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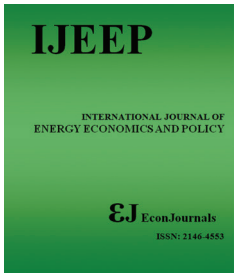

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Ukraine`s Bioenergy Sector: Trends and Perspectives for the Post-war Green Energy Transition

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ABSTRACT

The paper investigates trends in bioenergy development in Ukraine and its role in accelerating the green energy transition in the post-war period. The focus of the article is on the use of bioenergy resources for electricity generation, heat energy and liquid biofuel production. In this context, the potential of biomass, state support mechanisms, the results of their influence on bioenergy capacities deployment and the barriers restraining this sector development are considered. The study's results proved that the inconsistency of the state policy and the failure to consider the specifics of energy production based on various bioenergy resources caused a significant lag in its development compared to other renewable energy technologies. With this in mind, the article systematizes strengths and weaknesses, opportunities and threats, and based on them, strategic recommendations for bioenergy development in Ukraine in the post-war period are developed.

Keywords: Bioenergy, Landfill Gas, Solid Biomass, Biogas, Liquid Biofuels, Energy Policy, Ukraine
JEL Classifications: Q2, Q42, Q48, H23

1. INTRODUCTION

In recent years, there have been clear global trends regarding the transformation of the global energy sector. The governments of most countries of the world have developed and are successfully implementing their strategies towards achieving sustainable development goals (Bardy and Rubens, 2022; Bashynska et al., 2022; Beyi, 2021; Sala et al., 2023; Keliuotytė-Staniulėnienė et al., 2021; Tu et al., 2022), including those directed to replacement of fossil fuels by renewable energy resources (Gencer and Ackere, 2021; Hyrchenko et al., 2021; Mišík, 2021; Mišík and Oravcová, 2022). Ukraine also did not remain aloof from global trends, having declared the renewable energy development vector in the Energy Strategy of Ukraine until 2035 (CMU, 2017a) and the National Action Plan for the Development of Renewable Energy until 2030 (CMU, 2012). Thus, according to (CMU, 2017a), the share of

green energy in the country's total energy consumption is expected to increase to 12% and 25% in 2025 and 2035, respectively. In turn, following (CMU, 2012), by 2030, it is planned to increase the share of green electricity to 27% in the electricity sector, 35% in the heating and cooling sector, and 14% in the transport one. To achieve the above goals, it is planned to use the potential of all available renewable energy sources in Ukraine.

The government implemented state support mechanisms to encourage green energy production to achieve the abovementioned goals, contributing to renewable energy sector development. Thus, as of the end of 2020, the share of green electricity in the total power mix was 8.3%, the share of heat energy from renewable energy resources in the total heat energy mix was 8.6%, and the share of green energy in the total country's energy mix was 6.9% (SAEEU, 2022). However, it was possible to achieve the specified indicators only due to the development of specific renewable energy technologies. Thus, in the electricity sector, as of the end of 2020, 90% of green electricity was generated by solar and wind power plants, the indicator in the heat energy sector was achieved mainly at the expense of traditional biomass, the contribution of modern biomass and liquid biofuels to the total energy mix remains extremely low.

Insufficient use of the bioenergy resources potential, which, according to the Bioenergy Association of Ukraine, amounts to 23 Mtoe/year (Economic truth, 2020) (annually, leads to the loss of significant economic, environmental, and social benefits (Kurbatova and Sidortsov, 2022; Chepeliev et al., 2021; Trypolska et al., 2021; Trypolska et al., 2022). In addition, the disproportion in the development of renewable energy technologies in the power sector in favour of solar and wind generation, which is unstable and difficult to predict, led to significant technical problems with balancing the United Energy System of Ukraine. The lack of energy storage manoeuvring capacities leads to the need to partially limit solar and wind generation to ensure its operational safety energy system (Ukrenergo, 2021). Thus, it can be argued that today the installed capacity of solar and wind power plants has reached a certain plateau effect, and the further increase of such capacities is impossible without a significant improvement of the energy policy. It, in turn, emphasizes the feasibility of bioenergy power plants development, the generation of electricity based on which is stable, as it does not depend on the time of day, weather conditions, etc. In addition to the power sector, the involvement of biomass in the heat energy sector is highly relevant since more than half of the final energy consumption in Ukraine is heat energy (Kurbatova and Sidortsov, 2022), and biomass is the most suitable for heat energy production in comparison with other renewable energy sources. Furthermore, bioenergy resources are of great interest in liquid biofuels production to replace the import of petroleum products, which has increased significantly in recent years in Ukraine (Uninan, 2022; Business Censor, 2022).

Bioenergy development becomes especially relevant against the background of Russian military aggression and its impact on Ukraine's energy sector. On the one hand, there is an urgent need to abandon the import of fossil fuels from Russia and Belarus, which bioenergy resources can partially replace. On the other hand, the Russian aggression against Ukraine emphasized another shortcoming of the state policy in the renewable energy field, namely the lack of regulation of the geographical location of generating capacities. Focusing installation of renewable power plants, particularly solar and wind, in regions with the most attractive climate has led to their significant losses due to the Russian military intervention. Thus, Ukraine lost 36% of all installed solar and wind capacities in Ukraine as of 2014 due to the annexation of Crimea, which had the best climatic conditions for their development. As a result of the full-scale intervention of Russia in 2022, Ukraine lost 90% of wind and 30% of solar power plants located in the South-Eastern regions of the country, which have the best conditions for their installation on the continental part of Ukraine. Given that bioenergy resources are mainly distributed evenly throughout Ukraine, focusing attention on the development of bioenergy potential in the post-war period will allow, among other things, to reduce the influence of geopolitical factors on the renewable energy development in Ukraine.

Nowadays, the Ukrainian bioenergy market is represented by using four bioenergy resources: agricultural biomass, solid municipal waste capable of decomposition, wood biomass, and liquid biofuels. Therefore, the main focus of the article will be directed to the study of their existing potential for producing electricity, heat and liquid biofuels, the features of the state promoting policy in the bioenergy sector, the assessment of the results of its influence on the generating capacities development, the analysis of barriers that restrain the large-scale bioenergy development in Ukraine. The analysis results will be the basis of a SWOT analysis, which will be used to form strategic recommendations for developing bioenergy in Ukraine and correcting the state policy in the post-war period to ensure the green energy transition.

The study aims to determine trends and perspectives of Ukraine's bioenergy sector development in the post-war energy transition to form strategic recommendations for improving state policy based on the SWOT analysis.

The research is conducted for three sectors of bioenergy industry, namely electricity generation, heat energy and liquid biofuels production. The main stages of the research algorithm include: (1) Identification of potential for bioenergy development in Ukraine; (2) Investigation of the state support policy to promote bioenergy deployment; (3) Analysis of outcomes of state support policy in the sector; (4) Identification of challenges for bioenergy development in Ukraine; (5) SWOT analysis of bioenergy development in Ukraine; (6) Development of strategic recommendations for improving the state policy in the bioenergy sector and provide its advancement.

It is worth noting that bioenergy development can play a significant role not only in the post-war recovery of Ukraine's energy sector of Ukraine but also make a considerable contribution to strengthening the energy independence of the European Union countries, which, against the background of the energy crisis are forced to look for an alternative to Russian energy resources. Most of the European Union countries have a similar to Ukraine's renewable energy structure, that is, the predominance of solar and wind generation,

so some recommendations given in this study can be used to improve their energy policy to accelerate bioenergy development.

2. LITERATURE REVIEW

Over the last decade, the interest of scientists and practitioners in various aspects of bioenergy has grown significantly. For example, an analysis of publications (articles, reviews, and conference papers) for 2012-2022 in the Scopus database as one of the most respected scientific databases shows the increasing number (up to 6669) of papers considering technical, environmental, economic, and other aspects of bioenergy development. Thus, in 2012, there were 384 documents, while in 2022, the number of publications on bioenergy raised by 1.5 times to 585 papers with a peak of 836 publications in 2021. The TOP-5 countries in bioenergy research are the US, China, the United Kingdom, India, and Germany. It is worth mentioning that American scientists take leadership in this field with 1775 papers for the last 11 years in comparison to their Chinese colleagues with 993 documents in the database for the same period. Despite the variety of publications, a small part of them (5.5% or 387 papers for 11 years) investigates economic and management aspects of bioenergy development. This fact may explain the difficulties with implementing bioenergy technologies in many countries worldwide since the economic and management mechanisms for stimulating the advancement of this industry are underdeveloped.

