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Theoretical and Energy Biomass Potential of Heat and Electricity Production in Kosovo

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Abstract: The energy use of residues from agriculture, forestry, and solid waste can foster the transition towards a more renewable energy supply. This paper analyzes the energy potential of the above-mentioned sources for energy applications in Kosovo. The analysis is based on statistical data from different studies and reports, analyzing and calculating them to determine the theoretical and energy biomass potential. Kosovo can increase its self-sufficiency by taking advantage of its rich but under-utilized potential of biomass energy sources. This is a novelty study in this area, considering Kosovo lignite-dominated heat energy and electricity consumption and the available special literature. According to our estimates, the theoretical potential is 6.13 million tons/year, while the biomass energy potential should be around 4.57 million tons/year, including approximately 74.6% of biomass, which can be used for energy needs (heating and electricity). Based on the data and calculations, the available and usable potential shows biomass as an energy source with high potential in Kosovo; its share is very low, but it is reasonable to grow for both environmental and economic reasons.

Keywords: renewable energy; energy production; renewable energy sources; bioenergy; energy potential; agriculture; forestry; solid waste

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1. Introduction

Energy is an essential and significant factor for social, economic, and industrial development. Economic growth has always required an increasing demand for energy, especially with electricity being the main part. The acceleration process of the use of fossil fuels and the negative impact of greenhouse gases (GHG) have created conditions and opportunities to be focused on the production of alternative fuels based on the use of resources from nature. Moreover, energy is also considered one of the most critical sectors of the 21st century [1], and is a key determinant of economic development and living standards [2,3]. As environmental awareness is much higher now than before, energy security has become more important. Furthermore, fossil fuel prices are high and unpredictable; therefore, investments in the RES sector have also multiplied [4,5].

This paper deals with the theoretical and available biomass potential for energy purposes, including electricity and heat generation. However, the application of biomass for fuels in the transport sector is still considered an unexplored area in Kosovo. Since electricity and heating are the two most significant sectors of household energy consumption, the development of new ways to generate alternative energy methods is an important issue. Raw material for the lignite-to-biomass transition in energy production is available in Kosovo, however, energy price ratios, infrastructure and-in the agricultural sector-farm size are strong limits for future use. Based on this, our aim was to explore the potential of

these sources in Kosovo and to make a comparison with national energy consumption and with other countries.

2. Literature Review

2.1. Importance of Renewable Energy Sources

According to BP [6], the share of renewable energy in the global primary energy mix fluctuated between 6 and 8% between 1965 and 2003. Since 2004, there has been a 3.46% yearly growth, including two peaks, a 6.38% increase in 2008 due to the global financial crisis, and a 9.95% increase in 2020 due to the logistical consequences of the COVID-19 pandemic. The global share of primary energy from RES was 13.47% in 2021.

Compared to developing countries, developed countries generally rely more on renewable sources. Globally, Iceland, Norway, and Sweden are the TOP3 countries with 86.87%, 71.56%, and 50.92%, respectively [6]. An important element of RE use is trust. According to Żywiołek et al. [7], this heavily depends on awareness and (the willingness to acquire) knowledge. In addition to the significant investment costs of RES, the trust level also appears to be higher in developed countries.

Regarding sources, hydropower dominates RE generation (Figure 1). Its volume was 4234 terawatt-hours (TWh) in 2021, providing 54.70% of the total RE generation, followed by wind (23.44%) and solar energy (13.20%) [8]. However, it should be noted that the annual growth of these RES changed remarkably in the last couple of decades. Table 1 gives an overview of these changes since 2000. It is obvious that the growth of RES production slowed down; for example, hydropower production was 1.62 times higher in 2021 compared to 2000, while this value decreased to 1.24 when 2021 was compared to 2010. Solar energy is undoubtedly showing the fastest growth; however, the 40% annual increase is not sustainable.

Table 1. Change of the different RES generation.

	Hydropower	Wind	Solar	Other Renewables
From 2000 to 2021 *	1.62	59.32	963.43	3.79
Annual growth rate (2000–2021)	2.34%	21.67%	39.91%	6.60%
From 2010 to 2021 *	1.24	5.34	33.51	1.94
Annual growth rate (2010–2021)	2.30%	17.29%	40.94%	6.75%

* The energy production of certain types of RES in 2021 is divided by its 2000 and 2010 values. Source: Authors' calculation based on Ritchie et al. [8].

2.2. General Information and Energy Situation in Kosovo

Kosovo has a total area of 1.1 million hectares of land, with agricultural land accounting for 53% and forest accounting for 41%. Kosovo has a population of 1.8 million inhabitants, with a rate of approximately 62% of inhabitants living in rural areas [9], a 0.7 human capital index (HCI) and 100% access to electricity [10]. In the development sector, agriculture and energy play an essential role in the GDP and employment of the country [11]. Furthermore, 130,775 agricultural properties occupy 419 thousand hectares (ha) of agricultural land [9]. The number of agricultural households is very important since they can use their by-products to generate energy for their purposes and, in this regard, increase self-sufficiency in their daily farm activities.

Although Kosovo is not yet part of the European Union, it is recognized by more than half of countries worldwide; Kosovo is working toward the EU targets and strategies for clean energy production and supply. Renewable energy is not a new term in Kosovo; it has been known for a long time, but its production is still not significant.

According to the Ministry of Economic Development [12], Kosovo is very rich in natural resources, especially in geological coal reserves such as lignite (12.5 billion tons), which places Kosovo as the second country with the largest lignite reserves in Europe, while being the fifth in the world. A decade ago, the electricity sector of Kosovo relied on coal-

fired power plants (97.5%) of the total energy consumption, while the other 2.5% was used for market consumption needs [12]. This sector is considered as one with great potential for development. However, even though it is rich in quantity, it is poor in quality because the quality of the coal is low, and the negative consequences in terms of the environment are very high. Moreover, the two main coal-fired power plants in Kosovo are outdated and cause significant heavy air pollution and environmental problems.

In 2020, the energy production of Kosovo was 79.5 TJ, 42% higher than in 2000, while electricity final consumption in 2020 was 5.45 TWh, 51.3% higher than in 2000 [13]. The growing consumption of fossil energy [14,15] and the inverse correlation between RES and population density [16] are very typical trends in developing countries and are valid for Kosovo. Figure 1 contains the energy potential of Kosovo, such as coal, petroleum products (gasoline, diesel, fuel oil, kerosene, and liquefied petroleum gas-LPG), biomass, hydropower, wind energy and solar energy for 2022 [17]. In the other category, the import/export of electricity is included. The total energy potential in 2022 was estimated at 32,135 GWh, which is equivalent to 2763 ktoe. If we convert to PJ, it will give us the total amount of 116 PJ, as shown in Figure 1.

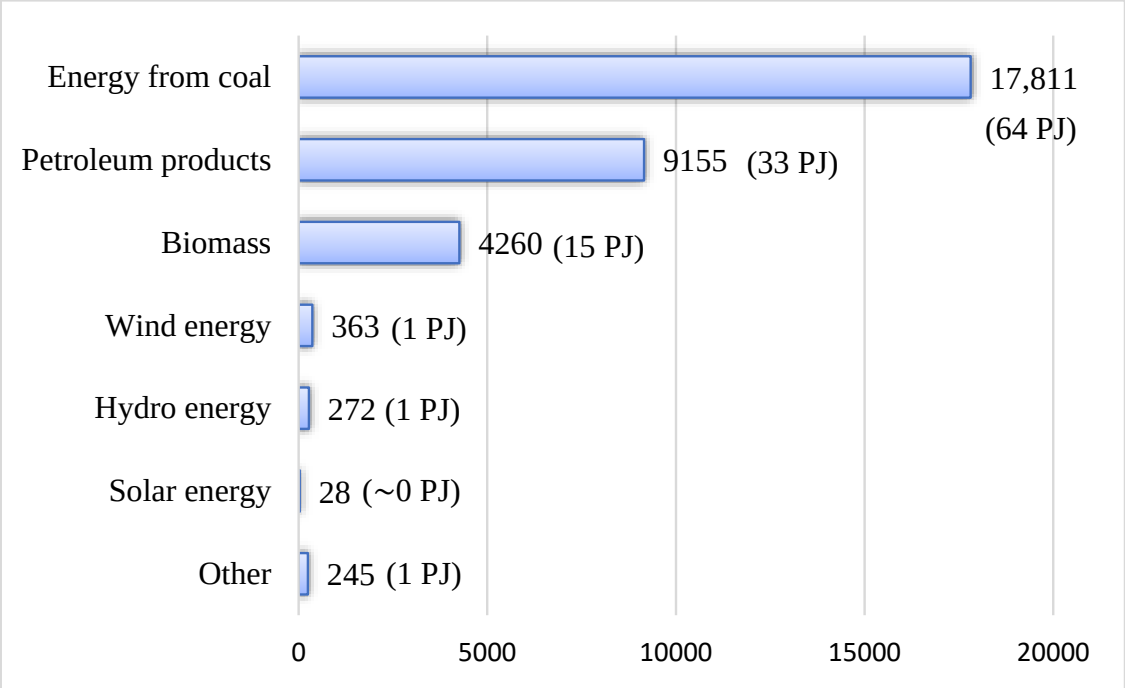

Figure 1. Overview of the amount of energy of primary energy sources (GWh). Source: Authors' own figure based on Kosovo Agency of Statistics [17].

