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The Potential of Ukrainian Agriculture's Biomass to Generate Renewable Energy in the Context of Climate and Political Challenges—The Case of the Kyiv Region

Adam Waś^{1,*} , Piotr Sulewski¹ , Nataliia Gerasymchuk², Ludmila Stepasyuk³, Vitaliy Krupin⁴ , Zoia Titenko⁵ and Kinga Pogodzińska¹

¹ Institute of Economics and Finance, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787 Warsaw, Poland

² Department of Marketing, Poltava State Agrarian University, 36003 Poltava, Ukraine

³ Department of Economic, National University of Life and Environmental Sciences of Ukraine, 03041 Kyiv, Ukraine

⁴ Institute of Rural and Agricultural Development, Polish Academy of Sciences, Nowy Świat 72, 00-330 Warsaw, Poland

⁵ Department of Finance, National University of Life and Environmental Sciences of Ukraine, 03041 Kyiv, Ukraine

* Correspondence: adam_was@sggw.edu.pl



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Abstract: Increasing the share of renewable energy in the final energy consumption is a way to ensure independence from external supplies of fossil fuels, which is a fundamental political and economic challenge for many countries nowadays. One such country is Ukraine, which depended on Russian gas supplies and energy (electricity) from nuclear power plants. Russian gas is not delivered anymore to Ukraine, and Russians have recently taken over some of the nuclear power plants. The changes in the political situation force Ukraine to search for alternative energy sources. In countries with high agricultural production potential, one of the basic options seems to be popularization of modern methods of obtaining energy from biomass (bioenergy), which so far has played a minor role in the country's energy mix (less than 2% in the case of Ukraine). The analysis carried out on the case of the Kyiv Region indicates that the annual economic potential of biomass in the region is equivalent to 1743 thousand toe (tonnes of oil), and its use allows them to save about 43% of fossil fuel annually.

Keywords: biomass; energy potential; alternative energy sources; resources; enterprises; fuel

1. Introduction

Due to globally observed climate challenges, the energy issue has become one of humanity's most important problems to solve in the near future [1–3]. Global energy production is still dominated by fossil fuels, accounting for 80% of the global energy mix [4]. Simultaneously combustion of fossil fuels (coal, oil, and gas for electricity, heat, and transformation) is the main contributor to global climate change, accounting for over 75% of global GHG emissions [5] and almost 90% of all carbon dioxide emissions [6]. Climate scientists' position is clear—moving away from fossil fuels is essential to stop further climate change [7,8].

The current level of renewable energy development differs significantly between different regions of the world and even neighboring countries [9,10]. On average, less than 11% of global primary energy consumption came from renewable sources in 2019, of which 6.4% was traditional biomass combustion [9]. These statistics show that biomass, particularly modern methods of its use, such as processing into biogas or biomethane, remains a relatively underused renewable energy source. Nevertheless, the production of agricultural biogas and other forms of biomass is an advantageous option in countries with

significant agricultural production potential [11,12]. One of them is Ukraine, one of the most important agricultural producers in Europe and the world [13].

In the case of Ukraine (and also in many other countries), increasing the degree of biomass use (including the production of agricultural biogas) is a way to increase energy independence [14,15]. Awareness of this challenge significantly increased after Russia invaded Ukraine. Although Ukraine has not imported natural gas directly from Russia since 2015, it still remains dependent on gas imports from Western countries [16]. However, the invasion has significant consequences for the global energy sector. In particular, it relates to natural gas, which can, at least partially, be replaced by gas from biomass.

In the face of the Russian invasion of Ukraine, the challenge of increasing energy independence has become much more critical than ever before. Searching for the possibilities of using biomass for energy purposes is, therefore, a task justified for environmental reasons (replacement of fossil fuels and reduction of GHG emissions) and political reasons (increasing energy independence). There is an urgent need to search for new, alternative sources of energy, and biomass use for energy production is the most attractive option [17]. In this context, the study's goal was to assess the potential of using agricultural biomass for renewable energy production in the Kyiv region.

2. Background Information

2.1. Biomass and Ukrainian Energy Sector—General Information

Biomass is a renewable organic material of plant and animal origin and can be helpful in substitution fossil fuels. Energy from biomass can be obtained in processes such as direct combustion, thermochemical conversion, and biological conversion [18]. In practice, the most frequently applied solutions include co-firing in coal power plants, combustion of biomass in dedicated power and CHP plants, or biomass conversion into biogas in anaerobic fermentation or thermo-chemical processes (pyrolysis) [19]. One of the essential advantages of generating energy from biomass is that it is a carbon-free process because emitted CO₂ was previously assimilated by plants [19]. Moreover, among the benefits of biomass can be mentioned wide availability, reduced overreliance on fossil fuels, usually lower prices compared to fossil fuels, and reduced waste in landfills [20]. Besides, biomass is a local fuel, and its use increases the regional added value by minimizing fossil fuel imports. Moreover, biomass production and supply contribute to creating new workplaces, mainly in rural areas, which is vital for the local economy.

Shortcomings of biomass use are reflected in the lower efficiency of some biofuels compared to fossil fuels. Although burning biomass is carbon neutral, it still generates air pollution. Overuse of wood can lead to deforestation, and biomass plants usually require a lot of space [20]. Biomass used for energy production may include wood and wood processing wastes, agricultural products, and food wastes as well as municipal, solid, and liquid wastes [18]. Particular hopes for the development of biomass are connected to the production of biogas [12,21].

