained when these limitations are taken into account, as shown in Table 7.

Table 7. Calculation of Real Energy Potential of Biomass in Vojvodina [6].

	Primary Energy [PJ]	Primary Energy [Mtoe]	Utilization of the Coefficient for Real Energy Purposes	Real Energy Potential [Mtoe]	Real Energy Potential [PJ]
Agro biomass as byproduct	61.5	1.469	25%	0.367	15.37
Agro biomass for 70 Mio. Liter biofuels [7])	1.9	0.045	100%	0.045	1.9
Livestock manure	1.7	0.040	30%	0.012	0.51
Forest biomass	4.3	0.103	50%	0.05	2.15
Fruit and wine growingpruning	1.16	0.027	50%	0.013	0.58
Municipal waste	0.8	0.019	50%	0.01	0.4
Sum of By-Products and Bio Fuels	71.36	1.695	Average 29.3%	0.497	20.9
In addition 100,000 ha of short rotation forest	21.6	0.516	50%	0.258	10.8
Firewood import	3.2	-0.076	100%	-0.076	3.2
Crops for transport fuels	2.0	0.048	100%	0.048	2.0
Total	98.16	2.335	Average 37.6%	0.879	36.9

[6] Source adapted from Ref. [7]. [7] Half ethanol, half biodiesel.

This means that, out of a total biomass of about 11 million tons, realistically about 4 million tons (or 37.6%) could be used for energy purposes, which corresponds to 879,000 toes. Table 8 shows total energy consumption in Vojvodina. This amounts to about 2.939 Mtoe in total consumption, and renewable currently account for 1.25% or 0.026 Mtoe [19].

Through analyzing the data on real energy that could be obtained from biomass and then comparing it to the total energy consumption in Vojvodina, it is possible to conclude that about 30% of total energy consumption could be provided through the real potential of energy produced from biomass. Further analysis of fossil fuel stores shows that 56% of total oil imports or 73.8% of natural gas imports in Vojvodina could be replaced with Vojvodina's own biomass resources. Furthermore, a year's worth of biomass in Vojvodina is enough to replace seven years' worth of coal imports. Of the real potential of 30%, only approximately 1.25%, or 24 times less than the potential, is currently being used. Below, we outline possible means for harnessing this potential through an analysis of relevant factors connected to the best means for using them.

Table 8. Sum (Σ) energy balance in Vojvodina [8].

Entry/Item/Rate		Mtoe	%
Primary energy production		1.509	41.03%
STOCKS		−0.288	−7.82%
Net imported fuel/energy		2.457	66.79%
Energy available for consumption		3.678	100.00%
Coal		0.125	3.40%
Oil		1.569	42.66%
Natural gas.		1.190	32.36%
Downloaded electrical energy		0.768	20.87%
Renewable energy sources		0.026	0.70%
Energy available for consumption		3.678	100.00%
In the energy sector		0.521	14.16%
For transformation		1.280	34.81%
For direct consumption		1.738	47.26%
Losses during transportation and distribution		0.139	3.77%
Transformation			
Energy for transformation	2.678	100.00%	100.00%
	1.280	47 81	47 81
	1.398	52.19%	52.19%
Production of transformed energy	2.458	100.00%	100.00%
	1.061	43.16%	43.16%
	1.397	56.84%	56.84%
Transformation efficiency			91.80%
Total final energy consumption		2.939	
Non-energy consumption		0.841	28.61%
Energy consumption—by consumption sectors		2.098	71.39%
Industry		0.543	25.90%
Transport		0.571	27.23%
Other		0.983	46.88%
Energy consumption—energy surpluses		2.098	
Solid fuel		0.125	5.94%
Liquid fuel		0.672	32.03%
Gaseous fuel		0.496	23.63%
Electricity		0.656	31.27%
Energy for heating		0.124	5.92%
Renewable energy sources		0.026	1.25%

[8] Source adapted from Ref. [12].

4. Structure and Available Forms of BiomassinVojvodina and Possibilities for Energy Transformation

Most biomass comes from harvest residues from corn, wheat, soya and sunflower (with husks), and residues from fast-growing trees. Harvest residues come from straw in the following forms: bulk biomass, baled biomass, briquette biomass, and pelletier biomass.