According to the Kosovo energy strategy report, the total installed electricity capacity in Kosovo is 1568 MW, with 82% based on lignite [18]. Both power plants, Kosova A and B, must be renovated to meet the required emission standards. In addition to the energy generated from lignite, in 2021, 137 MW of wind generation units were put into operation in Kosovo, resulting in a wind participation of 9% of the installed capacity. Hydropower is also a vital element of the electric power system, with a participation of ~8.4% of the total installed capacity. Regarding biomass, this contributes 1.2 MW to installed capacities, even though, according to Sertolli et al. [19], biomass makes a good substitute for fossil energy sources and is an excellent source of energy generation, especially in heating production. However, the situation for electricity generation in May 2023 is shown in Figure 2.

Biomass-based electricity production was not significant within the total electricity generation in last May [20]. This means that the biomass potential, which is estimated at 4260 GWh [17], is still not used for electricity generation. Moreover, in recent years, the

awareness and willingness of the population to use biomass is changing in a progressive way. For example, one municipality implemented a district heating system with support from the European Union through the IPA 2015 program to finance the project to build a new thermal power plant with cogeneration units fueled by biomass [21]. The project included the supply of a 1.1 MW high-efficiency steam turbine, resulting in a heat recovery capacity of 4 MW, and two heat-only boilers with a thermal capacity of 5.5 MW each. There are also other less significant examples, which, for now, have not had an impact on the total energy production in Kosovo. Moreover, it is worth mentioning that import and export in terms of electricity generation are also quite balanced, as shown in Figure 2.

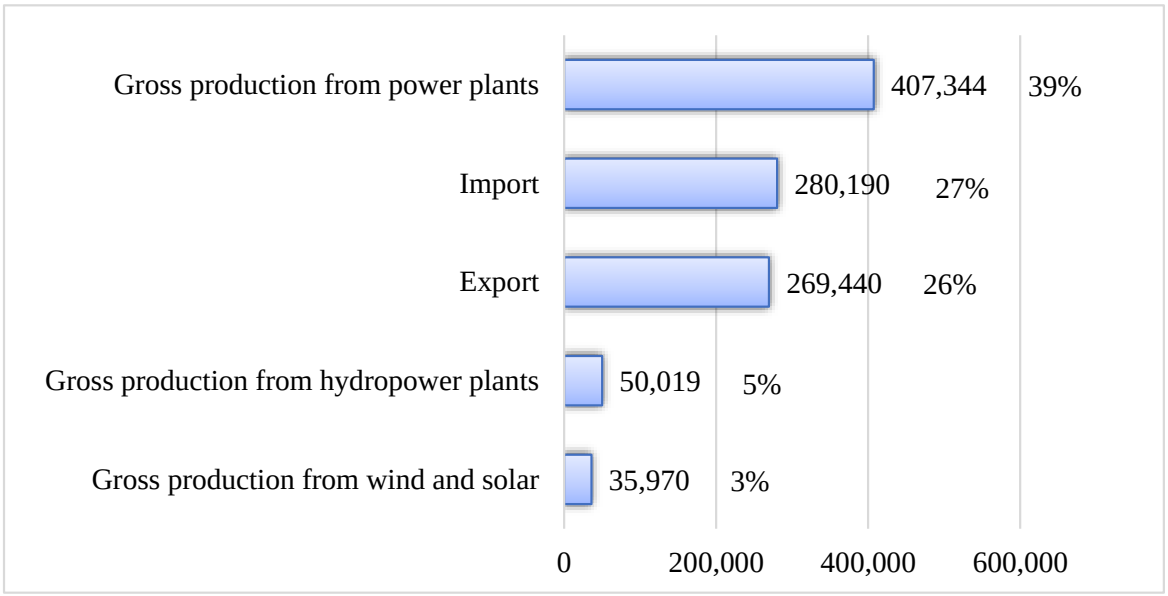

Figure 2. Total electricity generation in May 2023 in Kosovo (MWh), and its percentages. Source: Authors' own figure based on the Kosovo Agency of Statistics [20].

In 2020, Kosovo exceeded the 25% participation target of RES, but the main problem is the imbalance of sectors using technologies from RES. In the heating sector, biomass provides about half of the required energy (wood, bio-pellet, bio-briquette), while in the electricity sector, lignite occupies the main primacy from which electricity capacities are generated. Based on the above-mentioned report, about 57% of households use wood as a heating source, which is similar to the study by Pestisha & Bai (2022) [22], in which 63.7% of people living at home use wood as a source of heating. For the rest, about 39% use electricity, 2% use central heating, 0.5% use coal sources, and 2% use other alternatives as heating sources.

As Kosovo is on the way to the European Union, it is critical that Kosovo harmonizes policies in this regard; therefore, biomass must meet sustainability standards in order to count towards renewables targets or be eligible for subsidies from EU countries [23]. The reformed Renewable Energy Directive 2018/2001 broadens sustainability criteria to include large-scale biomass for heat and power, as well as biofuels and bioliquids for transportation. Moreover, it applies new criteria for agricultural waste and residues, forest biomass, biofuel plants, and bioelectricity. Furthermore, Kosovo has a few strategy documents describing its energy and climate policies, emphasizing an Economic Reform Programme for the country for the years 2021–2023 and a Climate Change Strategy for 2019–2028 [24], and Kosovo also has laws for energy efficiency from 2018 and for building energy performance from 2016. The Kosovo Energy Efficiency Fund (KEEF) went into operation in 2020 with the objective of improving access to financing energy efficiency initiatives. Kosovo has previously established several renewable support mechanisms, including feed-in tariffs (FiTs) and a net-metering program for consumers of renewable energy.

2.3. Agricultural Potential in Biomass Production in Kosovo and Self-Sufficiency at the Farm Level

One study examines [25] three types of biomass sources (wood, livestock waste, and agricultural straw), which are considered as the main potential to generate electricity from biomass resources in Kosovo. The annual amount of energy generated from biomass resources available in Kosovo is estimated to be approximately 6600 GWh/year.

Agricultural census data show that, in 2014, the total area of utilized agricultural land was 413,635 ha (owned by 129,884 agricultural farms with an average farm size of 3.2 ha) [26]. According to a study by the World Bank [27], the share of the agricultural sector in GDP was around 11%. In Kosovo, the total number of people involved in agriculture is 362,700, while the number of registered agricultural farmers is 130,775 [28]. Generally, the sector is characterized by small farms, fragmented lands, low efficiency, and inadequate infrastructure. In this sense, energy self-sufficiency might become very important and can play a key role in increasing the efficiency of farms.

According to Kashif et al. [29], the generation of renewable energy from crop residues will boost the local circular economy and create thousands of jobs in several sectors.

In rural Kosovo, the livestock sector is a significant source of employment for marginal and landless farmers. This sector meets the daily needs of the people of the country. The total number of livestock in Kosovo is 551,169 heads [30].

Dairy cows, which represent the primary specificity of maintaining animals due to milk production, play the most important role among cattle. Regarding the total number of cattle, there were 132,076 heads of dairy cows, which is 53.41% of the total [30]. These facts and numbers significantly show that due to the small size of the farms (Figure 3), the production of by-products from the plant and animal categories is not concentrated and, for this reason, can be used for local thermal energy utilization in the short term.

2.4. The Situation of Forest Residues and Solid Waste in Kosovo

Forest covers approximately 44.7% of the total surface of Kosovo and represents a resource of great importance for the economy of Kosovo [31]. In total, 38% of the forest area (180,800 ha) is classified as privately owned, while 62% (209,200 ha) is public forest. The total standing volume of wood is estimated to be 53 million m^3.