Ukraine is one of Europe's largest energy consumers, with a primary energy consumption of 93 Mtoe (million tonnes of oil equivalent) in 2018. Domestic energy production is insufficient to meet total energy demand; it covers about 65% of energy needs [22]. In recent years, there has been a significant decrease in domestic energy production compared to 2007 by over 30% (Figure 1). Energy exports have also dropped significantly, and to a lesser extent, imports. As a result, Ukraine is most dependent on imported oil (83% of consumption) and to a lesser extent on coal (50% of consumption) and natural gas (33%), which meant that in 2018 it was necessary to import 8.5 Mtoe of natural gas, 13.5 Mtoe of coal, and 10.4 Mtoe of oil products [22].

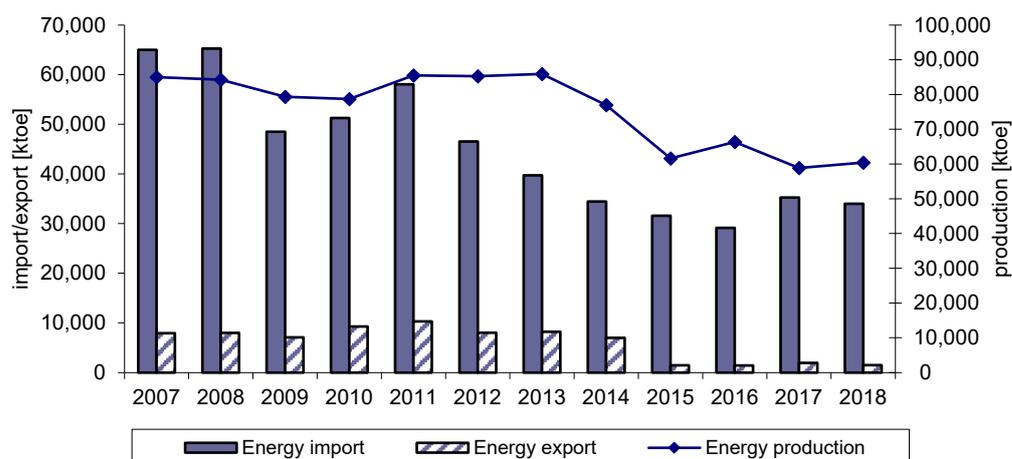


Figure 1. Production, export, and import of energy in Ukraine, in thousands toe. Source: The author's calculations are based on statistics from the State Statistics Service of Ukraine [23].

The Ukrainian energy sector is mainly based on fossil fuels (natural gas, oil, and coal) and nuclear energy [22]. In the structure of primary energy consumption dominates coal (28.3%), followed by natural gas (28.2%), nuclear energy (23.4%), and oil (13.8%) [4]. The share of other energy sources, including hydropower, wind, solar, and other renewables, is less than 6% [4] (Figure 2).

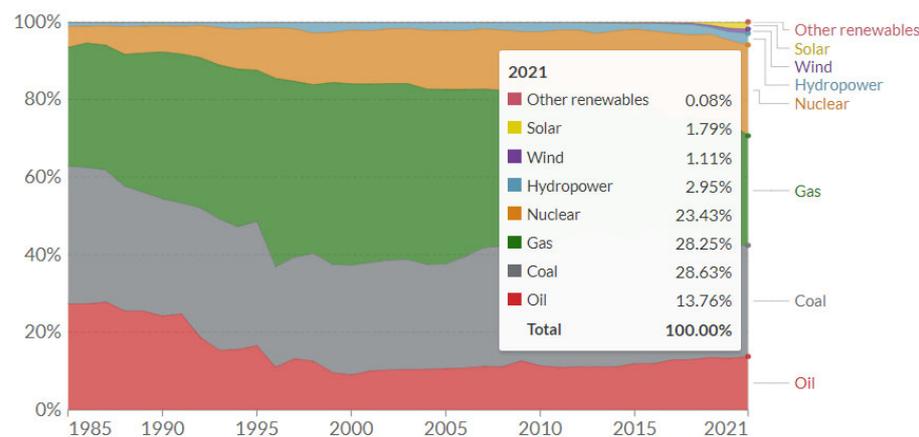


Figure 2. Structure of primary energy consumption in Ukraine by source. Source: [24].

The importance of nuclear energy for Ukraine should be emphasized—although it accounts for less than 25% of the total primary energy, it meets half of the country's electricity needs [22]. Nuclear power plants increase the country's energy independence, but they also pose a severe threat to the whole world in the face of the Russian invasion of Ukraine. An example is the Zaporizhzhia Nuclear Power Plant (the largest nuclear plant in Europe), occupied by the Russians, over which the Ukrainian authorities lost control [25]. This case, as well as other negative experiences with the safety of nuclear power plants, forces us to ask about the further development of the energy sector in Ukraine. It is also worth paying attention to the changes in the share of renewable energy. Although it is still relatively small, in the last few years, it has increased from less than 2% in 2015 to about 6% in 2021 (excluding traditional biofuel use) [4]. The progress in the development of RES observed in recent years is connected with increasing awareness that renewable energy sources have a high potential to reduce natural gas dependency and enhance energy security. The government's decision in 2016 to withdraw from subsidizing the production of heat from natural gas turned out to be particularly important for the development of RES and made the production of heat from renewables (including biomass) comparatively

competitive (in comparison to fossil fuels) [22]. The share of renewable energy in the heating and cooling sector in 2020 was 9.3%; in the electricity sector, it was 13.9%; and in the transport sector, it was 2.5% [26]. The total installed capacity of active renewable energy projects (excluding large scale hydro generation >10 MW) was around 7.7 MW, of which 72% belong to industrial solar, 8% solar in a private household, 15.7% wind, 1.5% small hydro, and 2.3% to biomass and biogas [27]. These data indicate the relatively low importance of biomass in energy production in Ukraine, although the analyses of Lakyda et al. [28] show that the technical potential of forest biomass can be estimated at the level of 2.1 Mtoe and that of agricultural waste at the level of 12 Mtoe. Assuming the demand for primary energy is at the level of 86.4 Mtoe (in 2020), this would meet approximately 16.3% of the country's energy needs.