The economic and management issues are critical for enhancing green energy technologies usage in developing and transition economies (Prokopenko et al., 2011; Domashenko et al., 2017; Kotenko et al., 2019). Powerful economic incentives can provide fast deployment of different bioenergy facilities and therefore reduce the amounts of agricultural and municipal wastes, strengthen the energy independence of territories, encourage decentralized electrical and heating systems development, and involve the local resource base in energy production. In this context, it is important to improve the state and local policies for bioenergy advancement in Ukraine. The country has sufficient potential of bioenergy resources but low level of their practical use along with significant deficit of own energy stock.

The analysis of studies devoted to bioenergy development in Ukraine has revealed 48 papers (0.7% of the total) for 2012-2022 in the Scopus database. Among them, 15 (31%) refer to economic, financial and management issues. Comparing this figure for Ukraine in Ukraine (31%) and the whole world (5.5%), we can conclude that effective economic and management mechanisms of bioenergy advancement are urgent for Ukrainians and require special attention to improve state policy in the field. Therefore, let us analyze the main results of these publications.

Soloviy et al. (2019) studied the opportunities of using forestry bioenergy resources in rural areas of Transcarpathia and Lviv. The authors indicated that the country has abundant wood resources and can successfully use them to meet the energy demand of local communities. However, the main threats are imperfect institutional, economic, and legal mechanisms that include unbalanced and shortsighted policy strategies, the export-oriented wood processing industry, corruption, illegal logging, etc. The researchers offered to improve the state policy in the sector by introducing certification for forest products and creating bioenergy cooperatives in local communities. Moreover, Melnyk (2018) analysed the mechanism of bioenergy fuels and biomass certification in the EU and Ukraine. The author developed policy recommendations for improving the organizational and economic basis for certifying biofuels produced in Ukraine to encourage the industry's deployment.

Brychko et al. (2018) investigated the promising directions of Ukraine's bioeconomy, including bioenergy advancement. The authors identified the innovative biotechnologies contributing to Ukraine's sustainable energy development and provided recommendations for their spreading on the domestic market.

Pryshliak et al. (2020) considered the issues of agricultural waste management to ensure additional energy resources for agricultural enterprises in Ukraine. The analysis of the potential, awareness and current state of agricultural waste use showed the high costs of providing agrarians with traditional energy resources while the bioenergy potential of waste was underused. In addition, Pryshliak et al. (2022) surveyed agricultural waste and energy dependence issues among Ukrainian small and medium-sized agricultural enterprises. The survey involved 354 responders. Based on its results, the researchers conclude that Ukraine's agricultural sector demonstrated slow rates of biofuel production despite the satisfactory (about 70%) level of managers' awareness about the opportunities for biofuel production from waste. The industry's development requires additional state support like soft loans for constructing biogas facilities, conducting information campaigns, and improving other regulatory tools.

Myronenko et al. (2017) studied the influence of bioenergy development on Ukraine's energy independence. The scientists concluded that the bioenergy industry advancement primary deals with overcoming related social and economic problems. The authors indicate targeted state funding, public-private partnership and foreign direct investments as perspective ways to implement bioenergy technologies and therefore increase the energy independence of Ukraine.

Yakubiv et al. (2014) designed an innovative model of balanced agricultural development based on bioenergy production to solve food and energy problems in Ukraine. The model helps to reach the expected economic, social and ecological results by making changes in its input parameters, including policy transformations.

Galchynska et al. (2021) identify bioenergy as an integral part of the energy security supply in Ukraine, given the significant potential of biomass available for domestic energy generation. The authors evaluated the bioenergy production growth in China, Germany, France, the US, Canada, Brazil, and Ukraine. They conclude that the cluster approach is the most feasible for Ukrainian bioenergy development. Using this approach, the researchers classified Ukrainian regions regarding the economic energy potential of wastes and energy crops in agribusinesses and offered the economic and management mechanisms to support the cluster projects.

Melnyk (2020) designed econometric models for Ukraine's bioethanol market operating to enhance biofuel exchange development and implementation. The scientist emphasized that state regulation of the domestic market should be improved. He suggested creating electronic trading platforms in biofuels exchange to increase the efficiency of policy regulations.

Merkulova et al. (2017) considered bioenergy and waste energy sectors as parts of a circular economy to build in Ukraine. The authors analyzed the Ukrainian renewable energy market's current governmental regulations and trends. They concluded that the growth of the green energy market and the bioenergy sector mainly, were based on innovations and should be supported with legal and economic mechanisms.

Karpenko et al. (2015) analyzed different opportunities to generate energy from renewables in Ukraine. They emphasized that the country has a considerable unused potential of biomass waste for energy savings. It could cover up to 18% of total primary energy consumption in Ukraine instead of the current 2%. The right policy would help implement the existing potential and increase the energy dependence of the state.

Onyshchenko et al. (2014) studied the renewable energy potential of Ukraine and concluded that wind power and biomass had the most significant economic potential. The authors proposed to improve the regulatory framework to create an integrated system for waste collection and disposal, adopt the feed-in tariff for electricity produced from waste and introduce tax privileges for waste recycling businesses.

Hryhoruk et al. (2021) identified factors influencing biofuel production in Ukraine and created a model to forecast the future development of renewable energy and bioenergy in the country. The researchers found that the feed-in tariff was one of the most effective mechanisms to stimulate the bioenergy market deployment. Other significant factors included electricity and gas prices. In addition, the industry was affected by gas imports, fluctuations in the national currency exchange rate, and other factors. The developed model helps build different scenarios of the sector's advancement and correct them by improving policy tools.

Chasnyk et al. (2015) discussed historical, technical, and economic aspects of biogas development in Ukraine and Poland. The authors mentioned the need for considerable investments in the industry to enhance its development and some improvement of legislation as well as provision of domestic renewable energy demand.

Given the above literature review, most researchers believe that the bioenergy potential of Ukraine is enormous but practically untapped. There are mainly economic and institutional obstacles in the development of the sector, particularly problems of financing such projects, insufficient economic stimulation of the development of small bioenergy capacities, etc. Therefore, it is essential to carry out further comprehensive studies of the bioenergy sector of Ukraine, including investigating the impact of on it. It will allow us to determine the latest trends in the development of the industry and to propose adequate changes in the state policy to revive bioenergy development.

3. RESULTS AND DISCUSSION

3.1. Potential for Bioenergy Development in Ukraine

3.1.1. Potential of electricity generation from biomass

Organic agricultural waste, biodegradable solid waste, and wood biomass can be used for biomass-based electricity generation. Next, we will consider in more detail the potential of the above types of bioenergy resources available in Ukraine for their use in the power sector.

One of Ukraine's most promising directions for bioenergy development is the use of agricultural biomass potential. Agricultural biomass can be conditionally divided into three groups: (1) primary, which is a by-product of crop production (straw, sunflower stalks, corn, etc.); (2) secondary, obtained during the processing of the main agricultural products (pulp, cake, etc.); (3) farm animal manure.

The prospects for this direction of bioenergy development are determined by the leading place of agriculture, among other sectors of the Ukrainian economy (Shkola et al., 2016). It is worth noting that the land fund of Ukraine includes 41.4 million hectares of agricultural land, of which 32.7 million hectares are arable land (AgroPolit, 2020). As a result, the most significant potential of agricultural waste, which can be used for energy purposes, is concentrated in crop production –9.4 Mtoe/year (Geletukha et al., 2022). As for the potential of animal husbandry waste, it is significantly inferior to the potential of plant biomass and amounts to about –1 Mtoe/year (Geletukha et al., 2022). However, it is the utilization of animal waste through the production of biogas and its subsequent conversion into electricity that is of particular interest.