According to the study by Bajraktari et al. [31], 1480 enterprises are registered as wood processors in Kosovo. The Association of Wood Processors represents 80 of the most important companies, employing more than 3000 workers. Unfortunately, the number of officially licensed sawmill industries is decreasing, according to the report of Krajnc et al. [32], while the number of sawmills processed logs in 2013 was less than 50,000 m^3. Three briquette producers, five pellet producers, one chip producer, and three charcoal producers were identified as operating in Kosovo [32]. Coppices, sawmill material, leaves, and several types of agricultural waste can be a perfect material for energy purposes. Short-rotation forestry and short-rotation coppices have higher energy yields than traditional crops for energy. Furthermore, a study by Pestisha and Bai (2022) [22] showed that higher-income people in Kosovo used wood pellets as their main heating source because of their convenience instead of firewood. In addition to traditional wood burning, the results were highly satisfactory with regard to biomass (wood pellets and bio-briquettes), especially for wood pellets, because of their considerable share of use as a heating material.

In terms of solid waste, Kosovo generates a lot of waste yearly. It means that waste management continues to be a challenge for institutions in the country. Their collection, transport, recycling, reprocessing, and disposal have an impact on citizens' lives [33]. According to MESPI (The Ministry of Environment and Spatial Planning) [34], at the national level, 78.5% of households were covered by municipal garbage collection services at the end of 2019. Five of the thirty-six municipalities have reported 100% coverage to the KEPA (Kosovo Environmental Protection Agency), according to the statistics in the report. About 90% of the garbage produced is dumped in sanitary landfills, while the rest is dumped in unhygienic landfills. Development strategies should emphasize the use of treatment to stop waste production and disposal.

2.5. Renewable Energy Potential of Kosovo

At the end of 2019, Kosovo registered 76 MW of hydropower, 34 MW of wind, and 10 MW of solar energy for a total capacity of around 120 MW, marking a 6% annual increase in the capacity of renewables [35]. Due to this activity, the electricity produced from renewable sources at the end of 2019 represented 5.5% of total production. The high dependence of Kosovo on lignite reserves and its large share in electric generation have created conditions of inflexibility in the energy sector, as well as issues of public health and economic difficulties.

At the end of 2015, only a marginal amount of solar PV and wind had been deployed in Kosovo, according to the IRENA report [36]. Biomass production is an integral part of RES. According to the article by Sahiti et al. [37], Kosovo has the potential to produce up to 15.43 ktoe of electricity based on the combustion of crop-based biomass. Biomass is expected to continue serving as the most important RES for the supply of human energy demand [19]. Moreover, the largest share of renewables was based on biomass heating. According to the study of the Institute for Energy Economics and Financial Analysis (IEEFA), the total technical potential of biomass in Kosovo was estimated to be 665 ktoe (6,654,450 tons/year), equal to 28 PJ [38]. Regarding the wind power plant, seven applications for wind energy are in the permitting process with a total installed capacity of 170 MW. Taking into account the geographical position of Kosovo, it has a significant wind potential, but only a portion of this is considered cost-effective due to mountainous terrain and wind speeds ranging from only 4 to 6 m/s in most of the suitable areas identified [36]. Solar panels are considered one of the best solutions to this problem due to the significantly high rate of air pollution from conventional energy. Kosovo has an excellent geographical position, which is a strength with regard to the use of solar panels or collectors. Kosovo has approximately 2000 sunny hours and 278 sunny days, with the maximum global solar radiation reached during July, whereas the minimum is reached during December in most of the cities [39]. According to the study by Berisha et al. [39], there are cities where radiation can exceed more than 1000 kWh/m^2/year; concretely, in the city of Shterpca, annual solar radiation is estimated to be 1333.7 kWh/m^2/year and in the city of Gjakova, 1495.1 kWh/m^2/year. Moreover, according to Tranter et al. (2011) [40], obstacles to the development of projects for renewable energy purposes include high-fixed costs and farmers' skepticism about the rate of return on renewable energy investments; also the potential for cost savings is what drives people to choose their energy sources [41]. However, it must be emphasized that creating a welcoming environment is a key factor in altering the goals of an energy policy as well as the mindset and behavior of energy users [42].

This article is important because it illustrates the theoretical and energy potential of biomass sources, considering the energy situation in Kosovo with quite old power plants that predominantly use lignite as raw material. As a result, the energy sector contributes 82% of the total gas emissions produced in Kosovo, making the energy sector the largest contributor to air pollution [43]. There is an estimate of carbon dioxide reduction of 54% when considering the maximum utilization of all types of renewables, starting with biomass, solar and wind energies, compared to the current scenario of reference [44]. According to Bekteshi et al. [45], carbon dioxide emissions are forecast to increase from 7.5 to 10 Mt/year, while dust and sulfur dioxide emissions are projected to decrease from 11.7 to approximately 6 kt/year and 22.5 to 16 kt/year, respectively.

Being aware of the increasing energy demand and agriculture is not competitive; in this regard, diversifying the farms would lift the farmers' revenues and make them more efficient, and all together would make the energy sector more stable. Moreover, this is the first article to shine a light on the theoretical potential of biomass and the potential for energy use at the country level and can be used as a reference for its potential being used in practice.

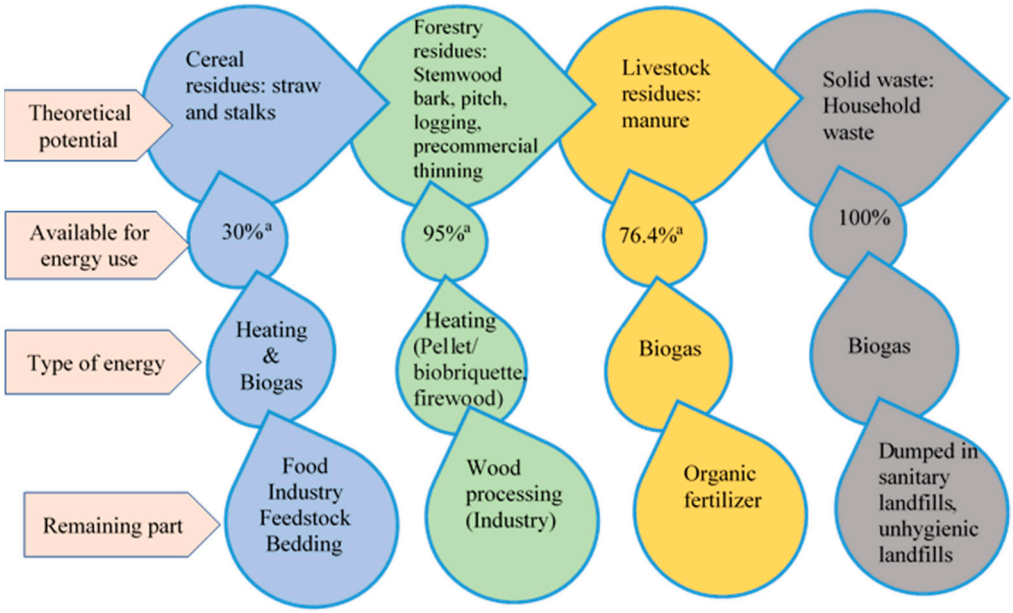

Figure 3. Main contributors to biomass potential in Kosovo. Legend: [a]—estimation of the Ministry of Economy [46]. Source: Authors' own figure.

3. Materials and Methods

3.1. The Methods to Examine the Biomass Potential

The examined country, Kosovo, has natural resources that make it possible to generate energy from renewable practices, including the biomass potential from cereals straw, livestock residues, forestry and solid waste. All forms can be used for a specific percentage, as the remaining part can be used for different purposes, such as organic fertilizer, wood industry, feedstock, bedding, etc., except solid waste, which can be used 100% for energy purposes, as shown in Figure 3. The reason behind 100% use of solid waste available for energy use is related to the opportunity to use all the amount of solid waste for biogas production, due to the non-applicable recycling or any alternative use of this solid waste. Moreover, there is a difference between theoretical potential and energy potential; the first one refers to every biomass source that can be used for any purpose, whereas the energy potential means the capacity of biomass sources used for the production of energy forms and is always less in quantity in comparison with the theoretical one, due to how it is utilized. However, there is a challenge because this energy can be used for heating, which means that, in practice, it will work during the winter period and cannot be used during the summer period. Moreover, wood is available locally in small quantities, which can be used as a direct heating source, possibly in the future as a higher size economy (for example, several thousand tons of wood/hectare can be used for pellet production, while hundreds of tons per hectare are more convenient to use as cogeneration).