Many authors underline the need to diversify the Ukrainian energy mix and improve energy efficiency. For example, Lewicki [29] stressed the need for diversification of supplies, differentiation of energy balance through increased use of renewable energy sources, and increasing the energy efficiency in the historical aspect, while Gerasymchuk [30] outlined the background of using renewable energy sources in order to ensure the energy efficiency of Ukraine, given the statistic and existing situation in the energy market, and analyzed the resource base for renewable energy sources and local fuels for the energy efficiency and the reliability of Ukraine's energy supply, which became a start for this research.

The use of biomass seems particularly justified in the case of heat production, because sometimes it seems to be the only feasible option to replace fossil fuels to provide heating for buildings without easy access to other supply options [31]. Ukraine's total thermal energy consumption in 2012 was estimated at 14.03 Mtoe, of which only about 6% was covered by biomass (solid biomass and biogas) [31]. Currently, the share of biomass in Ukraine's total heat production is estimated at 9% [32].

The growth of energy production from renewable sources is an important area for replacing natural gas, as there is a large reserve for reorientating biomass exports to the domestic market. Energy security in the face of the Russian military aggression against Ukraine is another perspective that needs to be assessed and considered in the energy and bioenergy development plans. Energy generation from biomass in this regard seems to be not only sustainable, but also highly dependable [33–35]. Local generation of energy based on locally available sources allows them to sustain the needs of particular farms or even communities and ensures maintaining of their functions regardless of the exogenous shocks and national or regional grid malfunctions [36,37]. In this case, a tight connection between food and energy security strengthens the sustainability and resilience of the local food systems. It allows them to carry on with the provision of essential system functions [38].

Although the current contribution of biomass to energy generation in Ukraine remains small, it can be expected that this situation will change in the future. Geletukha et al. [39], in their complex assessment of the future bioenergy developments in Ukraine, assume the country would follow the European Green Deal and align its climate neutrality achievement and environmental development along the current European priorities. Ukraine is also a member of the European Energy Community, which has declared its conscious participation in a global policy aimed at sustainable development and reduction of harmful effects on the environment. As Ukraine is already committed to the Paris Agreement to work on the reduction of greenhouse gas emissions and the Energy Community Treaty to work towards transformation to clean energy, the development of the bioenergy sector to fulfil its green transitions is crucial.

2.2. Ukrainian Agricultural Sector—Supplier of Biomass for Energy Generation

As a country with a large agricultural sector, Ukraine has significant development potential in bioenergy. The development of the bioenergy sector is eased by vast areas of fertile croplands and less productive lands suitable for growing undemanding energy plants, a favorable climate for plant and livestock production, and the availability of the necessary human and material resources. In addition, high yields of major crops provide a

sustainable resource base, which has not been exploited so far. In this regard, plant biomass plays one of the key roles in the development of bioenergy.

In the European Union, biomass for energy generation reached a share of ca. 60% among renewable energy sources, which directly contributes to the EU's energy security, as most of the demand (about 96%) is covered by domestically produced biomass [40]. Already, as of 2020, the volume of biomass consumption for energy production in the European Union is more than 120 million tonnes of oil equivalent per year [41]. As Ukraine has been granted EU candidate status, compliance with EU legislation and principles will be increasingly important. According to the EU Energy Security Strategy [42], members need to become more energy "independent" by saving energy and producing more local (RES) energy.

According to Geletukha et al. [43], Ukraine has considerable potential for renewable energy sources, one of the most extensive being biomass. Despite some fluctuations, Ukraine's volume of agricultural biomass increases almost every year due to the general trend of growth in the production and yield of major crops. Thus, in 2019, the country harvested a record amount for the last 20 years of sunflower, corn for grain, and some other cereals. Since 2000, the energy potential of straw of cereal eared crops, byproducts and waste of grain, corn and sunflower production in Ukraine has tripled, from 2.8 Mtoe in 2000 to 8.5 Mtoe in 2020. As the abovementioned authors state, agro-biomass (agricultural residues and energy crops) will remain Ukraine's primary type of bioenergy potential. Expanding the use of agricultural residues requires working out technologies for baling corn and sunflower stalks. On the other hand, energy crops for solid biofuels will continue to grow on unused (low-yield) agricultural lands.

Given that the agro-industrial resource is becoming a leading strategic bioresource, biomass from products produced in the agricultural sector can give Ukraine new opportunities for sustainable development through the production of cheap, environmentally friendly bioenergy products through efficient use of agricultural biomass. However, analysis of the use of agricultural biomass for energy purposes showed that the current level of use of energy potential of biomass in the country is very low—from 0 to 2–3% depending on the specific species, and only sunflower husk shows the level of 73.1% [44]. As the authors state, biomass's leading destination is thermal energy production, which is used for heating and hot water supply. Between 2014 and 2018, biomass's share of thermal energy was within 97% of all renewable thermal energy.