Bulk biomass consists of raw straw (wheat, soya, and rapeseed straw), cornstalks, and sunflower stems with flower heads. This form of harvest residue, left behind after the grain harvests, remains scattered over the soil in the fields in bulk. The straw yield ranges from 3 to 6 t, corn from 6 to 8 t, and sunflower stems with flower heads are at about 2 t. Bulk biomass is characterized by high mechanical and manual labor costs and a small use of space. It is collected with various types of hand tools, and straw loading can be carried out by loaders, self-loading trailers, and silage harvesters. Bulk biomass is stored in piles under roofs to protect it from rain and has a moisture content of 12–14%. Although it is lightweight, biomass requires a large storage area. It is also difficult to load onto trailers for transport, and to arrange in piles because it is loose, unbound, and slippery.

Baled biomass is pressed on the field into bales of different shapes and dimensions. The bales can be as follows: small conventional (prismatic) bales, round (cylindrical) bales, large prismatic bales, and haystacks.

Conventional bales are usually manually loaded, unloaded, and stacked one-by-one, which leads to high operating costs. The density and dimensions of the bales can be adjusted, but generally do not weigh more than 10 to 11 kg because they need to be carried. The moisture content of the bales can be 14–20%. Usually, a mass of 90–110 kg/m^3 for bales with equilibrium moisture content is achieved [13]. This is suitable for firing at smaller facilities [20].

Cylindrical bales can be small or large, or have variable dimensions. Small cylindrical bales are 150 cm in diameter and 120 cm in length, and large cylindrical bales are 180 cm in diameter and 150 cm in length. Variable dimensions range from 60–120 cm in diameter and 120–180 cm in length. Small cylindrical bales weigh 140–240 kg, large ones 250–420 kg, and those of variable dimensions range between70–680 kg. The moisture content is 14–20%. All forms of cylindrical bales have a mass of 70–110 kg/m^3. These bales are easy to store, but they have the disadvantage of needing to be broken down first to be used in some types of heat generators. Cylindrical bales are suitable for mechanized loading and unloading but, due to their shape, they have a lower storage density, and less biomass can be loaded onto transport vehicles. This results in higher transport and storage costs. In order for harvesting straw in the form of cylindrical bales to be economically feasible, the land parcel should be at least 3 ha, and the distance to the first warehouse cannot exceed 10–15 km.

Large square bales can be pressed at normal and high pressure. Bale dimensions can be 150 × 150 × 210–240 cm and 70 × 120 × 160–270 cm, depending on the pressure value. The unit weight is 240–570 kg and 500–1000 kg. The moisture content of the bale can be 14–20%. The mass is 50–100 kg/m^3 and 140–180 kg/m^3. These bales are easy to store, but they also have the disadvantage of needing to be broken down first for some types of heat generators. The use of presses for large square bales is economically feasible only for parcels larger than 10 ha. However, they have an advantage in terms of longer transport distances and are used to supply larger energy units. Haystacks (large rounded stacks) are 240 × 300 × 260–640 cm, weigh 1300–2000 kg, and have a mass of 60–90 kg/m^3.

The second category of biomass in Vojvodina is wood biomass, i.e., wood biomass from fast-growing forests, wood from forests, and firewood from imports. Table 9 gives an overview of the mass of firewood as an indicator of the potential of this type of biomass, depending on moisture content and shape.

Table 9. Density of various types and shapes of wood [9].

Moisture Content [%]	Beech			Oak			Soft Wood			In Storage, Stacked		
	WM	CR	WC	WM	CR	WC	WM	CR	WC	WM	CR	WC
	Mass [kg/m^3]											
0	558	390	230	588	411	242	361	253	149	448	313	184
10	620	434	255	654	457	269	401	281	165	498	348	205
15	657	459	270	692	484	285	425	297	175	527	369	217
20	698	488	287	735	514	303	452	316	186	560	392	231
30	798	558	328	840	588	346	516	361	212	640	448	264
40	930	651	383	980	686	403	602	421	248	747	522	307
50	1117	781	459	1177	823	484	722	505	297	897	627	369

WM–wood without space, wood mass, CR–cords, average; WC–wood chips, stacks[9] Source adapted from Ref. [16].