In Kosovo, in terms of pellet production, five registered producers had a capacity of 20,500 tonnes annually, while the largest producer produced 14,000 tonnes. Compared to pellets, the production of briquettes was much smaller, producing 5100 tonnes [32]. With regard to pellets, the market is growing rapidly with respect to users and producers. The briquette market is significantly smaller, more stable, and more locally orientated. The production of agricultural raw material (crop residues, manure) depends on climatic issues, while its technical production and potential depend on the amount generated each year and its calorific value for energy production. The agricultural factors and most important characteristics of the above-mentioned sector in Kosovo contributing to biomass production are listed in Figure 4.

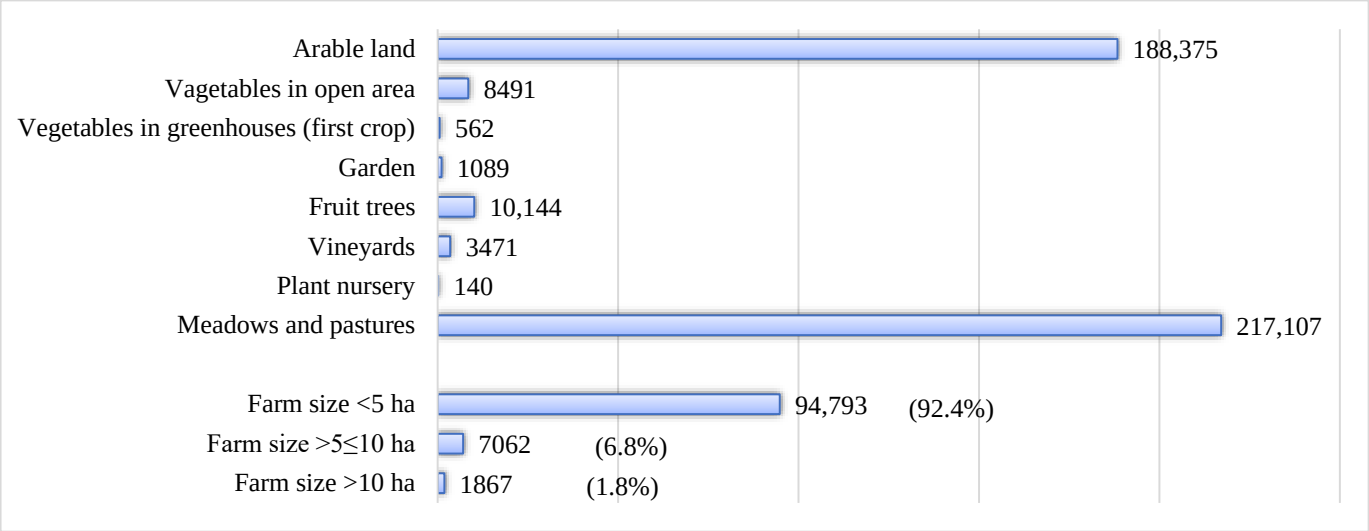

Figure 4. Farm size classification in percentage and categories of agricultural land in ha. Source: Authors' own calculation based on the Green report [30].

An insight article [41] estimated the potential of agricultural and forest biomass and its economic possibilities in the valley of the river Hernad. The authors analyzed the energy of agricultural and forest plant production, the available practical amount of woody phytomass, the amount of wood used in forest-based industries and the economic calculations (the value of the actual energy potential). The results were calculated from the distribution of agricultural and forest areas by settlements and their sowing structure, the amount of biomass generated during one year, and their conversion energy value. The authors took into consideration (a) the calculation of the available biomass from forestry, agriculture (crop and livestock), wood industry, and solid waste; (b) the conversion of the above-mentioned capacities into energy value; (c) different from the study, not only the crop biomass but also the livestock (manure) contribution to biogas energy is calculated.

Another study [47] estimated the sustainable potential of cereal straw in an energy assessment in Germany considering two aspects: agricultural prerequisites and global warming. To assess the energy potential from straw, they estimated Germany's total annual straw production, excluding the non-harvestable residues that remained in the field and the straw used for the animal husbandry sector (bedding purposes). All data have been used to better analyze the capacities of energy production and the impact of global warming using the LCA (Life Cycle Assessment) approach. For our study, the generation of cereal straw and its importance in energy production were of interest to investigate.

3.1.1. The Examination of the Agricultural Biomass Potential

Agricultural by-products are a great source of energy production, such as straw and maize stalks that are generated after harvest. Vines and wood chips from vineyards and orchards were not included, as they are an insignificant proportion of the agricultural and biomass yield of Kosovo. The amount of biomass available as main products and by-products was calculated with the help of the latest reports in this regard.

Therefore, the estimation of agricultural biomass potential was made, taking into account the following factors:

- Area of crop production and crop types;
- Yields of crops;
- Crop residue-to-yield ratios, depending on the crop yields and types.

The biomass potential of the cereals was determined on the basis of the area cultivated and the yield. The total area cultivated with grains (cereals and fodders) in Kosovo, taken into consideration in this study, was 232,885 hectares. From this area, the crops that

occupy the largest part of the cultivation are maize and wheat, which also have the largest capacities in biomass production. To perform calculations of the biomass produced by this category, it is necessary to know the ratio between the production of the fruit (seed) and the plant. In our case, this interval varied between 1:0.5 and 1:1.5, depending on the type of crop [41,46,48]. To continue with the calculation of the energy potential that can be produced, it is necessary to know the lower heating value (LHV) and the conversion rate into biogas for forage (fodder) crops. This potential of agricultural biomass can be utilized through the production of electric and thermal energy. Moreover, biogas from fodder crops can be used for heat production.

The production of cereals in Kosovo is essential for both food security and energy production. The calculations for the main products were based on national data, the average yields from 2017 to 2021 provided by the Green Report [30], as shown in Figure 5. The standard deviation for the area resulted in 1626.8, and for production, 34,877.5; both show quite balanced numbers.

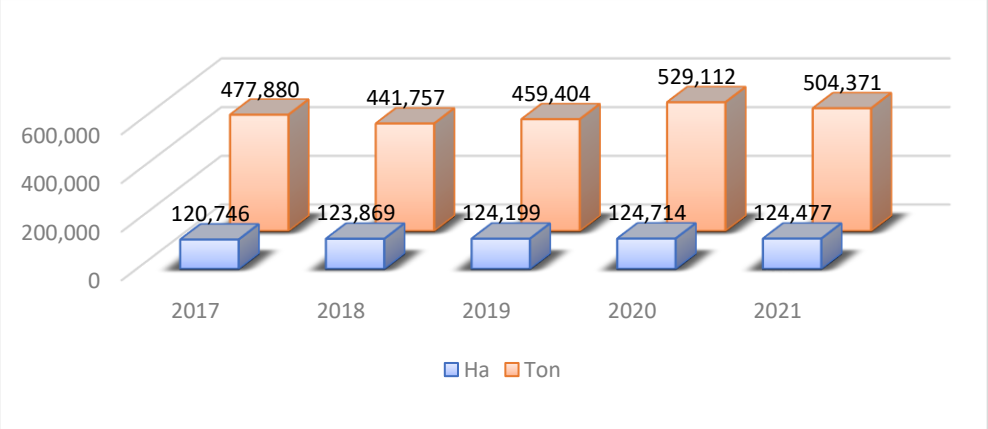

Figure 5. Cereal area, production, and yield in Kosovo, 2017–2021. Source: Authors' own calculation based on Green report [30].

3.1.2. The Examination of Livestock Potential

In rural Kosovo, the livestock sector is a significant source of employment for farmers and the rural population. This sector generates a huge amount of manure with the most common manure management methods, such as manuring in open spaces, landfill dumping, composting, and disposing of waste in common effluent treatment plants.

Therefore, the estimation of livestock biogas potential was made, taking into account the following factors:

- Number of animals and animal types;
- Manure quantity;
- Living mass of animals.

The acquisition of livestock data is a preliminary step in assessing the bioenergy potential of livestock in Kosovo. In the present study, the livestock population is referred from the Green Report of the Ministry of Agriculture [30] to assess the information through which biogas potential calculations can be performed.

According to Table 2 the total number of animals in Kosovo is 3,339,169, including poultry. The live weights of these animals differ according to their breeds. The daily generation of manure (kg/day) is calculated based on the report from the Ministry of Economy [46]. Then, the calculated animal unit (AU), as a comparison unit for the mass of live animal of all categories, based on the above-mentioned article, is 500 kg. Total animal manure is calculated by knowing the number of animal units for all categories and the average amount of daily manure. The live animal weights in these categories and the average daily generation of manure are reported in Table 8. To calculate the potential of

biogas production from livestock manure, the total amount of manure generated from animals and the biogas capacity production from a ton of manure are crucial to know.

Table 2. Livestock structure in Kosovo, 2021.