Kulyk [45] emphasizes that bioenergy development in Ukraine requires searching for ways to reduce the cost of various types of bio-raw materials in the economic justification of their production. Currently, the main components of the bioenergy production potential in Ukraine are primary agricultural residues (cereal straw, corn, and sunflower residues) and industrial cultivation of energy crops. However, the biomass production of renewable plant material from energy crops depends on many factors determining their cultivation's feasibility. Environmental influences on energy crop cultivation are mainly reflected in its effect on seed germination and the initial stages of plant growth. In order to achieve balanced cultivation and use of energy crops as plant material, ecological aspects must be taken into account. Reducing the pressure on the environment requires establishing energy plantations and growing energy crops on marginal lands with low fertility, showing signs of degradation and requiring reclamation [45,46].

Other studies [47] show that the estimated biological yield of plant biomass in Ukraine could be 64.3 million tonnes. They have also established that an increase in the use of straw for energy needs can be ensured only by increasing green manure crops in crop rotation (in particular, cultivations of cover crops within crop rotation cycles). At the same time, Hutsol [41] states that at this time, Ukraine has not approved a standardized system for measuring and accounting for solid biomass resources of forest and agricultural origin. Lack of such information, especially on energy crops, hinders the development and implementation of sustainable energy policies and projects in a particular area and the country as a whole. They also emphasize that it can be argued that there is the active use of

renewable energy and increased energy efficiency in the regions of Ukraine. However, many certain regions are cautiously implementing renewable energy production systems. The authors stress, among others, that the results of their research on solid biomass (mainly from agricultural residue) in Ukraine have a high potential for fuels that can be quickly applied.

The potential of biogas production from the livestock sector of Ukraine has been assessed previously [21]. It was found that, in absolute terms, Ukraine has a significant potential for the production of agricultural biogas from animal manure, reaching nearly 3 billion m³. However, the practical possibilities of using this potential are severely limited by the dual structure of agriculture. More than half of the available manure is produced on small livestock farms that are too small scale to consider investing in biogas plants.

It should be kept in mind that the ongoing war is also affecting the agricultural sector. Reduced production (reduced sown area) of primary agricultural commodities reduces the potential for food production and limits the amount of biomass used to generate energy (even if only agri-food waste was included). Therefore, looking for biomass sources other than agriculture is worthwhile.

3. Material and Methods

3.1. Case Study Area Description

Sustainable development of bioenergy requires, first of all, a careful assessment of the available biomass potential. Therefore, we assessed, as an example, the potential of biomass used as an energy source in the Kyiv region.

The Kyiv region is one of the largest regions of Ukraine, with an area of 28.1 thousand square kilometers (without the city of Kyiv), which is 4.7% of Ukraine's territory (Figure 3). By size, the Kyiv region ranks eighth among other regions of Ukraine. Kyiv region is a metropolitan region, in the center of which is located Kyiv, the capital of Ukraine, a powerful political, business, industrial, scientific, technical, transport, and cultural center of the country, connected with the region with close commercial and social ties. The distance from Kyiv to the region's northern border is 118 km, to the southern border is 128 km, to the western border is 76 km, and to the eastern border is 112 km. A feature of the Kyiv region is the absence of a regional center. Kyiv city, where the central administrative bodies of the region are located, is the autonomic region and does not count in Kyiv region statistics. Another feature of the region is the presence of a Slavutych city, which belongs to the Chernihiv region.



Figure 3. Geographical location and herb of the Kyiv region in Ukraine. Source: Strategy of Kyiv region for 2021–2027 years [48].

Kyiv Region has favorable conditions for agriculture, namely the region's climate, the structure of agricultural lands, availability of the capital city Kyiv as a sales market, and a robust scientific base for implementing innovative technologies in the production and processing of agricultural products. As a result, by volume of gross agricultural production, the region ranks second among all other regions of Ukraine.

Crop production in the total agricultural production of the region takes a significant share with 62.4%. The main crops grown are grain crops, potatoes, sugar beets, and sunflowers, with a large share of perennial gardens. By zone division, the north part of the Kyiv region is located in the Polissia zone, which is characterized by a larger share of forests over the fields with the developed forest harvesting, and the south is in the forest-steppe zone. The Kyiv region is one of the leaders among grain and oil storage market operators in Ukraine, with 53 elevators operating in the region with a total capacity of 2.6 million tonnes storage of the specified crops and 45 fruit storage refrigerators. The region ranks fourth in Ukraine for egg production and takes first place by volume of livestock meat and poultry.

The Kyiv region belongs to the energy-rich regions. Energy enterprises located on its territory have a total capacity of 3200 MW, namely the Trypilska thermal power station, Kyiv hydroelectric power station, Kyiv Hydroaccumulating Electric Power Station, Bilotserkivska Thermal Power Station, and small hydroelectric power stations, as well as the Dymerska solar power plant that is among the ten most powerful solar power plants of Ukraine [48].

The Kyiv region is an agrarian region in which large volumes of byproducts and waste suitable for energy use are generated. Large areas of agricultural land create significant potential for growing energy crops. The main source of biomass in the Kyiv region is primary crop waste.

3.2. General Assumptions—Methods of Calculating

Typically, three main types of biomass potential are considered when energy production possibilities are considered, i.e., theoretical, technical, and economic potentials.

The theoretical potential is the maximum amount of terrestrial biomass theoretically available for energy production. For example, the theoretical potential of waste and residues of various types is the total volume from which energy can be extracted. The technical potential limits the theoretical to the amount of biomass that is available for processing, which is available at a specific moment under certain structural, technical, and technological conditions. When calculating it, it is essential to consider spatial restrictions caused by competition between land users and environmental factors [49].