Firewood is sold in cords. For many heat generators, it is preferable for them to be split lengthwise and cut into logs of, usually, 25 or 33 cm in length. Cords can also be stored in yards next to houses and for central heating in buildings with a small number of apartments.

A particular form of wood biomass is woodchips, which is produced by chopping wood. Branches that are usually up to 15 cm in diameter and material from fast growing forests are used.

The moisture content of the wood chips depends on the raw material, but the percentage from remains from the timber industry can be up to 55%. This kind of material is not suitable for combustion in smaller boilers and other heat generators and needs to be burned in special boilers. For smaller units up to 100 kW, the moisture content can be up to 25%, and this can be obtained from branches that have been left out in the open during the summer.

Storing overly moist wood leads to losses from microbial degradation. The loss of solid mass in woodchips with moisture content ranging between 30–40% is up to 2% per month and depends on a number of factors, including moisture content, external temperature, size of the chips, how long they are stored, the initial amount of microorganisms present, etc. The areas of loss are shown in Table 10.

Table 10. Annual losses of solid mass when storing moist wood [10].

Material	Dry Matter Losses [%]
Firewood, moist, uncovered	1 to 3
Small woodchips, moist, uncovered	20 to >35
Small woodchips, dried, covered	2 to 4
Large woodchips (7–15 cm), moist, covered	approx. 4

[10] Source adapted from Ref. [16].

Drying woodchips is not cost effective, except under certain circumstances. Hot air drying-active ventilation with special equipment and additional consumption of electricity can be used. Active ventilation lowers the moisture content and reduces microbial degradation. Woodchips are easier to transport than some forms of straw. Larger quantities are stored in piles outdoors, and smaller quantities are stored under canopies, in ventilated areas, or, for short-term needs, in silos. Transshipment is also easily achieved by pneumatic transport.

Biomass is compressed under high pressure into briquettes, which have a significantly reduced volume, which allows for transport over distances longer than 100 km, storage in a smaller space, and easier handling. Briquettes are formed by pressing milled particles of lignocelluloses, usually without a binder and under specific conditions, which include high pressure, elevated temperature, and optimum moisture content. The impact pressure of the piston press is 150–210 bar. When pressing biological material, the volume is reduced 10–12 times, resulting in briquettes with a high mass of 100–1400 kg/m^3 [16]. The bulk density of the briquettes is 600–750 kg/m^3, and storage space is three times smaller than that needed for bales [16]. The input material for granulation is 3–5 mm, and the optimum moisture before being introduced to the press is 15%. The briquettes are cylindrical, with a diameter of 25–90 mm and are of varying lengths [21]. The briquette is packaged in thermo-permeable foil, cardboard boxes, or paper or plastic bags [22–25].

In addition to briquettes, biomass is also pressed into smaller units (pellets), which have better fuel value and increased bulk mass, and make mechanized and automated handling and long-distance transport (up to 1000 km) more cost-effective. The pellet market has grown rapidly over the last ten years and is expected to expand even further in the near future. Pellets are 6–20 mm in diameter and 5–40 mm in length. The biomass must be milled more finely than when producing briquettes (4 mm), and the pressing pressure should be 400–450 bar.

The volume mass of the pellets is 1000–1400 kg/m^3,and the bulk density is about 650–700 kg/m^3. The storage area needed for pellets is three to five times smaller than what is needed for bales. The comparative production price of briquettes and pellets produced from harvest residues and wood pellets is given in Table 11.

Table 11. Annual losses of solid mass when storing moist wood [11].

Price	Agro Briquette	Agro Pellet	Wood Pellets
Price of baled straw for agro products and wood for pellets with transport	3.0–3.4 c€/kg	3.0–3.4 c€/kg	4–4.3 c€/kg
Mulching	2.0 c€/kg	2.5 c€/kg	3 c€/kg
Pressing	5.0 c€/kg	6.0 c€/kg	6.0 c€/kg
Packaging	1.5 c€/kg	1.0 c€/kg	1.0 c€/kg
Storage	1.0 c€/kg	1.5 c€/kg	0.5 c€/kg
Transport	2.0 c€/kg (do 500 km)	3.0 c€/kg (do 1000 km)	3.0 c€/kg (do 1000 km)
Total	14.5–14.9 c€/kg	16.0–16.4 c€/kg	17.8 c€/kg

[11] Source adapted from Ref. [22,23].