It is worth noting that a feature of most Ukrainian agricultural enterprises, private farms and households is the accumulation and storage of manure in open lagoons, which are placed on the fields as organic fertilizer. Storage of organic animal waste in this way often leads to the pollution of underground and surface waters. In addition, excessive manure adding to the soil leads to the oversaturation of the soil with nutrients, which leads to a decrease in soil fertility and a reduction in the amount of land suitable for agriculture. Moreover, manure is a source of emissions into the atmosphere of ammonia, methane, nitrous oxide, and other gases, negatively affecting global warming and climate change (NECU, 2015). Thus, anaerobic fermentation of animal waste brings not only significant economic benefits in the form of electricity generation but also prevents significant environmental problems.

Another source of bioenergy resources that can be used to generate electricity is municipal solid waste capable of biological decomposition. In recent years in Ukraine, there has been an annual increase in the volume of municipal solid waste generation. The indicator of waste generation per person in country is 250-300 kg on average per year and has a growing tendency. It leads to the accumulation of 9-12 million tons of municipal solid waste annually (BAU, 2019).

The primary approach to managing municipal solid waste in Ukraine is its removal and disposal at landfills. The main reason

for this situation is low tariffs for such services. Thus, the average tariff for removal and disposal of municipal solid waste is UAH 118.07/m^3. Payment for a person per month in different regions of Ukraine ranges between UAH 21.35 and 32.54 for apartment buildings and UAH 32.14-36.03 for private houses (BCC, 2022).

Currently, only one waste incineration plant and 34 waste sorting lines are operating in the country. As a result, as of the end of 2020, only 6.3% of municipal solid waste was processed and disposed, of which: 1.7% was incinerated, 4.6% went to recycling points and waste processing lines, the rest –93.7% was placed on landfills (MDCT, 2020).

The total area occupied by landfills as of 2020 exceeded 9,000 hectares; 14% of the landfills do not meet environmental safety standards, 4.3% are overflowing, and 400 require reclamation (SFA, 2021).

Significant amounts of accumulated solid household waste in Ukraine and the lack of effective measures to prevent their generation and recycling lead to the deterioration of the environment and the loss of significant economic benefits (Chepeliev et al., 2021; Panchenko et al., 2021). Therefore, the collection and utilization of biogas, which is formed in the anaerobic fermentation of biodegradable waste and its further conversion to electricity, can be considered a practical approach to solving the above two problems. Another type of bioenergy resource that can be used for electricity generation is wood biomass. The primary sources of wood biomass in Ukraine are wood waste in forestry, the woodworking industry, and special energy crop cultivation.

The main source of wood biomass in Ukraine is forests, which occupy 16% of its territory. Even though the number of forests in the country is relatively small, in Ukraine, there is an annual increase of wood by 17% of the available volume. As of 2020, the forest wood stock was estimated at 1.5 billion m^3. In the same year, 15.2 million m^3 of liquid wood was harvested, of which about 55% is suitable for use for energy purposes (MDCT, 2020).

When assessing the potential of wood biomass, it is worth paying attention to the felling residues, which are an essential source for producing modern types of solid biomass. Considering that their volume on average is about 14% of the total annual liquid wood harvesting, as of the end of 2020, the volume of felling residues was 2.13 million m^3. Given that 20% of logging waste must be left in the forest to preserve biodiversity, the volume available for producing wood chips from felling residues was 1.7 million m^3 in 2020.

The direction of growing energy crops is also attractive for the wood biomass sector development. The most common types of energy crops include fast-growing trees (poplar, bush willow); perennial herbs (miscanthus); annual herbs (sorghum, triticale). In the climatic conditions of Ukraine, the most suitable for growing for energy purposes are energy willow, poplar and miscanthus. Thus, energy willow has a yield of about 16-20 t/ha/year with a 4-5-year harvesting cycle, energy poplar –8-15 t/ha per year with a harvesting cycle of 2-3 years; about 10 t/ha can be obtained from miscanthus annually for 15 years (SFA, 2021; Geletukha et al, 2014).

There are about 4 million hectares of land in Ukraine that are unsuitable for growing agricultural crops and can be used for these purposes. However, only 0.1% of it is used today to grow energy crops. It proves that this type of bioenergy resource in Ukraine is not being given due attention today.

3.1.2. Potential of heat energy production from biomass

Historically, solid biomass has been used to obtain mainly heat energy. Its undoubted advantage is ecological neutrality, ensuring a zero balance of carbon dioxide emissions, provided that such biomass is grown permanently and its use does not reduce the number of green spaces on the territory (USAID, 2018).

The most common types of biomass used to produce heat energy are the following (Geletukha, 2015):

- Straw, stalks of corn, sunflower, etc. (bales, granules (pellets), briquettes);
- Husks and other waste from the processing of sunflower, grain and other agricultural crops (pellets, briquettes);
- Wood, its waste and products of its processing (pellets, chips, briquettes, firewood);
- Animal and poultry waste;
- Waste of vegetable crops and products of their processing;
- Vegetable waste from the food industry;
- Annual and perennial grass biomass (energy willow, sorghum, miscanthus, etc.);

Therefore, most of the specified types of solid biomass can also be used for electricity generation.

The advantages of using solid biomass in heating processes include the following:

- Biomass is a local type of fuel. Therefore, its production and use contribute to the development of the local economy by creating new jobs, introducing innovative energy technologies and reducing the amount of unprocessed waste;
- Rational use of biomass, which is a renewable type of fuel, provides an almost inexhaustible source of energy and sustainable development of territories;
- Low sulphur content and the possibility of avoiding emissions of nitrogen oxides when burned at low temperatures make biomass an environmentally friendly type of fuel compared to fossil fuels;
- Considering the rapidly increasing prices of natural gas, oil, and coal, biomass is a cheaper fuel of local importance (USAID, 2018).

In Ukraine, the main component of the energy potential of solid biomass is agricultural biomass, which includes waste and by-products of agriculture and energy plants. At the same time, agricultural residues amount to 9.4 million tons per year (43% of the total potential), and energy plants –7.5 million tons per year (34% of the total potential). The most significant shares of the potential of agricultural residues are straw of cereal grain crops

(36%) and by-products/waste of grain corn production (33%) (Geletukha, 2015). Table 1 shows the potential of solid biomass for obtaining heat energy in Ukraine.

Despite some fluctuations, agricultural biomass volume in Ukraine grew almost annually until 2022 due to the general increase in agricultural production and the yield of main crops. In particular, 2019 was indicative in this context. Over two decades, the energy potential of the straw of grain crops, by-products, and waste from the production of corn for grain and sunflower in Ukraine has increased 3 times-from 2.8 Mtoe/year (2000) up to 8.5 Mtoe/year (2020) (Geletukha et al., 2022).

In connection with active phase of the war started in February 2022 and restrictions for agricultural activities related to a land mine and explosive contamination, active hostilities on certain agricultural lands, and crop loss due to fires and arson, it is expected that the energy potential of agricultural biomass will significantly decrease over the next few years. It is also because, in 2022, no more than 70% of all agricultural areas were sown due to the occupation of certain areas by Russian troops and the constant shelling of border areas.

Despite the significant growth of agricultural biomass volumes in the last pre-war decades, the share of wood biomass in the energy potential of Ukraine is still relatively small (about 2.6 Mtoe/year, namely 12% of the total volume. At the same time, woody biomass consists of two parts: the first comes from traditional sources (firewood, felling residues, woodworking waste), and the second comes from additional sources (dry, wood from the reconstruction and restoration of protective forest belts, waste from pruning and uprooting of orchards and vineyards) (Geletukha et al., 2022). At the same time, the shortage of natural gas and other energy resources, which is especially evident during the heating seasons in the country actualizes the growth of the share of wood and other types of solid biomass in heating Ukrainian homes.

3.1.3. Potential of liquid biofuels production

Ukraine has significant potential for liquid biofuels market development due to the availability of significant land resources and favourable climatic conditions for the cultivation of the raw material base. Thus, the annual technically achievable energy potential of liquid biofuel in Ukraine is equivalent to 1 million Mtoe (SAEEU, 2020). According to the Roadmap for bioenergy development in Ukraine, by 2050, liquid biofuels may constitute about 3.5 Mtoe, which will include 15% (in energy terms) of the entire biomass use in Ukraine in 2050 (Figure 1).