Economic potential is an even narrower concept because it includes only that share of technical potential that provides the desired level of profitability. Therefore, within this study's framework, the cost estimation method was used instead of profitability analysis for its evaluation based on the resource-consuming concept. This approach better represents the importance of the amount of available biomass when planning the production of energy products [50]. Furthermore, the used technique allows, in addition to planning the volume of energy production, to forecast financial results from the activity.

Wood biomass, which can serve as fuel, is produced due to general and sanitary felling. Firewood, wood chips, branches, stumps and crowns, and secondary processing products—shavings and sawdust—are involved in energy production. We used the approach of determining the energy potential of wood waste P_w according to the formula:

$$P_w = (V_w * K_1 + (V_w - V_{com}) * K_2) * Q_w$$

where:

V_w —a volume of wood logging, m³;

$K_1 = 0.1$ —waste ratio;

V_{com} —the volume of round timber, density m³;

$K_2 = 1 - (0.2 \dots 0.25) = 0.8 \dots 0.75$ —the total coefficient of waste of wood's main and secondary processing. Considering standard losses during wood processing of 5–10%, we accept $K_2 = 0.70$;

$Q_w = 0.186 \text{ toe/dense m}^3$ —calorific value of dense wood during logging [51].

We suggest calculating the energy potential of biogas (toe) from organic waste using the formula:

$$E_{LS} = \sum_{i=1}^n \frac{365 * N_i * q_{mi} * \frac{TS_i}{100} * \frac{VS_i}{100} * q_i^{bg} Q_{LHV}^{bg}}{Q_{LHV}^{oe}}$$

where:

N_i —the total number of animals of the i species, heads;

q_{mi} —yield of organic waste of the i -th type, kg/(hour-day);

TS_i —share of dry substance in organic waste of the i -th type, %;

VS_i —the proportion of organic substance in the dry residue, %;

q_i^{bg} —expected yield of biogas from an organic waste of the i -th type, $\text{m}^3/\text{kg DOM}$ (dry organic matter);

Q_{LHV}^{bg} —expected lower heat of combustion of biogas (LHV), generation from an organic waste of the i type, MJ/nm^3 ;

$Q_{LHV}^{oe} = 41.868 \text{ MJ}/\text{kg}$ —lower heat of combustion of oil equivalent [46].

The formula determines the economic potential of biomass from pruning of fruit trees:

$$P_e = \sum Spac_i * Pr_i * Kt_i * Koe_i$$

where:

$Spac_i$ —land, the area of which is occupied by fruit trees of the i -th species at the fruit-bearing age, thousand hectares;

Pr_i (2.4 for pome fruit, 3.0—for stone fruit trees)—specific productivity of pruning fruit trees of the i species at the fruit-bearing age for calculating the theoretical potential of biomass, t/ha;

Kt_i (2.4 for seed trees, 3.0—for stone trees)—the criterion of the technical possibility of pruning for calculating the technical potential of biomass;

Koe_i (0.406 for pome fruit, 0.400—for stone fruit trees)—the potential biomass coefficient in oil equivalent: the calorific value of plant waste in oil equivalent [51].

The following formula is used to determine the economic potential of processing waste:

$$P_e = \sum_{i=1}^n Cpr_i * Kr_i * Koe_i$$

where:

Cpr_i —the volume of processed raw materials of the i -th type (for example, sunflower seeds);

Kr_i —the coefficient of waste generated during the processing of raw materials ($Kr = 0.15$ for sunflower seeds shows that 1 tonne of processed seeds yields 150 kg of husk, i.e., 15% of the total volume);

Koe_i —coefficient of conversion of biomass potential into oil equivalent: (for sunflower husk, it is 0.358) [51].

4. Results

Based on the results of the analysis of sunflower seed processing by agricultural enterprises in the Kyiv region, it is clear that from 2014 to 2019, its volume remained practically unchanged. In the reporting year (i.e., 2019), it amounted to 370,000 tonnes. Therefore, the economic potential of such energy-oriented production, calculated according to the above formulas, is 19.9 thousand toe (Figure 4).

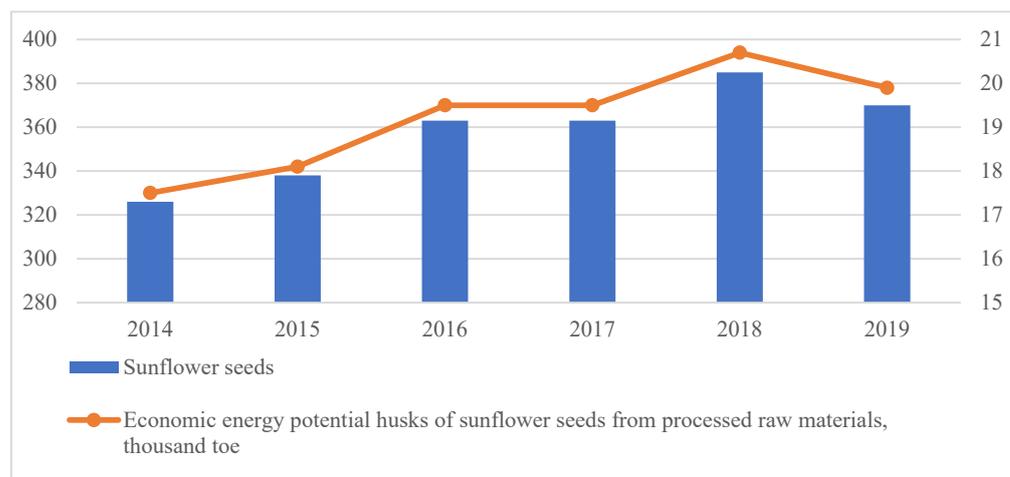


Figure 4. Volumes of processed raw materials, thousand tonnes. Source: author’s calculations are based on statistics from the State Statistics Service of Ukraine [23].