5. Analysis of Ecological Aspects and Thermal Values When Using Biomass for Energy Purposes

The use of biomass as an energy source is a logical choice in Vojvodina given its availability and quantities, and especially because the production and combustion of biomass for energy production is a closed CO_2 cycle that reduces the greenhouse effect by stabilizing CO_2 emissions. Table 12 gives a comparison of CO_2 emissions from the different sources from which electricity can be generated. The data in Table 13 show that using biomass as an energy source available in Vojvodina to produce 1 GWh of electricity generates almost 20 times less CO_2 than using coal, 16 times less than oil, and 11 times less than natural gas.

Table 12. Summary of Lifecycle GHG Emission Intensity [12].

Technology	Low	Mean	High
	Tons of CO_2/GWh		
Lignite	790	1054	1372
Coal	756	888	1310
Oil	547	733	935
Natural gas	362	499	891
Solar PV	13	85	731
Biomass	10	45	101
Nuclear	2	29	130
Hydroelectric	2	26	237
Wind	6	26	124

[12] Source adapted from Ref. [26].

Table 13. Summary of Lifecycle GHG Emission Intensity [13].

Type of Fuel	Moisture Content [%]	Caloric Values Lower Heating Value to Higher Heating Value [MJ/kg]
Briquette	10	16.74–17.10
Pellet	9	17.10–17.46
Sawdust	8	17.28–17.64
Wood chips	50	8.10–8.46
Crude Oil	0	43.05–45.30
Coal	5	22.732–23.968
Natural Gas	0	45.86–50.84

[13] Source adapted from Ref. [27,28].

In addition to biomass producing far less harmful CO_2, it is worthwhile to consider the consumption of different energy sources for energy production. Table 13 shows that 1 kg of biomass pellets and briquettes produces less energy than burning coal. In comparison to oil and natural gas, this energy is 2.5–3 times less.

Nitrogen (N) and sulfur (S) as fuel constituents are undesirable because they contribute to the generation and emission of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) during combustion. In comparison to coal, biomass has a low sulfur content because it simultaneously binds with existing SO_2 in the ash, so it easily complies with SO_2 emission limit values. The nitrogen content in the fuel depends on the type of biomass used and the way it was planted. Wood has a low nitrogen content, but when burning straw, it can be the same or higher than that of coal, depending on the amount of fertilizer used and the means of delivery applied to the fields. Chlorine in fuel is much more problematic than nitrogen and sulfur due to the emissions and issues it can cause in the combustion facility. The high chlorine content of straw or energy cane in comparison to coal is the result of using potassium fertilizer (KCl) in agriculture. Chlorine causes corrosion in steam heaters, especially at high temperatures. Thus, wood biomass as a fuel is more appropriate and more environmentally friendly. Due to their fuel components, straw, energy cane, and other grains can cause technical problems in combustion facilities, so pellets are recommended for small- and medium-sized boilers.

6. Uses of Crop Residues for Energy Purposes and Proposals for Future Action

Of the total amount of biomass available, the largest share comes from harvest residues. A realistic estimate is that 25% of harvest residues can be used for energy purposes. In order take advantage of biomass's full potential, the collecting and baling of biomass must first be organized, followed by transport and specific means of storage.