To establish the new targets in renewable energy, Ukraine developed the National Renewable Energy Action Plan until 2030 (CMU, 2012). It had relatively high chances of being adopted, but the Russia-Ukraine war hindered the process. According to the latter, the output of the second-generation bioethanol in Ukraine had to start in 2023, of the second-generation biodiesel-in 2024 (Figure 2).

Altmann et al. (2020) indicate that Ukraine could reach even 13.8% of energy from renewable energy resources in the transport sector by 2030, and biofuels would play the primary role from animal fats and algae, as well as electricity and renewable biomethane. The practical use of raw materials such as used vegetable oils or animal fats for biofuel production remains in question mainly due to the lack of established economic ties.

However, despite the significant potential and ambitious goals, raw materials for the production of liquid biofuels, in particular grain for the production of bioethanol, are mainly exported to other countries and are almost not used for the domestic production of motor biofuels in Ukraine.

With the war outbreak, as the Russian army destroyed Ukrainian oil refineries, Ukraine became the net importer of oil products. Additionally, the Russian navy and armed forces blocked most of Ukraine's marine ports. As a result, Ukraine temporarily lost its ability to export grain by sea vessels. It should be noted that before the war, Ukraine exported 45-60 million tons of grain annually (e.g., in 2020/2021 marketing year Ukraine exported 45.7 million tons of grains, of which wheat was 17.5 million tons and corn was 23.5 million tons) (Landlord, 2021).

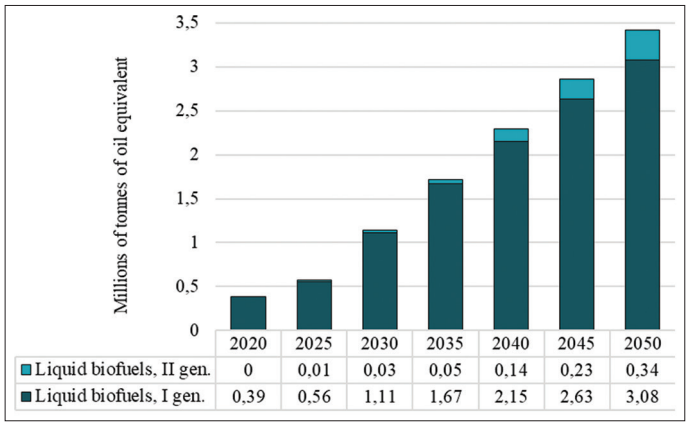
With the seaports blockade, Ukraine exports a maximum of 2 million tons of grain per month, which equals 24 million tons per year. As the possibilities of grain storage are limited, abundant grain must be processed inside the country. Producing even first-generation biofuels is a solution to the problem. From the perspective of the feedstock availability, remaining 23 million tons of grain, even with the low starch content (60%), could yield 8.28 billion litres of ethanol (provided that 1 ton of grain with 60% contents of starch yields in 360 L of ethanol. It is usually the case with wheat and barley, whereas corn usually has 70% starch, yields 420 L of ethanol (GWA, 2006). At the ethanol density of 0.783 kl/l, 8.28 billion liters transform into 6.48 million tons of ethanol. In 2020, Ukraine consumed 1.77 million tons of petrol (SSSU, 2021).

Table 1: The potential of solid biomass for heat energy production in Ukraine as of 2020

Type of biomass	Theoretical potential, million tons	Potential available for energy purposes (economic)	
		A share of theoretical potential, %	Mtoe
Straw of grain crops	33.1	30	3.39
Rapeseed straw	4.6	40	0.63
By-products of the production of corn for grain (cobs, stalks)	39.4	40	3.01
By-products of sunflower production (stalks, capitulum)	24.9	40	1.43
Secondary agricultural waste (sunflower husks)	2.2	100	0.92
Wood biomass (felling residues, woodworking waste)	6.7	95	1.57
Wood biomass (dry, wood from protective forest belts)	8.8	45	1.02
Energy plants (willow, poplar, miscanthus *)	11.5	100	4.88

*Subject to the cultivation of 1 million hectares of unused agricultural land. Source: Geletukha et al. 2022

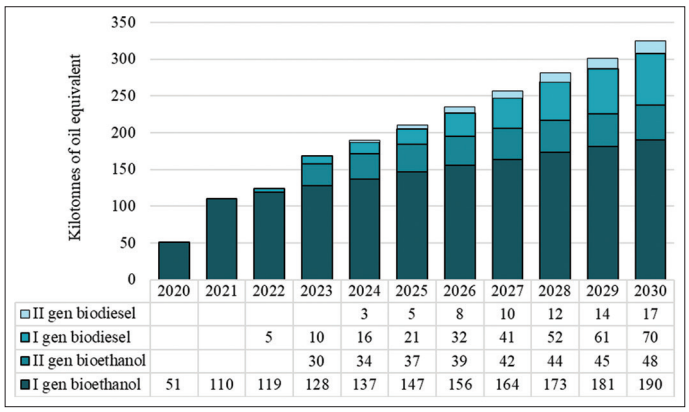
Figure 1: The projected use of liquid biofuels in Ukraine until 2050, Mtoe



	2020	2025	2030	2035	2040	2045	2050
Liquid biofuels, II gen.	0	0,01	0,03	0,05	0,14	0,23	0,34
Liquid biofuels, I gen.	0,39	0,56	1,11	1,67	2,15	2,63	3,08

Source: BAU, 2020a

Figure 2: The projected output of liquid biofuels in Ukraine until 2050, Mtoe



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
II gen biodiesel					3	5	8	10	12	14	17
I gen biodiesel			5	10	16	21	32	41	52	61	70
II gen bioethanol				30	34	37	39	42	44	45	48
I gen bioethanol	51	110	119	128	137	147	156	164	173	181	190

Source: Pryshliak et al. 2020

From the point of view of feedstock availability, Ukraine has 3.7 times more feedstock for bioethanol than it can consume for petrol (in volume values). Considering the production facilities, Ukraine already now can ensure the E10 blend, with the prospect of increasing the blend to E30 and above, which may result in significant tailpipe CO_2 emissions reduction (Alsiyabi et al., 2021).

3.2. State Support Policy to Promote Bioenergy Development in Ukraine

3.2.1. Motivational mechanisms for the promotion of electricity generation from biomass

The countdown to stimulating electricity generation from biomass in Ukraine began in 2013, when the first motivational mechanisms were introduced, which were further improved following indicators of the renewable energy sector development and market requirements.

The feed-in tariff is the primary economic mechanism impeding bioenergy development in the power sector. According to the Law of Ukraine "On the Electricity Market" (Business censor, 2022), the feed-in tariff is a special tariff for purchasing electricity generated from renewable energy resources, including biomass.

The feed-in tariff is calculated for each generating facility separately based on special coefficients that depend on the bioenergy power plant capacity and the year it was put into operation. Every month, feed-in tariffs are recalculated by the National Commission for State Regulation of Energy and Public Utilities by converting them into euros at the National Bank of Ukraine's official exchange rate to protect investors from possible inflation.

The law of Ukraine (VRU, 2017) provides a fixed allowance to the feed-in tariff for using domestically produced equipment in the construction of bioenergy power plants. Thus, for power plants put into operation from July 1, 2015, to December 31, 2024, when using Ukrainian equipment at 30% and 50%, the allowance to the feed-in tariff is 5% and 10%, respectively.

In addition to the feed-in tariff, investors implementing bioenergy projects in the power sector can take advantage of the following tax and customs benefits (VRU, 2011; VRU, 2012):

- Exemption from payment of the value added tax of materials and equipment used to generate electricity from biomass;
- Exemption from payment of customs duties on the import of materials and equipment used to generate electricity from biomass.

It is worth noting that the above tax and customs benefits can be used only if identical goods with similar quality characteristics are not produced in Ukraine.

The procedure for stimulating the generation of electricity from biomass exclusively with the help of the feed-in tariff and tax and customs benefits was in effect until 2020. Starting from 2020, following the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding Ensuring Competitive Conditions for the Generation of Electricity from Alternative Energy Sources" (VRU, 2019), business entities that intend to generate electricity from biomass instead of the feed-in tariff can participate in green auctions. Support based on the auction results is carried out by guaranteeing the purchase of the entire volume of generated electricity at the auction price. The auction price is the price of 1 kWh offered by the business entity that is determined as the auction winner.