At the same time, it was observed that timber felling in the region increased significantly: from 1608.7 thousand m³ of wood in 2015 to 2015.2 thousand m³ of wood in 2019. Thus, the difference between the reporting and base years exceeds 25%. At the same time, the volume of wood harvesting increased by 2.1 times. This increased the economic potential of wood by 1.6 times (Table 1).

Table 1. The economic potential of wood waste.

Years	Wood Logging, Thous. m ³	Round Wood (Commercial Wood), Thous. m ³	The Volume of Wood Waste		Firewood Logging, Thous. m ³	The Economic Potential of Wood Waste, Thous. Toe
			Logging, Thous. m ³	Processing, Thous. m ³		
2015	1608.7	563.5	161	732	518.7	262.5
2016	1785.3	547.1	179	867	551.6	297.0
2016	1912.2	522.7	191	973	1139.0	428.3
2017	1916.0	440.0	192	1033	1219.2	454.6
2018	2077.5	589.2	208	1042	1196.5	455.0
2019	2015.2	559.7	202	1019	1100.8	431.7

Source: author’s calculations based on statistics from Kyiv Oblast Statistical State service [52].

A representative sample is key to objective analysis and reliable results. Based on this postulate, we took for the study of economic energy potential only agricultural enterprises of the Kyiv region with a significant number of livestock, namely: cattle—from 2000 heads, pigs—from 9000 heads, and poultry—from more than 400,000 heads. Small enterprises that do not have a centralized collection of organic waste in animal husbandry were not taken into account.

The results of the calculations show significant dynamics in the size of livestock. Thus, from 2014 to 2019, the poultry number increased by 6%, while the number of cows and pigs decreased by 15% and 1.3% (Table 2). In animal husbandry, poultry farming is the largest source of organic waste for obtaining biogas. The bird population in 2019 was the largest and amounted to about 17 million. From this volume, it is possible to get 40.6 thousand toe. Therefore, the total livestock that was analyzed to calculate the economic potential of biogas production can provide a sound output of 62 thousand toe.

Table 2. The economic potential of biogas from organic waste.

	2014	2015	2016	2017	2018	2019
Cattle total, thousand heads	40.0	38.0	37.0	35.0	34.0	34.0
Biogas from organic waste cattle total a thousand toe	10.2	9.7	9.4.0	8.9	8.6	8.6
Pigs, thousand heads	228.0	226.5	225.0	224.0	226.0	225.0
Biogas from organic waste pigs, thousand toe	13.0	12.9	12.8	12.8	12.9	12.8
Poultry, thousand heads	15,958.0	16,005.0	16,402.0	16,454.0	16,589.0	16,921.0
Biogas from organic waste poultry, thousand toe	38.3	38.4	39.3	39.5	39.8	40.6

Source: author's calculations based on statistics from Kyiv Oblast Statistical State Service [52].

Corn and sunflower stalks, wheat, rye, barley, buckwheat, pea, soybean, rapeseed, and millet straw can be used in crop production for energy needs. Almost all grain and oil subsectors have significant potential for biogas production. The byproduct output rate determines the available amounts of straw in accordance with the agricultural crop yield. Table 3 presents the results of the analysis of the economic potential of crop production in the Kyiv region. Enterprises in the region specialize in growing corn, sunflower, soybeans, rapeseed, barley, and wheat. Byproducts are used as fertilizer, as well as for livestock maintenance, especially barley straw. This trend confirms the structure of the use of byproducts adopted in our methodology, namely that 40% of oil crops and 30% of cereals are free for biogas production.

Table 3. The economic potential of grain and industrial waste, thousand toe.

Crops	2014	2015	2016	2017	2018	2019
Wheat	123.6	143.3	167.1	91.8	125.1	153.8
Rye	3.7	3.4	3.4	3.7	4.0	3.5
Barley	22.9	22.6	27.6	13.3	18.6	27.8
Oat	1.0	0.7	0.6	0.4	0.4	0.4
Millet	0.1	0.1	0.1	0.0	0.1	0.5
Buckwheat	1.0	1.0	1.0	0.9	1.0	0.8
Legumes	2.5	2.4	2.7	2.3	2.2	2.6
Corn stalks	592.0	413.0	525.0	456.0	819.0	795.0
Sunflower stalks	60.0	59.0	91.0	80.0	114.0	100.0
Soybean straw	104.0	87.0	98.0	73.0	86.0	61.0
Rapeseed straw	30.0	26.0	13.0	20.0	34.0	36.0
Total	940.8	758.5	929.5	741.4	1204.4	1181.4

Source: Own calculations based on statistics from the State Service of Statistics [53].

In addition, the methodology uses the coefficient of losses and the volume of slaughtered products for fertilizers and animal husbandry needs (up to 50%).

The distribution of straw in the enterprises of the Kyiv region by areas of use shows that in 2019 the available amount of straw was 1538.4 thousand tonnes, 769 thousand tonnes of which are applied as fertilizers, 189 thousand tonnes were used for litter, and 547.8 thousand tonnes can be used for energy production.