Sections 2–4 explain the structure of biomass in more detail. The baling method is performed through a specific mechanical process, which includes various types of baling presses. Baled biomass has a low bulk density and a large volume (bulk material), so transport is directly affected by transport costs and indirectly affected by its effect on the environment. Transport costs are thus directly dependent on the amount of biomass to be transported, the distance it needs to be transported, and the cost per unit of transport. Furthermore, collecting and baling agricultural biomass is a seasonal job, which must also be taken into consideration. The impact of transport on the environment is directly related to the emission of harmful gases, which are again directly related to the transport distance and the mode of transport used. For the transport of baled biomass, tractors with a trailer are used for distances of up to 40 km, and trucks with trailers are used for longer distances. Rail and river transport could allow for less expensive transport and would have a significantly less harmful impact on the environment. However, it is important to note that the state of the railway transport network in Vojvodina is currently not sufficient for this. There is a clear lack of wagons, locomotives, and handling equipment, which, taken together, creates a significant barrier to even considering the use of this type of transportation. As for a navigable transport network, there are canals and rivers as well as a waterway fleet. One issue with water transport is the lack of mechanical handling equipment. Another is that baled biomass from the field must be transported first by road to transshipment points and vessels, and after water transport is complete, in order to reach end users, it must again be transshipped to road transport [13]. As a result, only road transport can be considered a secure means of transport for baled biomass.

The way biomass bales are arranged in dedicated warehouses is extremely important. They must be arranged in compliance with fire protection regulations and in a way that ensures fire engine access while also allowing for any possible fires to be localized in one area of the storage facility. Protection against lightning strikes is also necessary. Another necessary consideration is mechanical equipment for loading and unloading bales and for moving them around inside the warehouse when adding and removing them from the stacks. Truck scales at the entrance to each warehouse are needed, as is equipment for measuring the moisture content of biomass, which changes over time and causes the overall weight of biomass in storage to change. Figure 3 shows the possible locations for large dedicated warehouses in Vojvodina, based on proximity to raw material being stored. It also shows potential locations for medium and large users.

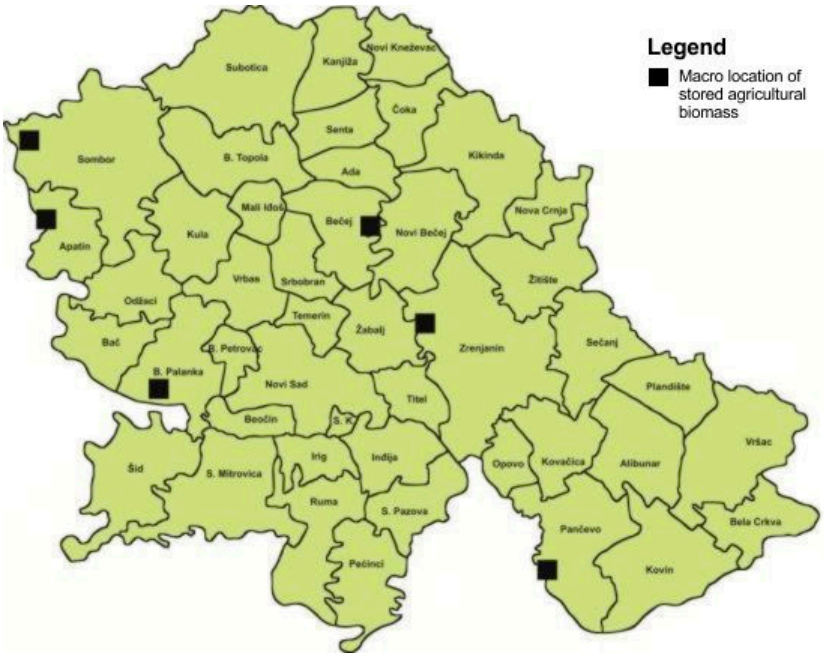


Figure 3. Potential macro locations of stored agricultural biomass in the Autonomous Province of Vojvodina (Sources adapted from Ref. [13]).

End users of biomass for energy purposes can be divided into three groups according to the amount of biomass they use: small, medium, and large. Small users of baled agricultural biomass have a smaller need for up to a few dozen tons of biomass per year. They are usually located either in the immediate vicinity of a biomass storage or no more than 20 km from the site. They use furnaces and boilers with a capacity of up to 50 kW that are intended for heating residential and business spaces. Medium users require up to 10,000 tons per year and usually use 50–500 kW boilers. They typically use biomass to heat glass and plastic greenhouses and medium-sized business facilities, and to produce pellets and briquettes with a capacity of up to 1 t/h. Finally, there are large users who use 500 kW boilers or larger. These include users of biomass for remote heating, drying agricultural products, and heating large facilities (halls), as well as those who use biomass to produce pellets and briquettes for energy purposes. Although there are few such large users in Vojvodina, there are a few, which include "Sojaprotein" in Becej, the oil factory "Victoriaoil" in Šid, and the starch producer "Ipok" in Zrenjanin. In Vojvodina, only one plant, located in Sremska Mitrovica, uses biomass for remote heating, and there are also a few factories producing pellets and briquettes. Although none currently exist, cogeneration plants could be potential large users in the future, but thermal energy from them would have to be used year-round for the investment to be profitable [13].