The Law of Ukraine (VRU, 2017) provides a one-stage closed auction model. According to it, auction participants must submit:

- A technical proposal containing the amount of capacity of the biomass power plant for which the business entity intends to acquire the right to support;
- A proposal that reflects an auction price for the sale of 1 kWh of electricity generated by the biomass power plant for which the business entity intends to acquire the right to support.

Winners are determined based on the results of the simultaneous opening of offers of all auction participants. The criterion for selecting auction winners is the price specified in the closed offer. Participants who offered the lowest price within the bioenergy quota are recognized as auction winners for their declared capacity.

Within 3 years after winning the auction, the winner must put the biomass power plant into operation. The state guarantees the purchase of the entire electricity amount generated by such a plant at a price determined by the auction results within 20 years from its commissioning. The Law of Ukraine (VRU, 2017) also provides a fixed allowance to the auction price following the level of use of Ukrainian-made equipment in constructing biomass power plants. Thus, when using Ukrainian-made equipment at 30%, 50% and 70%, the amount of the allowance to the auction price is 5%, 10% and 20%, respectively.

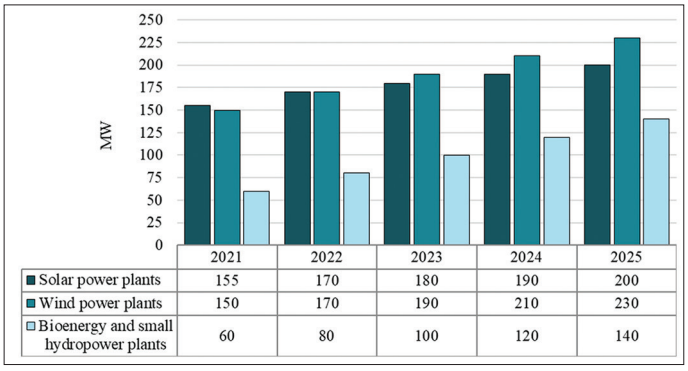
It is worth noting that the start of green auctions was planned for 2020 but was postponed due to the COVID-19 pandemic. Due to uncertainty, the annual quotas that determine the total capacity of renewable energy, which claims state support, were not formed. Only at the end of 2020 were approved indicative forecast indicators of annual quotas for supporting renewable energy for 2021-2025 (Figure 3).

However, as seen in Figure 3, bioenergy does not belong to the priority areas of renewable energy development in Ukraine because among all presented technologies, the government gives the most support to solar and wind ones.

It is worth noting that the implementation of green auctions was prevented by the full-scale military intervention of the Russian Federation on the territory of Ukraine in 2022. However, in general, its full realization in the future can contribute to more effective renewable energy development in general and bioenergy in particular.

One of the key advantages of auctions compared to current feed-in tariff is the creation of competition between participants in the renewable power market. Competition makes it possible to determine a fair price for electricity from renewable energy resources for both investors end consumers. It, in turn, will ensure the further development of green energy and the achievement of a balance of interests between participants in the renewable energy market. In addition, auctions are an extremely flexible mechanism that can be adapted depending on the needs of the energy market in a specific period. Quotas can be distributed by region, stimulating the development of green generating capacities where there are not enough or regulating the deployment of desirable for the state of renewable energy capacities within the limits of the general quota.

Figure 3: The Indicative annual quotas of support for renewable energy development under green auctions for 2021-2020, MW



	2021	2022	2023	2024	2025
Solar power plants	155	170	180	190	200
Wind power plants	150	170	190	210	230
Bioenergy and small hydropower plants	60	80	100	120	140

Source: Getmarket, 2021

Another advantage of the green auction compared to the feed-in tariff is the fixed duration of the support scheme. As mentioned above, the validity period of the state support scheme based on the feed-in tariff is set from 2009 to 2029. Under such conditions, a certain injustice arises regarding the period of sale of electricity at the feed-in tariff, depending on the year of generating facility commissioning. Thus, owners of power plants put into operation in 2009 have the opportunity to sell electricity at the feed-in tariff for 21 years, while putting the generating facility into operation in 2022 will allow selling electricity at the feed-in tariff only for 8 years. In the case of green auctions, the same period of validity is legally fixed for each generating facility from the moment it is put into operation – 20 years. In addition, in the case of green auctions, the investor receives state guarantees of the purchase of electricity at the auction price before the start of construction of the generating facility that claims state support, while, as in the case of the feed-in tariff-after its putting into operation.

The main disadvantage of auctions is the risk of investors refusing to implement renewable energy projects due to the low auction price. It is worth noting that the Law of Ukraine (Myronenko et al., 2017) provides certain sanctions, namely the deprivation of the right to participate in further auctions for 1 year of the business entity that became the winner of the auction but refused to conclude a contract with a state enterprise that is responsible for green electricity purchase. However, the specified legal norm is not strict enough to reduce potential risks.

3.2.2. Motivational mechanisms for the promotion of heat energy production from biomass

Due to the 100% electrification of Ukraine's territory, from the very beginning of implementing motivational mechanisms for the bioenergy development in 2009, the government preference was given to the electricity production from biomass. Instead, the promotion of thermal energy generation from this source was not actively provided. In our opinion, the reasons were the presence of many centralized and decentralized heat grids in the country, the difficulty in connecting individual bioenergy plants to such grids due to the threat of unbalancing the latter, small-scale heat production accompanied with high generation costs and costs of connecting to the grid, a significant dependence of bioenergy plants on local resource base, high prices for solid biofuel, etc. Given the existing difficulties, the production of thermal energy by bioenergy facilities was mainly carried out under the condition of the availability of a sufficient amount of biofuel at acceptable market prices, and without significant state economic support.

With the beginning of Russian aggression in the east of Ukraine and the annexation of Crimea in 2014, the national government adopted some resolutions aimed at stimulating the replacement of natural gas with alternative energy types and harmonizing Ukraine's renewable energy sector with the European one. Thus, the Plan of short- and medium-term measures to reduce natural gas consumption for the period until 2017 provided for essential measures related to the spread of the use of solid biomass, including:

- Granting the status of priority to investment projects for the transfer of consumers from natural gas to other types of energy, including solid biomass;

- Simplification of the procedure for the transfer to concession, lease and lifting of the ban on privatization of heat energy facilities under communal ownership;
- Implementation of the term "biomass" in national legislation following Directive 2009/28/EU;
- Simplification of the land acquisition procedure for the heat energy and/or electricity production facilities using fuels other than natural gas;
- Shortening the terms of issuing and the number of permits for the implementation of gas substitution projects;
- Introducing changes to the laws of Ukraine regarding the transition to alternative fuel types and stimulating regulation of the relevant economic entities (CMU, 2014).

In addition, special mechanisms were introduced to stimulate the substitution of natural gas in heat supply for the population and budget organizations (CMU, 2012). Relevant government regulations set the tariff for heat energy "produced not from natural gas" for the population's needs at the level of the tariff for heat energy produced from natural gas at market prices. The difference between the "produced not from natural gas" tariff established by this resolution and the actual tariff paid by the population was to be compensated from the state budget, considering the marginal level of profitability not higher than 21%. Due to the inconsistency of the developed additional mechanisms with the current regulatory framework, their implementation faced severe problems.

Another lever was the stimulation of the population to implement energy-efficient measures, introduced by Resolution of the Cabinet of Ministers of Ukraine No. 491 of October 1, 2014 (CMU, 2014b). This mechanism reimburses part of the body of the loan granted for purchasing boilers using any fuel (except for natural gas), particularly solid biomass boilers. Reimbursement of part of the loan amount is made once to each borrower in the amount of 20% of the loan amount for a boiler purchase, but no more than UAH 5000 for each loan agreement. It should be noted that additional factors that contributed to the expansion of the use of biomass and the reduction of natural gas consumption in 2014 were the increase in gas prices for the population and enterprises of housing and communal services, the establishment of administrative limits on gas consumption (30% reduction in consumption for industry, budget spheres and housing and communal services, 10%-for the population) (CMU, 2014c). During 2015-2021, these factors contributed to the further reduction of natural gas consumption and its replacement by other energy sources, including solid biomass.