The results show that the area under grain fruit plantations for 2014–2019 decreased by 2.6 times, and fruit trees remained unchanged under the stones. Therefore, according to our calculations, the economic energy potential of perennial plantations in the Kyiv region is 0.9 thousand toe (Table 4). However, its potential is somewhat irrelevant due to the relatively small scale of plantations.

Table 4. Areas of perennial plantations in fruiting age in agriculture enterprises of Kyiv region, thous. ha.

Plantations	2014	2015	2016	2017	2018	2019
Thousand ha						
Areas of perennial plantations in fruiting age in agriculture enterprises						
Pome fruits trees	2.6	1.8	1.5	1.3	1.0	1.0
Stone fruits trees	0.1	0.1	0.1	0.1	0.1	0.1
The economic potential of energy from pruning of fruit trees and vineyards waste wood						
Thousand toe						
Pome fruits	2.0	1.4	1.2	1.0	0.8	0.8
Stone fruits	0.1	0.1	0.1	0.1	0.1	0.1
Total	2.1	1.5	1.3	1.1	0.9	0.9

Source: Own calculations based on statistics from State Service of Statistics [53,54].

Considering the direct relationship between the yield of crops and the economic potential of byproducts, the results of the analysis showed that, in 2019, the most significant potential in oil equivalent was as follows: straw waste in the amount of 1182 thousand tonnes, wood at 432 thousand tonnes, and manure at 62 thousand tonnes. On the other hand, the husk has the lowest energy potential at only 19.9 thousand toe (Table 5). Thus, the total economic energy potential of agricultural enterprises of the Kyiv region in the amount of 1697 thousand tonnes is distributed by sources in the following ratio: stalks and straw occupy 70% of the structure, wood accounts for 25%, manure for 4%, and sunflower husks produce only 1% (Figure 5).

Table 5. The economic energy potential of waste in the Kyiv region, thousand toe.

Source of Energy	2014	2015	2016	2017	2018	2019
Straw and waste	941.0	758.0	929.0	741.0	1205.0	1182.0
Sunflower husk	18.0	18.0	20.0	20.0	21.0	19.9
Pruning trees	2.0	1.0	1.0	1.0	1.0	1.0
Wood	262.0	297.0	428.0	455.0	455.0	432.0
Manure	61.4	61.0	61.6	61.1	61.3	62.0
Total	1284.4	1135.0	1439.6	1278.1	1743.3	1696.9

Source: Own calculations based on statistics from the State Service of Statistics [53].

In 2018, 4019 thousand toe was used in the Kyiv region. At the same time, according to the results (Table 5), the economic energy potential of crop, livestock, and horticulture waste amounted to 1743 thousand toe. This amount could provide about 43.3% of the fuel needs at the expense of alternative types of biofuel. Such optimization will contribute to reducing the destructive impact of harmful emissions from petroleum fuel on the environment, increase the self-sufficiency of enterprises and their organizational and financial independence from external conditions, and reduce the production process cost.

There are no specific data about current renewable energy usage in Kyiv oblast. However, the share of the total capacity of boiler plants operating on alternative fuel types to the total number of boiler plants is 16.9% (against 16.594 in 2019), which is 0.4 percentage points more than in the same period of the 2019 year.

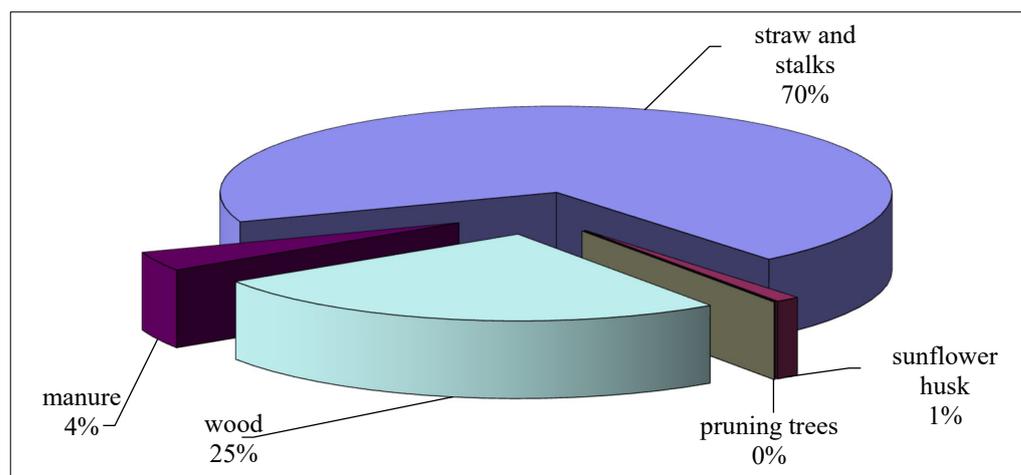


Figure 5. Structure of energy potential of the agricultural production in the Kyiv region, 2019. Source: Own calculations based on statistics from the State Service of Statistics [53].

As of January 1, 2021, 378 boiler stations for communal purposes were converted to alternative fuels, which is 23 units more than in the same period in the previous year. The number of boiler plants producing energy from installations converted to alternative fuel is constantly increasing and is 27.3% now against 26.7% for the same period in 2019. There is a positive trend in implementing measures to replace natural gas consumption [55].

Referring to one of the best practices of usage of renewable energy could be mentioned company “UMK” in the Zguriv district of the Kyiv region, which implemented the biogas project of the “Ukrainian Dairy Company” with a capacity of 1 MW, which processes manure from 4000 cows and corn silage. The energy produced is enough for a dairy farm and the village of Velikiy Krupil.