Number and Types of Animals	Year 2021
Cattle fund	260,528
Sheep fund	211,354
Goats fund	30,039
Pigs fund	47,384
Poultry	2,788,000
Other	1864
Total	3,339,169

Source: Authors' composition based on the Green report [30].

3.1.3. The Examination of Forest Biomass Potential

Forest-based biomass includes firewood, forest residues, and wood industry residues. Firewood is the form of wood that is used primarily for heating in households. Forest (or logging) residues are woody biomass by-products that are created during harvest, and are mostly used for pellet and briquette production. On the contrary, wood industry residues are woody biomass by-products originating from wood processing.

In terms of wood species and their volume in Kosovo, Table 3 lists the most common broadleaves and conifers. *Fagus* sp. Has the highest volume, followed by both types of Quercus (18,524 thousand m^3 and 7951 thousand m^3). Pinus sp. Has the most significant volume for the conifers, followed by *Picea abies* and *Abies alba* (2502 thousand m^3, 1840 thousand m^3, and 1573 thousand m^3, respectively).

Table 3. Volume in thousand m^3 for most common broadleaves and conifers in Kosovo.

Wood Species	Volume in Thousand m^3
Quercus cerris	4282
Quercus petraea	3669
Other quercus sp.	1292
Fagus sp.	18,524
Other broadleaves	6750
Abies alba	1573
Picea abies	1840
Pinus sp.	2502
Other conifers	77
Total	40,509

Source: Authors' own calculation based on the Ministry of Economy report [46].

The total volume of forests in Kosovo is 40,509 thousand m^3 (which is a unit of volume in the metric system and is equivalent to 1000 cubic meters), considering that the average density of one m^3 in Kosovo is equal to 798 kg/m^3, according to the report of the Ministry of Economy of Kosovo [46]; moreover, to support this number, there is another international report indicating that the values range from 290 to 800 kg/m^3 [49]. It results in the fact that the total of forests expressed in tons in Kosovo is equal to 32 million tons.

3.1.4. Examination of Solid Waste Potential

Despite Kosovo's efforts to promote garbage recycling and reuse, there is still an issue with the first layer of the waste hierarchy, i.e., the excessive amount of waste produced. As a result, the problem should be addressed starting with preliminary measures to prevent the large amount of trash generation, and moving on to encourage the reuse, recycling, treatment, and proper and final disposal of garbage. Human activities produce most of the garbage. The high rate is an issue for the whole world, but it is particularly acute in Kosovo, where the vast majority of this garbage is disposed of in landfills. According to official reports, Kosovo produces a lot of municipal waste [34].

This article aims to provide more information on the potential these wastes could offer in energy development, considering their conversion capacity. This paradigm shows that waste generation capabilities can help produce thermal, electrical, and combined energy. Calculating the biomass potential from solid waste is performed by considering the amount of waste and the LHV (Lower Heating Value).

4. Results

When examining the energy possibilities of biomass use for energy purposes, the authors took into consideration these types of biomass categories:

1. Biomass from agricultural crops;
2. Biomass from forests;
3. Biomass from livestock;
4. Biomass from solid waste.

4.1. The Actual Agricultural (Plant Production) Potential in Kosovo

According to the data of the Ministry of Agriculture [30], the total amount of biomass from cereals, after our calculations, turns out to be 503,930 tons/year, as shown in Table 4. Knowing that wheat and maize are the most cultivated crops, there are two ways to use agricultural crops to produce biomass: either directly from the crops themselves (straw, maize stalks, etc.) or directly from the fruits of the crops (wheat, maize, barley, etc.). The generation of biomass from the fruits of agricultural crops is considerably more challenging when considering the need of Kosovo to use grains for food. The trade balance (export-import) numbers for the two major crops also support this. As a result, residues (straw, maize stalks, etc.) must be the primary source of biomass for energy production from cereal crops.

Table 4. Area, yield, and biomass production of cereals in Kosovo, 2021.

Cereal Type	Area (ha)	Production (t/Year)	Mass Ratio (t/t)	Weight of Residues from Cereal Crops
Wheat	79,970	322,018	1:0.5 [41]	161,009
Maize	39,710	170,393	1:1.01 [48]	172,097
Barley	2060	5610	1:1 [46]	5610
Rye	555	1409	1:1.5 [41]	2113
Oat	2030	4500	1:1 [46]	4500
Total	124,325	503,930		345,329

Source: Authors' own calculation based on different reports and articles [30,41,46,48].

However, due to the wider use of cereal biomass (for animal feed and animal bedding, a considered amount remains on agricultural land after harvest and for various industrial needs), this amount cannot be used for energy production. According to the report of the Ministry of Economy [46], the percentage of cereal biomass use for energy production ranges from 10% to 40%. In our case, based on the above-mentioned study, as a result of the small consumption of biomass in the industrial sector, a biomass use of 30% for energy needs can be considered. Although Table 4 shows that 345,329 t/year of biomass is

produced from cereal residues, with 30% capacity to be used for energy needs, the annual energy potential of Kosovo, in terms of the total biomass capacity used for energy purposes, turns out to be 103,599 t/year.

Kosovo has a high negative trade balance with respect to wheat and maize [50]. In the last six years, Kosovo has imported an average of 106,700 tons of wheat and approximately 47,200 tons of maize, while it has exported an average of only 257 tons of wheat and 115 tons of maize in the last six years. Significantly, it can be said that Kosovo is highly dependent on the import of the two most essential cereals; in addition, most of these cereals are used for food.

The amount of biomass readily available is calculated using the harvest ratio, which is taken from different sources, as indicated in Table 4. These ratios indicate the approximations of values that correspond to the unique agro-ecological characteristics of the cultivation area and the agro-technical practices used to cultivate arable crops [51].

To calculate the theoretical and energy potentials of biomass, it is necessary to know the LHV, which is different from one crop to another and depends on the moisture, composition, total amount of ash, etc. In our case, LHV ranges from 14.0 to 17.9 MJ/kg [46,51].

Table 5 shows the area of cereals in hectares, the yields, the mass ratio between the fruit and the plant weight, the available biomass potential, the low heating value, and the energy potential from the available biomass in Kosovo, considering the most common cereals. The reported numbers for available cereal crops, biomass for energy production, and energy potential are based on 30% of the total available biomass. According to the data in Table 5, it seems that maize and ray have the largest theoretical potential for energy (21,414 and 15,994 MJ/ha, respectively); this is due to the higher yields and the ratio, which is considered.

Table 5. Biomass production from cereals and its energy potential in Kosovo.

Cereal Type	Area (ha)	Yield (t/ha)	Fruit Weight/Plant Weight	Weight of Residues from Cereal Crops (t/ha)	Available Biomass for Energy Ab30% (t/ha)	LHV (MJ/kg)	Energy Potential Ab30% (MJ/ha)	Heating (TJ)
Wheat	79,970	4.03	1:0.5	2.01	0.60	16.44	9930	794
Maize	39,710	4.29	1:1.01	4.33	1.30	16.47	21,414	850
Barley	2060	2.72	1:1	2.72	0.82	17.9	14,624	30
Rye	555	2.54	1:1.5	3.81	1.14	14	15,994	9
Oat	2030	2.22	1:1	2.22	0.67	14.5	9643	20

Source: Authors' own calculations, based on MAFRD and Ministry of Economy report and Bilandzija et al. [30,46,51].

The group of cereals derived from fodder crops and green cereals are typically used as animal feed. However, it is possible that these plants could be used to produce biogas. Table 6 shows the values of these plants expressed in area, production within the year, specific values of biogas conversion, and the amount of biogas that can be produced within the year.

It is important to note that the calculations in Table 6 have considered stored biomass losses (silage) in the amount of 12% [46]. The total amount of biomass produced by forage and green cereals in Kosovo is 481,952 tons/year, while 30% can be used for energy purposes. The total production of forage and green cereals is 144,586 tons/year. If the total amount of green cereals and forage was used, then the total amount of biogas production could be 76,164 thousand m^3/year. However, only 30% of the capacity is supposed to be used, which means that the amount of biogas production is potentially 22,849 thousand m^3/year.

If we take into account the total biomass from the tables "cereals" and "forage and green cereals", and the total use of it for energy needs, then it results that the total biomass amount would be 827,281 tons/year. Furthermore, in terms of the total heating value for both tables (cereals and forage and green cereals), it is 3226 TJ.

Table 6. Area, yield, and biomass production of forage and green cereals in Kosovo, 2021.