3.2.3. Motivational mechanisms for the promotion of liquid biofuels production

Stimulation of the production of liquid biofuels in Ukraine began in 2013 when the government introduced requirements for the content of biocomponents in motor fuel. Thus, following the Law of Ukraine "On Alternative Fuels" (VRU, 2000), the recommended content of bioethanol in motor gasoline produced and/or sold on the territory of Ukraine in 2013 was to be at least 5% (mass), the mandatory content of bioethanol in 2014-2015 was not <5% (mass), and starting since 2016, at least 7% (mass). The above-mentioned legislative requirement was an impetus for developing the liquid biofuels market in Ukraine. However, it was cancelled in 2015. The main reason for its cancellation was the fear that the domestic production facilities would be unable to provide the necessary volumes of the biocomponent, and, as a result, there may be a need for its import. Another reason related to the fact that 2/3 of Ukraine's car fleet at that time was not adapted to the use of motor fuel with a high bioethanol content.

In 2020, the legislative bodies again tried to implement the above mechanism within the framework of Draft Law No. 3356-d "On Amendments to Certain Legislative Acts of Ukraine Regarding Mandatory Use of Liquid Biofuel (biocomponents) in the Transport Industry" (VRU, 2020; CMU, 2014). The main reason was the urgent need to replace oil and oil products, which in 2020 took first place in the commodity structure of Ukraine's imports.

This regulatory act provided for:

- Establishment of a mandatory share of liquid biofuel (quota) in the total annual volume of gasoline sales: from May 1, 2022 - at least 5% (mass);
- Introduction of accounting and control of the content of biocomponents in gasoline;
- Establishment of responsibility for non-compliance with quotas by business entities engaged in the production, import and sale of gasoline in the customs territory of Ukraine;
- Introduction of requirements for compliance with sustainability criteria for biofuels from July 1, 2022.

However, the aforementioned legislative requirements will not be implemented due to Russia's full-scale military invasion of Ukraine. The only motivational mechanisms aimed at stimulating the liquid biofuels market development are tax benefits. Thus, according to the Tax Code of Ukraine (VRU, 2011), liquid biofuels (ethanol and biodiesel) are subject to excise duty. The excise duty rate on motor gasoline containing at least 5% (mass) of bioethanol is EUR 213.5/1000 cubic litres (as for other gasolines). The excise duty rate on alternative motor fuel (that is, fuel with an oxygen content of at least 30%) is EUR 162/1000 litres. The excise tax rate on biodiesel and its mixtures (which do not contain or contain <70% (mass) of petroleum products) is EUR 106/1000 litres. Zero excise duty applies to the ethanol used for bioethanol production. In addition, the funds paid by the taxpayer for converting the vehicle to biofuel are subject to a tax discount.

Thus, it can be stated that today the state policy regarding the liquid biofuels market development is fragmentary. With the beginning of the war, when Ukraine became a net importer of fuel, it is expected an increase in interest in liquid biofuels, which may lead to a radical revision of state support for this industry.

In this light, innovative business models can serve as a guide for meeting new energy needs (Olaniyi and Gerlitz, 2019) Furthermore, Ukraine shall consider grasping potentials of transitional fuels and related technologies, like ammonia, which might serve as a paragon and amplify future environmental transition (Gerlitz et al., 2022). In this light, deployment of innovation-driven models, like ecosystem approach, can facilitate transition towards higher environmental efficiency and digital affinity (Gerlitz and Meyer, 2021).

3.3. Outcomes of the State Support Policy to Promote Bioenergy Development in Ukraine

3.3.1. Results of the state policy on the promotion of electricity generation from biomass

The results of the state policy on stimulating electricity generation from biomass are the most successful compared to the effects of promoting the production of heat energy and liquid biofuels due to a more consistent and effective support policy.

Among the bioenergy technologies presented on the Ukrainian market, the most significant progress was achieved in the electricity generation from agricultural and landfill biogas. Even though it is possible to produce heat energy and motor fuel on their basis, investors prefer electricity generation due to the possibility of obtaining more considerable economic benefit (Table 2).

Thus, as of 2020, 53 power plants in Ukraine generated electricity from agricultural and landfill biogas. Their number increased 1.6 times compared to 2018 and 4.8 times compared to 2015. The total installed capacity of such power plants as of 2020 was 103 MW. It is 2.2 times higher than in 2018 and 6.1 times higher than in 2015. In 2020, 471 million kWh of electricity was generated by power plants operating on agricultural and landfill biogas; it was almost 7.7 times higher than in 2015.

The involvement of solid biomass in electricity generation processes also had positive dynamics in recent years (Table 3).

At the end of 2020, 18 power plants generating electricity from solid biomass operated in Ukraine. Their number increased 1.8 times compared to 2018 and 3.6 times compared to 2015.

The total installed capacity of solid biomass power plants at the end of 2020 was 109 MW, which was 2.1 times higher than in 2018 and 3.1 times higher than in 2015. It, in turn, had a positive effect on the increase in the amount of electricity generation, which in 2020 reached 279 million kWh; it was 3.6 times higher than in 2015.

However, despite positive trends in the involvement of bioenergy resources in electricity generation, their share in the total renewable electricity mix remains insignificant (Table 4).

Thus, bioenergy in the electricity sector is currently of secondary importance and significantly inferior to other renewable energy technologies, particularly solar and wind ones.

3.3.2. Results of the state policy on heat energy production from biomass

Due to the implemented state policy of gas saving and other administrative and economic incentives, the number of boilers based on solid biomass has increased significantly at municipal heat supply enterprises. In addition, there are positive changes in the use of boilers based on solid biomass by the population for heating due to the compensation mechanism for the cost of boilers introduced by the government as part of the state program "warm credits." The transition to these energy technologies encourages the further development of the domestic solid biofuels market.

Today, solid biomass from firewood, wood chips, pellets (granules), briquettes, and baled straw occupies the largest segment in the Ukrainian bioenergy market. Fuel briquettes in Ukraine are produced in smaller volumes than pellets, mainly from wood, husk, straw, and reed. Domestic features of solid biofuel production

Table 2: The indicators of the development of power plants generating electricity from agricultural and landfill biogas in Ukraine in 2015-2020

Indicators for power plants development generating electricity agricultural and landfill biogas	2015	2016	2017	2018	2019	2020
Number, units	11	12	21	33	49	53
Installed capacity, MW	17	20	34	46	86	103
Amount of electricity generation, million kWh	64	89	93	176	247	471

Source: SAEEU, 2022

Table 3: The indicators of the development of power plants generating electricity from solid biomass in Ukraine 2015-2020

Indicators of the development of power plants generating electricity from solid biomass	2015	2016	2017	2018	2019	2020
Number, units	5	6	6	10	15	18
Installed capacity, MW	35	39	39	51	95	109
Amount of electricity generation, million kWh	77	80	101	103	162	279

Source: SAEEU, 2022

Table 4: Thetotal renewable electricity mix in Ukraine as of 2020

Renewable power plants	Installed capacity		Amount of generated electricity	
	MW	%	million kWh	%
Solar power plants	6873	80,7	6725	61,4
Wind power plants	1314	15,4	3271	29,9
Small hydropower plants (capacity <10 MW)	117	1,4	209	1,9
Bioenergy power plants	212	2,5	750	6,8
Total	8516	100	10955	100

Source: SAEEU, 2022

are its regional unevenness and, dispersion, proximity to the raw material base. The market is represented by many small and medium-sized enterprises working with traders (USPP, 2019).

Manufacturers of wood and peat pellets are mostly concentrated in the west of Ukraine. A small number of them are also located in the centre and east industrial areas. At the same time, up to 70% of the production of wood pellets is provided by 7 regions-Zakarpattia, Volyn, Chernihiv, Kyiv, Zhytomyr, Lviv, and Sumy. Instead, producers of sunflower husk pellets are located in the central and eastern regions due to the available raw material of secondary sunflower processing waste due to the large concentration of oil extraction plants. Thus, only 4 regions of Ukraine (Dnipropetrovsk, Zaporizhzhya, Odesa and Mykolaiv) provide production of more than half of all husk pellets in the country (USPP, 2019).