Pellet and briquette producers as potential users are particularly interesting because they provide an additional step to finalizing biomass and would thus have a significant effect on job growth. Pellets and briquettes are much easier to manipulate in furnaces and boilers and to transport and resell to other users for energy purposes. Pellet stoves and boilers already have a degree of utilization that is almost the same as gas stoves, and pellets also enable the highest level of automation for heating systems. Figure 4 shows the biomass pelleting process in more detail. The pellets produced have a bulk density of about 650 kg/m^3, which is seven times higher than that of baled straw. This also means that biomass in the form of pellets and briquettes occupy seven times less volume than baled biomass, which makes them ideal for transport by lowering transport costs over greater distances. Furthermore, because they are so compact, pellets burn more evenly, and the process of obtaining thermal energy from them is much easier to control. In the case of briquettes, dosing for furnaces and boilers must be reconfigured, and they do not have the same degree of flexibility and automation

as pellets do. Because of this, demand for briquettes has been declining from one year to the next, and users are increasingly turning to pellets.

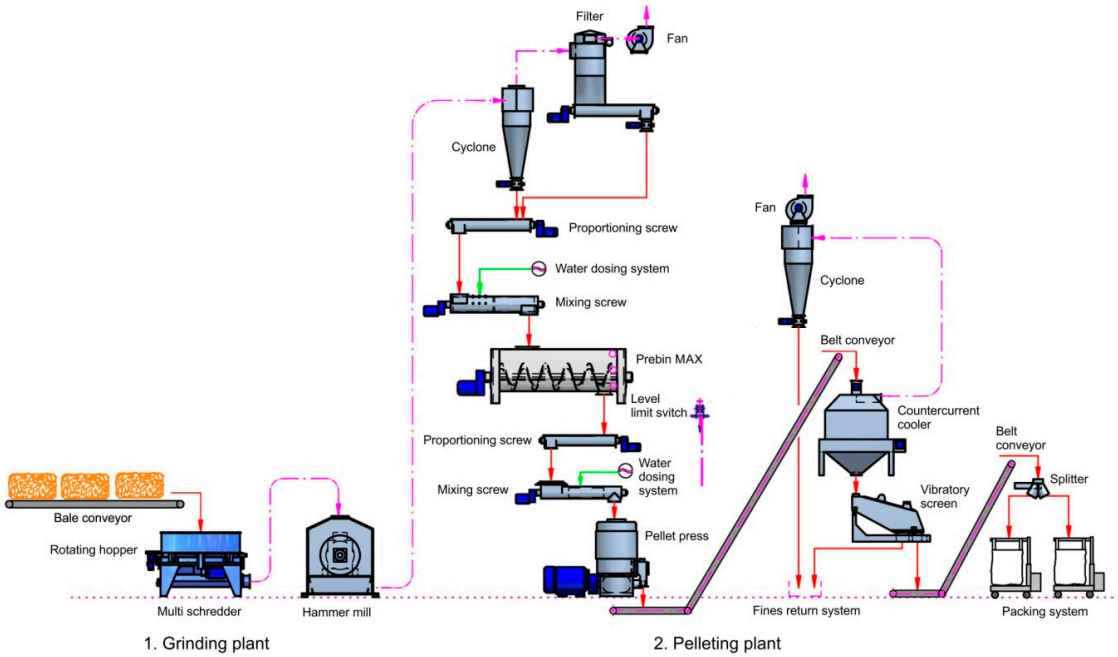


Figure 4. Technological scheme of straw pelleting line (Sources adapted from Ref. [29]).