Forage and Green Cereals	Area (ha)	Production (t/Year)	Specific Production of Biogas (m^3/t)	Biogas Production (Million m^3/Year)	Heating (TJ)
Green maize	7061	118,937	202	21	423
Green maize (second crop)	210	2875	202	0.5	10
Hay (meadows)	70,723	233,323	172	35	706
Grass	9293	28,819	172	4	87
Alfalfa	18,360	82,330	172	12	249
Clover	931	3551	172	0.5	11
Other green forage	1982	12,117	172	1.8	37
Total	108,560	481,952		76	1523

Source: Authors' own calculation based on the MAFRD and Ministry of Economy report [30,46].

4.2. Energy-Related Potential of Livestock Production

When examining the possibilities of the energy-related potential, we considered the participation of livestock through the production of manure for energy generation. Livestock data are provided by the Ministry of Agriculture [30] and the Ministry of Economy report [46]. In Table 7, the authors have separated categories of different types of animals to make the calculation more accurate due to the difference in the living mass per category. The largest and most relevant sector with regard to livestock in Kosovo is cattle, considering the number of animals and the mass of manure. To calculate the potential of biogas production, we need to know the number of animals, the amount of waste (manure produced), and the parameter per AU (animal unit). The values of the necessary parameters to calculate the amount of biogas that can be produced from animal waste have been found based on the report of the Ministry of Economy [46]. Moreover, the animal unit is a factor of comparison between the total living mass of animals and has the value of 500 kg. According to Table 7, cattle have the highest AU for animal categories, followed by sheep and goats.

Table 7. Calculated number of animal units per animal category 2021.

Animals	Amount	Living Mass	Total Living Million Mass	Animal Unit (AU)	AU for Animal Categories
Cattle stocks	260,528				227,241
Male and female calves under 1 year old	83,238	167.5	13.9	27,885	
Foals and heifers 1–2 years old	26,836	400	10.7	21,469	
Bulls and heifers over 2 years old	16,341	500	8.1	16,341	
Dairy cows	132,076	600	79.2	158,491	
Other cows	2037	750	1.5	3056	
Pigs	47,384	60	2.8	5686	5686
Horses, donkeys, and mules	1864	400	0.7	1491	1491
Sheep and goats	241,393		0	0	25,530
Sheep for breeding	156,666	50	7.8	15,667	
Other heads (lambs, rams, etc.)	54,688	72	3.9	7875	
Goats	28,410	35	0.9	1989	
Poultry	2,788,000	1.5	4.1	8364	8364

Source: Authors' own calculation, based on the Green report and Ministry of Economy report [30,46].

To find the potential of annual biogas production, the authors have taken into account the daily production of manure for AU, which differs based on animal categories. Table 8 shows the total potential for animal manure production in Kosovo, which is estimated to be 3,842,602 t/year in total. According to the Kosovo Agency of Statistics [52], the average amount of organic fertilizer used during 2020 was 14.5 t/ha and 908,650 t/year in total,

respectively. In addition, biomanure can also be used as an organic fertilizer after anaerobic digestion. Figure 3 shows that the remaining part (76.4%) of the amount of organic fertilizer can be used for energy needs, which equals to 2,935,748 tons/year.

Table 8. Total manure production in Kosovo, 2021.

Animal Category	Number of AU per Animal Category	Daily Manure Production per AU	Annual Manure Production (Million t/Year)
Cattle	227,241	40	3.3
Pig	5686	25	0.05
Sheep and goat	25,530	35	0.3
Horse	1491	23	0.01
Poultry	8364	44	0.13
Total			3.84

Source: Authors' own calculation, based on the Ministry of Economy report [46].

From the calculation of the annual production of manure for different types of animals, the total amount of biogas that can be produced in Kosovo, for which the total amount of manure used for the production of biogas, is 76.4% of the total value, since 23.6% is used as organic fertilizer for agriculture land. As shown in Table 9, the total potential amount produced from organic fertilizer as biogas is 142.6 million m^3/year. Cattle contributed the most to this value, with around 80%, followed by sheep and goats with around 12%. While the total heating value for biogas is 2853 TJ, since biogas has a calorific value of 20–26 MJ/m^3, the authors used the value of 20 MJ/m^3, [53–56].

Table 9. The potential of annual biogas production per year in Kosovo, 2021.

Animals' Category	Annual Manure Production (t/Year)	Production of Biogas per ton of Fresh Manure (m^3/t)	Biogas Production per Animal (Million m^3/Year)	Heating (TJ)
Cattle	2,534,740	45	114	2281
Pig	39,641	60	2.3	48
Sheep and goat	249,179	70	17.4	349
Horse	9564	60	0.5	11
Poultry	102,625	80	8.2	164
Total	2,935,748		142.6	2853

Source: Authors' own calculation, based on the Ministry of Economy report [46].

As mentioned in the text, 30% of cereal biomass potential is calculated to be used for energy purposes, while the remaining 70% is used primarily for farm bedding. This material is known as usually being organic, and used for animals to support their bodies while resting or when they are stationary. In Kosovo, straw is used for bedding, then combined with manure, is used only as a solid fertilizer for agricultural lands in order to increase the soil quality. It can be used for biogas production in the future. In this regard, Table 10 shows the calculated amount of straw used for bedding according to the number of animal funds.

Table 10. The total amount of straw calculated that is used for bedding in Kosovo.

Animals	Amount	Straw/t/db/Year	Total Amount of Straw for Bedding
Dairy cows	132,076	1.3	171,698
Pigs	47,384	0.15	7107
Horses, donkeys, and mules	1864	2.15	4008
Sheep and goats	185,076	0.25	46,269
Poultry	2788	1.75	4879
Total			233,961

Source: Authors' own calculation, based on the MAFRD and Corporate planning book [30,57].

The total amount of biomass used for bedding is 233,961 tons annually; however, in practice, this number is expected to be lower considering that most of the time (spring to autumn), many farms let their animals graze, which contributes to the reduction of the amount of straw used for bedding. However, few farmers use straw for different purposes [58].

4.3. Forestry Potential

Initially, to estimate the allowed amount of cutting, it is mandatory to take into account the sustainable development and annual growth of forests. According to the NFI-II (National Forest Inventory) [59], the annual growth of trees is dlg $\geq$ 7 cm (dlg = the yearly increase in wood volume) of the total forest, which is 1,556,000 m^3. On the basis of this standard, it turns out that 1,200,000 m^3 can be cut in Kosovo. Based on the secondary data found, 95% of this amount is used for consumption as firewood and the remaining 5% for the needs of the wood industry, as shown in Figure 6.

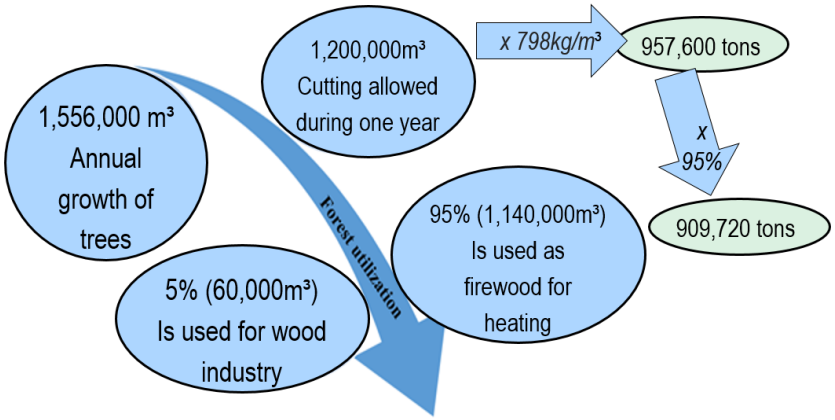

Figure 6. Potential forest utilization in Kosovo. Source: Authors' own figure based on the Ministry of Agriculture report [59].

The total amount of biomass used as firewood for heating purposes is 909,720 tons.

The contribution of this sector to the economy is highly valued, and it can be between approximately 50 and 75 million euros, resulting in a contribution by the wood industry of between 1.8 and 2.6% to GDP [31]. Wood as fuel is one of the most important energy sources in Kosovo's households. In addition to heating purposes, it represents an important input for the domestic wood processing industry. The wood processing industry is also an important source of wood biomass available for home heating. Furthermore, most sawmills in Kosovo do not appear to recognize or have not yet explored the potential value of waste products from lumber production, i.e., sawdust and wood chips. Taking into account the estimated potential of forestry, it turned out that the heating value was 17,285 TJ from 909,720 tons of firewood, calculated with a calorific value of 19 GJ/tons for wood [60].