Currently, wood biomass is most actively used (more than 90% of the economic potential), and the use of waste and by-products of agricultural origin remains low. Of the various types of agricultural biomass, only sunflower husks are actively used for Ukraine's energy needs-more than 70% of its potential. The production of biofuels from straw is at the level of about 3% of the available potential. There are isolated examples of the energy use of corn. On average, Ukraine's biomass energy potential, including heat energy production, is used by ~11% (Geletukha et al., 2022). At the same time, the installed capacity and the volume of thermal energy generated by biomass power plants demonstrated positive growth trends in 2016-2020 (Table 5).

According to the "Concept of the state policy implementation in the heat supply field", it is planned to achieve 30% of heat energy from renewable energy sources in the total heat energy mix by 2025 and up to 40% by 2035. Such indicators can be achieved mainly due to energy from biomass (CMU, 2017b; BAU, 2020).

3.3.3. Results of the state policy on liquid biofuels production

The results of support policy to promote liquid biofuels production is far from being successful. As of 2020, biofuels in Ukraine were almost not produced. The biofuels consumed in the country are mostly imported and entirely comprise of bioethanol (Table 6).

At present there are about 20 domestic producers who potentially could produce bioethanol with a total installed capacity of 300 thousand tons a year. Nonetheless, the realistic capacities are those at the disposal of 8 companies with an installed capacity of 128 thousand tons of bioethanol a year (BAU, 2022).

As for the biodiesel production, Ukraine had 14 large biodiesel plants with an installed capacity of 300 thousand tons per year and about 50 small biodiesel plants with a capacity of 25 thousand tons yearly. All available biodiesel capacities were mainly converted to the colour's producing facilities; as a result, biodiesel is not produced in Ukraine (BAU, 2022).

The unsatisfactory pace of liquid biofuels sector development did not allow to achieve the planned indicative goals of the National Renewable Energy Action Plan until 2020 (CMU, 2014a) in the transport sector. Thus, in 2020 it reached only 2.47% compared to the 10% planned (Figure 4).

The mentioned 2.47% was achieved through biofuels and electricity from renewables through road vehicles and the railway. In the entire amount of renewable energy consumed by the transport sector, the share of biofuels reached only 35%, whereas the remainder was electricity (SAEE, 2021). A particular share of biofuels was not taken into account, as those are non-compliant biofuels.

The mentioned 2.47% was achieved due to biofuels and green electricity use for road vehicles and the railway. In the entire amount of renewable energy consumed by the transport sector, the share of biofuels reached only 35%, whereas the remainder was electricity (SAEE, 2021).

Experiences from other European regions reveal that the develop of a common development strategy for green and blue industry together with a regional investment strategy is recommendable to reach the sustainable goals and to benefit from the growth potential especially for the SME – sector. Special growth potential of biofuels lays in the transport sector since it represents one of the main decarbonization targets of the near future within the European Green Deal initiative of European Commission to achieve climate neutrality in 2050.

3.4. Challenges for Bioenergy Development in Ukraine

Nowadays, some barriers that prevent the involvement of bioenergy resources in energy production processes and which are common to all bioenergy technologies, namely:

- Russian military intervention, which negatively affects Ukraine's investment climate, deepens the economic crisis and leads to direct losses in the bioenergy sector. According to the European-Ukrainian Energy Agency estimates, since the beginning of the full-scale war, 29% of biogas plants and 48% of biomass generating capacities from their total number are located in the occupied territories and in the areas of active hostilities (Ecopolitics, 2022). Most of the bioenergy facilities in these territories have stopped their activities due to damage to transformer substations, power lines, threats to personnel, etc.;
- The need for significant initial investments for the construction of bioenergy facilities. Currently, in Ukraine, there is no

Table 5: The indicators of the development of generating capacities producing heat energy from biomass in Ukraine in 2016-2020

The indicators of the development of generating capacities producing heat energy from biomass in Ukraine	2016	2017	2018	2019	2020
Installed capacity, gcal/h	3606	4078	5626	5275	5524
The amount of heat energy produced, thousands of gcal	5131	6239	7637	7367	7463

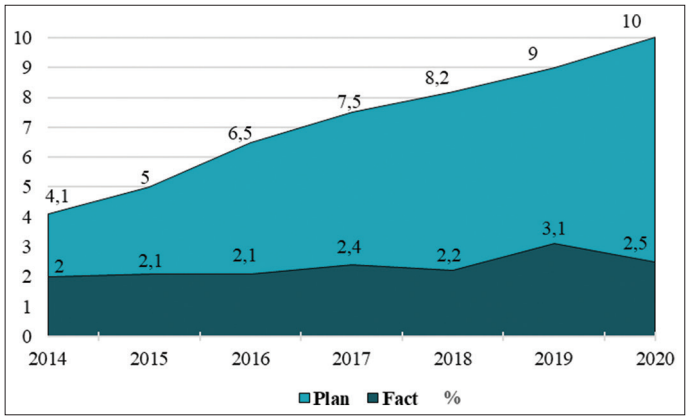
Source: SAEEU, 2022

Table 6: The output and consumption of biofuels (bioethanol) in Ukraine in 2013-2020, thousand tons

	2015	2016	2017	2018	2019	2020
Output	16	6	21	4	70	C[1]
Import	46	58	54	56	70	77
Export	-9	-6	-4	-4	-7	0
Domestic supply	53	58	70	56	133	77

*C1: Classified data; it means that the number of producers does not exceed two entities.
Source: SSSU, 2022

Figure 4: The actual and planned share of renewable energy resources in the final energy consumption in the transport sector of Ukraine, %



Source: SAEEU, 2021

available long-term crediting for bioenergy investment projects in the national currency, which would allow investors to attract financial resources on acceptable terms. The situation is somewhat better with external lending, which is carried out within the framework of international programs that implement sustainable energy development projects in Ukraine. To date, several credit lines of the European Bank for Reconstruction and Development have been opened in Ukraine (NecGroup, 2022; IC Group, 2022) for Ukrainian companies aiming to invest in renewable energy projects. However, high requirements regarding the financial, technical and environmental criteria of the projects do not allow all willing investors to get the necessary financing;

- State subsidization of prices for natural gas, electricity and heat energy for the population makes it unprofitable for the population to use bioenergy resources within the decentralized electricity and heat supply framework. Thus, in the budget of Ukraine for 2022, UAH 37.9 billion has been allocated for the provision of benefits and subsidies for the payment of housing and communal services, the purchase of solid fuel and liquefied gas (PFU, 2022);
- Lack of stimulation of energy consumption from bioenergy resources. All current mechanisms for supporting bioenergy development (feed-in tariff, green auctions, tax and customs benefits) are aimed only at promoting energy production from biomass and in no way encourage an increase in the demand for such energy from the population.

At the same time, since bioenergy resources are used for electricity generation, heat energy and liquid biofuel production, investors also face other specific barriers related to the particularities of using different bioenergy technology. Next, we will consider them in more detail.

3.4.1. Barriers to electricity generation from biomass

Common barriers to electricity generation from biomass include:

- Constant introduction of amendments to regulations in the field of electricity generation from biomass, particularly regarding changes in the feed-in tariff rates, the use of a share of domestically produced equipment in the implementation of bioenergy projects, the conditions for bioenergy power plants connection to electric grids, etc. The instability of legislation makes the conditions for conducting bioenergy business in Ukraine unclear and, as a result, undermines the confidence of investors;
- Arrears regarding payments under the feed-in tariff. It is worth noting that problems regarding payments for green electricity producers under the feed-in tariff repeatedly arose during the entire period of the bioenergy sector development in Ukraine and were quite noticeable for investors during the COVID-19 pandemic (Energy reform, 2022). After the full-scale Russian intervention in Ukraine in 2022, the payments fell to critical levels. So, from March to June 2022, they accounted for only 20-25% of the total amount, and in July–38.7% (Ligazakon, 2022).