This clearly demonstrates that there are a number of challenges that need to be addressed in order for the biomass potential to be more feasible for end users. Certainly, a clear strategy and support from local government is needed, followed by support from the Autonomous Province of Vojvodina and the Republic of Serbia, in order to give railway and water transport an opportunity, which would reduce transport costs and create benefits to help protect the environment. Support is also needed to establish large, public, dedicated biomass warehouses and to create a market for biomass in Vojvodina.

There are, of course, already a significant number of concrete initiatives and ideas that would be a step forward toward using biomass as a potential energy source in Vojvodina. The following is a summary of several specific proposals, which appear to have support from locally interested parties. Specific suggestions are:

- Develop a network and form a unique system for educating all interested parties about the field of using biomass for energy purposes. Because these proposals address some of the key issues and remove a number of existing barriers in this area, they could be the basis for developing strategic plans for increasing the use of biomass for energy purposes;
- Establish a network by delegating responsibilities according to hierarchies within the system of regional chambers of commerce and the principles of their existing cooperation with local governments;
- Establish an advisory and coordinating body for implementing projects;
- Establish a permanent expert body to provide technical support for implementing projects;
- Engage scientific institutions in developing standard technical solutions that can be broadly applied;
- Establish a system of advisory and administrative assistance at local and provincial levels;
- Ensure that regulations protect small manufacturers, which would encourage the development of family businesses;
- Create a proposal for tax incentives related to using biomass for energy purposes;
- Adopt laws and create a fund for implementing programs to use biomass for energy purposes;
- Establish permanent funding at all levels of government;

- Provide low cost loans and support for banks to facilitate guarantees and other conditions for the use of these funds;
- Resolve the long-term parity of biomass prices in relation to conventional energy and electricity sources, which would provide security for development and investment in the field as a whole;
- Create conditions for incentives and planned use of budgetary funds for heating schools and other public institutions owned by the state or local authorities so they would be transitioned into the use of biomass for heating these facilities;
- Secure VAT exemption for biomass production and use.

7. Conclusions

This paper points to the extensive untapped potential of biomass in Vojvodina, which could be harnessed for energy purposes and thus decrease energy dependence on imported fossil fuels. It also illustrates the importance of this "forgotten" potential, which is renewed every year, and which should be used in significant quantities as a substitute for imported fossil fuels. This dependence on imported fuels causes unnecessary expenditure and increased energy dependence on outside sources. Recent data on the total potential of raw materials have been presented, as well as calculations of both the primary and real energy potential of biomass in Vojvodina. The structure of available biomass in Vojvodina and the possibilities for converting it to energy were analyzed. In addition, the paper highlighted the current global problem of CO_2 emissions, the effect of greenhouse gases, and the benefits to be gained by substituting biomass for a significant portion of fossil fuels.

The paper emphasizes that, given the current low utilization, this area may create additional large-scale projects in the near future, which could in turn create a large number of new jobs that could be evenly distributed among the municipalities in Vojvodina. This might help stem the tide of large amounts of the workforce moving abroad in search of work, and also have a positive impact on the still-high levels of unemployment in the region despite the current exodus. The use of biomass as an energy source could drive the chain of employment in systems ranging from the manipulation of raw materials in the fields and forests to the numerous possibilities for use and finalization, through to combustion for energy consumption. Biomass could be a driving force in the local and regional economy of Serbia by generating income that can be retained both locally and throughout the country, rather than losing it abroad by purchasing fossil fuels. The increased use of biomass will further reduce the cost of its use, and the ultimate scenario would be the establishment of a stable biomass market and, consequently, the sustainable use of renewable energy in the future.

The subject of research in this area in the future should address the challenge of organizing the consolidation of areas during the collection of biomasses in order to reduce the cost of raw materials and thus increase their cost-effectiveness. This includes exploring the optimal number and distribution of future biomass processing plants and finalizing them into a finished product, while also managing technical and economic constraints. A special segment for future research could be the development and organization of a regional biomass market, and the integration of it into the surrounding markets that have already been developed for this raw material. Furthermore, research should focus on improving the technical characteristics of boilers and burners that use biomass as fuel, as well as the facilities where biomass is processed into briquettes and pellets. This would mean researching ways to create production lines, particularly for briquettes and pellets, in order to increase the use of these systems and reduce the length of production cycles from biomass in the field to products that are available for use in the creation of energy.

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