4.4. Solid Waste Energy-Potential

In the case of solid waste, the operation of companies responsible for the collection of waste is an important factor in the total amount of waste generated within the country. Based on data of the Kosovo Environmental Protection Agency, the total potential of waste based on the number of inhabitants turns out to be 506,630 t/year, considering the average waste per capita of 0.78 kg/day [61]. This amount of waste (Table 11) can be used for energy production in the form of biogas. The amount of energy produced by biogas is significant; however, the capacities of Kosovo in terms of practical use are a bit uncertain due to the high installation cost and the inappropriate machinery.

Table 11. Total amount of waste in Kosovo.

Number of Population	Average Waste Per Habitant (kg/Day)	Total Amount of Waste (ton/Year)
1,779,521	0.78	506,630

Source: Authors' own calculation, based on Kosovo Environmental Protection Agency [61].

Kosovo is divided into seven regional administrative units, each responsible for waste collection. The total amount of waste collected in tons per year is 485,000 [62]. Taking into account LHV, the authors have calculated the potential of different forms of energy that could be produced and expressed in TJ/year and GWh/year, as shown in Table 12 If these wastes were used for the production of electricity, they would result in 303 GWh/year with an efficiency percentage of 30%. Although the percentage of thermal energy production efficiency is 85%, in this regard, it would give a total of 3092 TJ/year. There is another way of utilizing this potential by the co-production of electricity and thermal energy, which has an efficiency of 20% of electricity and 60% of thermal energy production. It would be 80% efficient with a 201 GWh/year, and 2182 TJ/year co-produced energy potential. Furthermore, the authors have calculated the heating value of solid waste through the calorific value which is 20.03 MJ/kg [63], which turned out to be 9715 TJ.

Table 12. Solid waste in Kosovo per year 2021.

Region	Amount of Waste (t/Year)	LHV (MJ/kg)	Amount of Electricity (GJ/Year)	Amount of Thermal Energy (GJ/Year)	Amount of Co-Produced Energy (GJ/Year)		Heating Value (TJ)
					Electric	Thermal	
Prishtina	151,000	7.5	339,750	962,625	226,500	679,500	3025
Ferizaj	37,000	7.5	83,250	235,875	55,500	166,500	741
Gjakovë	48,000	7.5	108,000	306,000	72,000	216,000	961
Gjilan	43,500	7.5	97,875	277,312	65,250	195,750	871
Mitrovicë	66,000	7.5	148,500	420,750	99,000	297,000	1322
Pejë	57,000	7.5	128,250	363,375	85,500	256,500	1142
Prizren	82,500	7.5	185,625	525,937	123,750	371,250	1652
Total	485,000		1,091,250	3,091,875	727,500	2,182,500	9715

Source: Authors' own calculation based on the Ministry of Economy and Kosovo Agency of Statistics report [46,62].

4.5. Total Potential of Biomass Production in Kosovo

In Table 13, the theoretical potential of the different types of biomass amounts to 6,131,719 t/year. The total amount that can be used for energy purposes has a value of 4,578,652 t/year. It is found that approximately 74.6% of the total biomass can be used for energy needs from all these forms of biomass on average.

It results from our estimation that the total biomass potential, which can be used for energy purposes, can reach the value of 33 PJ heating potential, while the total primary energy consumption in Kosovo in 2022 reached the level of 116 PJ (according to Figure 1). In addition, it can achieve a 28% share in the total energy consumption in Kosovo, which is a promising value.

According to Figure 1, the total share of energy from biomass was 15 PJ for the year 2022, whereas according to the study of the Institute for Energy Economics and Financial Analysis (IEEFA), the total technical potential of biomass in Kosovo is 28 PJ [38]. In this regard, our calculations stand close to the particular study of IEEFA, with 33 PJ heating potential from the types of biomass that are included in this article. From all these calculations, it is accurate that biomass is of great importance and should be treated as a critical energy source for energy production in Kosovo.

To simplify the understanding of the total biomass potential for energy use, the authors created Figure 7, which is a final figure with the most important calculations performed.

Table 13. Theoretical and energy potential of biomass production in Kosovo and its heating value.

Type of Biomass	Total Biomass Produced (t/Year)	The Total Amount That Can Be Used for Energy Purposes (t/Year)	Heating Value (PJ)
Forest Biomass	957,600	909,720	17
Cereals Biomass	827,281	248,184	3 *
Livestock Biomass	3,842,602	2,935,748	3 *
Municipal waste biomass	506,630	485,000	10 *
Total	6,134,113	4,578,652	33

* The values are calculated based on the calorific value for each of the categories of biomass (biogas 20 MJ/m^3; wood 19 GJ/ton; solid waste 20.03 MJ/kg) [53–56,60,63]. Source: Authors' own calculation.

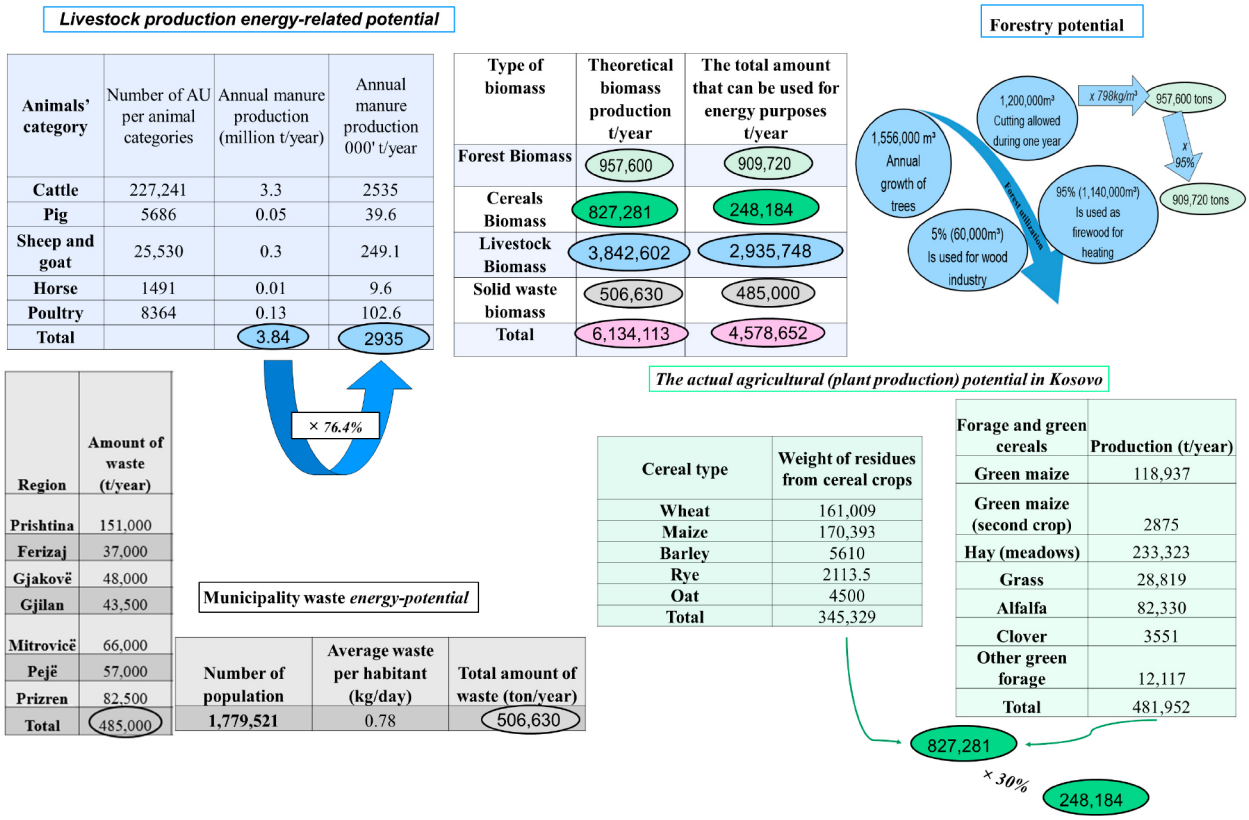

Figure 7. Summary of the results. Source: Authors'own calculation.

5. Discussion

According to the findings of the biomass potential in Kosovo, livestock has the highest contribution to the biomass potential with 64.1%, followed by forests with 19.8%, while solid and cereals have a contribution of 10.6%, and 5.4%, respectively.