Another example of the use of alternative energy sources is a large biogas plant located in the village of Rokytne, Kyiv region, with a capacity of 2.38 MW. The enterprise’s output to the design capacity made it possible to provide energy to about 800 individual households. Furthermore, the project initiator—the group of companies “Silhosproduct”—plans to use the mentioned technologies to construct similar factories [39].

Research on the economic efficiency of production and implementation of granules from agricultural raw materials on the domestic market shows that the average payback period of these projects is 2.8 years for the production of sunflower husk pellets and four years for the production of pellets from grain straw and corn stalks. In addition, the population uses straw fuel briquettes to heat their buildings in solid fuel boilers as a substitute for coal. [56].

5. Discussion and Conclusions

International studies of the energy security of humanity indicate trends in the increase in the price of energy sources. This issue is particularly tough for Ukraine, as the country depends on oil supplies from abroad. The civilian population and producers in various areas of the economy are sensitive to price fluctuations. The fuel shortage endangers the operation of vehicles, machines, and equipment involved in the production. National authors Geletukha and Zheliezna [39], in their Roadmap for Bioenergy Development in Ukraine, until 2050, have forecasted the growth of renewable energy generation and its implications. While the authors of the current work can highly relate to the trends for the next two to three decades described in the referenced article, it is doubtful that it would be possible to achieve the complete transition to renewables in energy generation by 2050. While it is a welcomed scenario, the current situation triggered by the Russian war against Ukraine will definitely set back the development of Ukraine, either economic or agricultural development, as well as development in energy transformation. Geletukha and Zheliezna [39] assumed the consumption of biomass for energy production in 2050 at

20 Mtoe/year, which seems to be quite substantiated and relevant to the expected share of renewables (63%) in the total primary energy supply in the same year. The achievement of the targets defined in the abovementioned roadmap requires numerous legislative improvements in Ukraine and considers the needed investments to neutralize the harmful effects of the Russian aggression and accompanied damages.

Modelling results based on the TIMES-Ukraine energy system model [57] prove the need to develop and implement the national strategy to increase energy generation from biomass. The highly valuable contribution proposed by the referenced authors includes the analysis of the current policy environment in the context of future biomass development and concluded with a set of policy recommendations for utilization of the biomass potential in Ukraine. However, as Kaletnik and Larina [17,58] point out, there are numerous issues hindering bioenergy development at the level of the legislative framework; methodological approaches to the economic, environmental, and social efficiency of production; and the use of biological types of energy. The Kyiv region has all the necessary conditions for biofuel production regarding available land resources and plant potential. Already today, the potential in the region of biomass, which is suitable for the cost-effective production of liquid biofuels (bioethanol and biodiesel), gives grounds to argue about the prospects of this area. According to our calculations (Figure 6), the energy from biomass produced in the Kyiv region can annually replace 43.3% of fossil fuels.

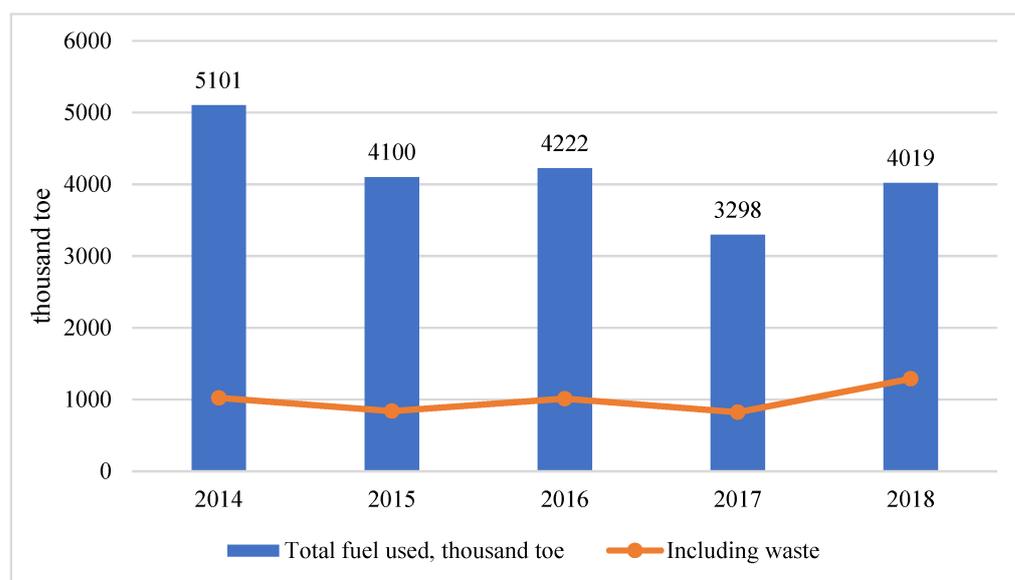


Figure 6. The total amount of fuel used in the Kyiv region (thousand toe). Source: own calculations based on statistics from [52].

It can be assumed that covering more than 40% of energy needs with locally produced biomass would represent considerable progress in the energy transformation of the region. However, this requires investments, which must be assessed regarding their profitability, energy security, and state security.

The findings of the current article support the abovementioned findings and show the urgency to implement legislative support for renewable energy generation, in particular forming a transparent and understandable regulatory environment for investments in bioenergy projects. These must be verified against the current conditions due to numerous changes in the local environment due to Russian atrocities and inflicted material and human damages on Ukrainian land. Approaches must be taken to intensify the restoration of the local economic infrastructure and farm property. Transport and energy infrastructure are of the utmost importance to ensure local development and the possibility of further improvements.

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