In order to make comparisons, different studies have estimated the potential of available agricultural biomass. In Greece, the total agricultural biomass available in the Thessaly region is estimated to be about 707,164 tons annually [64]. In terms of per capita production, the population of the Thessaly region is 354,290 [65], with a biomass production of 2 tons per capita, while Kosovo, with 1,770,721 inhabitants, has an average of 2.6 tons per capita. The situation in Turkey indicates that the total agricultural residues are estimated to be 75,084 kilotonnes, with a theoretical energy potential of 998,473 TJ and 364,446 TJ available energy potential [66]. In this regard, Turkey has a population of 85,895,103 with an average of 0.87 tons per capita based on the total agricultural residue potential, less than the capacity of the biomass potential of Kosovo. At the European level, biomass has the largest share of energy production at 63.11% (123,592 ktoe), followed by hydro and wind energy [51]. Furthermore, in EU28, the importance of biomass is high, considering that the production

of solid biomass energy increased by 134% between 1990 and 2017, while the top five producer countries accounted for 51.2%, Germany (503 PJ), followed by France, Sweden, Finland, and Italy (328–452 PJ each).

The same study shows that in Croatia, annual biomass amounts to 3372.2 thousand tons generated from around 80% of total agricultural land. With 4,004,690 inhabitants on average, it produces 0.84 tons per capita, more than Turkey. A case study [67] shows that the total biomass potential of the Czech Republic from arable land ranged between 78.9 and 96.1 PJ. The per capita biomass production is 2 tons, the same as in the Thessaly region for 10,496,797 inhabitants. Another study in the same country states that biomass is considered a dominant renewable energy source [68]. Almost 90% of the current contribution of RES to primary energy sources comes from biomass in all its forms in the Czech Republic. In terms of Hungary, the total biomass supply is estimated to be approximately 350 to 360 million metric tons. Between 105 and 110 million tons of this supply are regenerated each year [41]. The national biomass energy potential is estimated to be between 297 and 417 PJ/year. This means that the per capita biomass production is 7 tons, making Hungary one of the countries with the highest biomass potential. For easier understanding and comparisons between countries, the authors illustrated in Table 14 that the biomass production potential per capita is an important indicator on the European continent. Furthermore, this ratio would serve as information on the possibility of meeting the level of energy demand. There are three differential groups in the table: Hungary leads with outstanding potential, Turkey and Croatia represent the minimal values in this regard, while Kosovo (like the Czech and Thessaly regions) has intermediate potential. The reasons for these numbers per capita are due to differences mainly in agricultural land, climate conditions, forest resources, technological infrastructure, population density, and biomass resources management.

Table 14. The total potential of biomass production in different countries.

Country/County	Number of Inhabitants	Biomass Potential per Capita (tons)
Kosovo	1,770,721	2.6
Thessaly region	354,290	2
Turkey	85,895,103	0.87
Croatia	4,004,690	0.84
Czech Republic	10,496,797	2
Hungary	10,127,294	7

Source: Authors' own calculation based on [41,51,64–67].

Each country has its own specifics in biomass production, but based on the study of [69], the land is a crucial factor in obtaining a great biomass yield. This is mentioned after analyzing 75 studies on the competition in terms of biomass.

Agricultural residues (specialized bioenergy crop residues), solid waste, animal waste, and sewage sludge are the four main categories of biomass energy sources in Egypt [70]. Approximately 12.33 million tons of dry biomass are produced annually from bioenergy crop residual sources, with rice straw accounting for 63.75%. At the same time, solid waste could generate 41.7% of Egypt's total theoretical potential energy from a volume of 34.6 million tons per year. Moreover, 9.7% of the total theoretical energy could be produced by 6.2 million buffaloes and cows. However, only 4.0% of the total theoretical energy generation comes from the 2 million tons of dry sewage sludge produced annually in Egypt.

Albania produced about 4.8 million tons of dry biomass at the neighbourhood level in 2005 [71]. Therefore, the theoretical energy content of biomass was 11.6 million MWh/a, and 3 million MWh/a of technical electrical energy was produced. The amount of electrical energy generated is equal to 45.8% of the annual national electrical consumption of Albania. According to the article, one-third of the theoretical heat energy can be converted into technical electrical energy using practical conversion processes.

6. Conclusions and Recommendations

With a greater understanding of the overall usable capacity, this study analyzes the potential of biomass resources (cereals, animals, forests and solid waste) and the degree of their conversion to renewable energy. Due to the location and climate of Kosovo, large-scale renewable energy sources such as hydropower, photovoltaic (PV), wind farms and biomass power plants should be used to meet the set goals. To address issues caused by high-energy import costs, air pollution, and increasing energy consumption, Kosovo has great potential to use renewable energy sources. Due to the low cost of labor and heat energy production, applying these approaches would also considerably attract the government. Biomass energy not only satisfies energy needs, but also stimulates economic growth. Thus, to achieve significantly greater macroeconomic savings, it is recommended that the country assist the development of bioenergy methods in underdeveloped areas.

Compared to the current use of energy from biomass sources in Kosovo, the data found and the calculations performed, the authors conclude that there is a significant potential for theoretical and energy production from biomass use in Kosovo. This process should start with the by-products of cereals, especially the two main cereals, wheat and maize. Such utilization of this type of biomass would also help farmers increase their income by diversifying production or even efficiency within the farm, or, on the other hand, lower energy costs for farmers. Unfortunately, in recent years, the phenomenon of burning after harvest has begun to appear, which has a negative effect on air quality and soil damage.

In the livestock sector, a large amount of organic manure is produced. It contributes to groundwater pollution, atmospheric air pollution, and strong gas emissions such as nitrogen oxide and methane, which can further contribute to environmental damage and pose hazards to human health. Using it for energy purposes, these negative externalities would be transformed into positive effects for the entire population of Kosovo. The idea of using this resource has good potential, especially in large cities where the number of large farms is higher and the distance between them is shorter, because this would increase the efficiency of the utilization process of this resource.

Regarding forest residues, the research findings show that there is a significant biomass potential, mainly used for heating at the household level or public institutions, such as schools, etc. However, to make rational use of this potential, central monitoring must also be operational, taking into account that the government owns a large part of forests and there is a need to determine the cut level allowed based on annual forest growth. In reality, utilizing this theoretical potential would stabilize the energy supply at the country level, and, more importantly, electricity would not be used for heating during winter.

Kosovo, with almost 2 million inhabitants, produces quite a significant amount of solid waste collected at the seven regional administrative levels. In addition to having positive externalities in the preservation of the environment, such waste collection would serve as a source of energy from biomass. There would be an excellent recommendation for higher instances for installing the liquid collection network to use it for energy purposes. This would be achievable by having a convenient infrastructure.

Approximately 4.57 million tons of biomass, which can be used for bioenergy purposes, are accessible in Kosovo each year when other alternative utilization options are considered. In general, it can be said that agricultural areas have enormous biomass potential, but it is quite challenging to take advantage of it. Due to the lack of interest, resistance, or financial capital of the population and local government, the deployment of efficient energy procedures is a highly challenging task.

Regarding sustainability criteria for cereal residues, it depends on the practices employed and the scale of production, while for forestry, it is the selective logging, reforestation, and afforestation efforts. For livestock residues, reducing the accumulation of manure and waste on farms is worth mentioning. In terms of solid waste in Kosovo, the volume of waste sent to landfills and the risk of soil contamination is reduced.

To ensure an adequate supply of biomass to meet short- and long-term needs, agricultural land, plantations, forests, and other renewable energy sources must be revitalized.

Over time, as technology advances and economies of scale are realized, biomass energy can become more cost-competitive with fossil fuels. This can lead to lower energy costs for consumers. Additionally, high energy prices can incentivize individuals and businesses to invest in energy-efficient technologies and practices (special stoves for direct burning, pellet, and biobriquette equipment). While this can lead to long-term energy savings, initial upfront costs can be a barrier to adoption. Therefore, to plan and meet the long-term needs of the nation for biomass, it is necessary to map the raw resources for biomass.

The authors suggest that any long-term policy from the central level would be welcome, which would stimulate local governments and guide farmers and any other stakeholders towards reaching long-term targets. Moreover, various investigations and research related to mapping the potential and the level of agricultural waste production from different cultures would significantly impact the existence of data.

7. Limitations

This article faced a limitation in terms of updated data available, especially for renewable energy sources and straw availability. It started with a lack of websites or reports that would provide data on cereal residues available in the field, followed by the perceptions and willingness of different farmers at the country level to use it. Moreover, it was not possible to include the potential of liquid waste, due to the lack of data. In the case of small-sized farms, they can use only small capacity options locally for their energy needs, especially in direct heating, but cannot use the automated, more expensive, higher-level technologies with high capacity. A possible solution may be to create local energy communities. Another aspect to consider is a low-price competitive product (lignite), which is difficult to substitute economically. Possible support would be the higher value of environmental aspects in the future for the sake of possible EU accession.

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