Key barriers to the involvement of agricultural waste in electricity generation include: (1) the insufficient number of large farms capable of independently providing for the necessary volumes of animal waste to operate profitable biogas plants. It is worth noting that almost half of the farm animals in Ukraine are kept in private households and small (SSSU, 2020); therefore, the construction of profitable biogas plants is possible only under the condition of their cooperation; (2) the absence of strict environmental requirements that could serve as an incentive for the effective utilization of agricultural waste through its anaerobic fermentation in biogas plants to reduce the amount of waste and the environmental risks associated with it (Kurbatova and Sidortsov, 2022); (3) lack of a program of state stimulation of the use of organic fertilizers to improve the structure of the soil and increase its fertility.

The main challenges that prevent the deployment of power plants based on landfill biogas include (1) the morphological composition of municipal solid waste at landfills, which due to the lack of sorting, includes a large amount of non-biodegradable garbage; (2) the absence of environmental requirements that would promote the effective collection and utilization of landfill biogas to reduce the negative impact on the environment.

Barriers to the large-scale involvement of solid biomass in electricity generation processes include (1) lack of state stimulation of the cultivation of energy crops; (2) the absence of a ban on the burning of felling residues; (3) the need to pay a tax on carbon emissions when burning solid biomass for electricity generation (VRU, 2011), although when burning solid biomass, CO_2 emissions are equal to their absorption during the life of the plant.

3.4.2. Barriers to heat energy production from biomass

A small share of the realization of the biomass potential for heat energy is explained by many barriers preventing its widespread use. Key among them are the following:

- Lack of adequate economic mechanisms to stimulate biomass's heat energy production. Mechanisms of state support based on the feed-in tariff and green auctions in Ukraine apply only to the generation of electricity from biomass, which reduces the investment attractiveness of the use of biomass in the heat energy sector;
- The lack of equipment among agricultural producers and the lack of development of technologies for harvesting corn/sunflower stalks, which significantly inhibits the use of waste from these agricultural crops for energy purposes;
- The complexity of organizing the procurement-supply chain, the general underdevelopment of the biofuel market in the country (the absence of a biofuel exchange), which slows down the processes of interaction between market participants, increases biofuel prices, and reduces the reliability and quality of supplies;
- Limited access to heat networks operated by local heat utilities enterprises, which are not interested in connecting new competing heat production facilities;
- Most of the energy crops used in Ukraine today are still not classified as agricultural, so their cultivation on agricultural land is impossible. Instead, the existing procedure for inclusion in the register of agricultural crops is lengthy and involves field tests for more than 3 years, which significantly postpones the prospects for the growth of the agro-energy business;
- State forestry farms do not have sufficient equipment and motivation to significantly increase the collection of wood biomass and useful utilization of wood waste, which leads to inefficient use of available bioenergy resources. Instead, private companies with the appropriate equipment are legally limited in procurement;
- Several government decisions adopted in 2014 were unfavourable for investing in bioenergy, in particular, the cancellation of the value added tax exemption for the sale of solid biomass, including firewood, chips, pellets, and briquettes, which increases their final price and reduces competitiveness on the energy market (USPP, 2019; VRU, 2000; Geletukha et al., 2022).

These issues need to be resolved as soon as possible. It will make it possible to activate the processes of the transition of the heat energy industry of Ukraine to use bioenergy resources.

3.4.3. Barriers to liquid biofuels production

There are numerous barriers to the effective development of the liquid biofuels market. They are as follows:

- Lack of blending mandate requirement. According to REN21 (REN21, 2017), blending mandate requirements are the most effective tools to increase biofuels consumption, followed by the requirements for maximum CO_2 emissions from vehicles and the formation of the necessary infrastructure. Ukraine applied a blending mandate requirement in 2012-2015 only, spurring market development. After its abolishment, the market advancement stopped. There were numerous attempts to enact it again, but they failed. In 2021, Draft Law No. 3356-d (VRU, 2020) was approved in the first hearing but never reached the second hearing and the respective adoption. The Draft Law envisaged 5% contents (in energy value) of ethanol in the petrol, while there was no blending mandate requirement for diesel and biodiesel, respectively;
- The limited number of entities allowed to blend biofuels. Only enterprises approved by the Cabinet of Ministers of Ukraine have the right to blend the biological component of the fuel. Currently, they are JSC Naftohimik Prykarpattia, JSC Lukoil-Odesa Refinery, JSC Khersonnaftoperobka, JSC Ukrgazvydobuvannya, JSC Ukrtatnafta (Kremenchutsk Refinery). Some ceased their operation before the war, and some were destroyed during the war. Thus, the governmental restriction prevents the formation of infrastructure for blending biological fuel components. Therefore, the Resolution of the Cabinet of Ministers of Ukraine dated 05.12.2007 No. 1375 that defines a list of enterprises with the right to blend (CMU, 2007) should be cancelled;
- Unsynchronized targets for biofuels. The Energy Strategy assumes that the share of green energy in transport has to be 20% in 2025 (CMU, 2012), and the 2020 National Renewable Energy Action Plan presumed that it had to be 10% in 2020 (SAEEU, 2021); the Updated Transport Strategy 2030 indicates that the use of alternative fuels and electricity should reach 50% by 2030 and does not specify the targets for liquid biofuels at all (MIU, 2020); The 2030 National Renewable Energy Action Plan is not yet adopted with the requirement of 14% of green energy in the transport sector (CMU, 2014) according to the transposed RED II Directive. Therefore, the targets need to be synchronized;
- A limited number of laboratories certify the quality of biofuels. Ukrainian laboratories are mostly not ready for mass certification of biofuels or feedstock. One of the few exceptions is Bureau Veritas Ukraine. Certification became possible due to the adoption in 2017 of sustainability criteria harmonized with European standards for producing biofuels and bioliquids for energy use (SE, 2017). These criteria include the assessment of conformity, in particular the chain of responsibility during the transfer of the goods and the balance of mass, biodiversity, and ecological aspects related to environmental protection and methods of calculating the balance of greenhouse gas emissions using product life cycle analysis;
- Lack of demand stimulation for biofuels. Information campaigns about the positive effects of using biofuel among consumers, cooperation between biofuel producers and car manufacturers, and the use of biofuels in the public procurement system are advisable.

3.5. SWOT Analysis and Strategic Recommendations for Bioenergy Development in the Post-war Ukraine

Based on the information analyzed in the previous sections, we conducted a SWOT analysis and systematized strengths (S), weaknesses (W), opportunities (O) and threats (T) for the future bioenergy development in Ukraine within three discussed industries, namely electricity generation, heat, and liquid biofuels production from biomass (Table 7).

On this basis, combining different strengths, weaknesses, opportunities, and threats, we developed the strategic

Table 7: SWOT analysis of the bioenergy development in Ukraine

Strengths (S)	Weaknesses (W)
• S1 presence of significant unrealized bioenergy potential in Ukraine; • S2 a significant land fund for growing energy crops as raw materials for the bioenergy industry; • S3 availability of qualified personnel for the practical implementation of bioenergy projects; • S4 existing experience of successfully implemented pilot projects in the bioenergy sector; • S5 availability of the necessary energy infrastructure for the implementation of bioenergy projects, in particular, electricity generation; • S6 high flexibility of bioenergy facilities in terms of installed capacity; • S7 stability of electricity generation based on bioenergy resources compared to solar and wind generation; • S8 need to replace fuel imported from the Russian Federation and Belarus; • S9 positive experience of using a feed-in tariff for electricity generation at bioenergy facilities; • S10 national goals for reducing greenhouse gas emissions are set, which are planned to be achieved, including with the help of bioenergy; • S11 absence (or compensation) of greenhouse gas emissions during energy production from bioenergy resources	• W1 problems of providing a reliable raw materials for bioenergy facilities, in particular, the insufficient number of farms capable of independently providing the necessary volumes of organic waste for the operation of profitable biogas plants; • W2 relatively high investment costs for the construction of bioenergy facilities; • W3 high cost of energy production from bioenergy resources compared to conventional energy production technologies; • W4 unfavourable investment climate in the renewable energy sector due to the war in Ukraine; • W5 weak awareness of the population and business regarding the economic, social and environmental benefits of bioenergy; • W6 shortcomings in the current legislation, fragmented state support for some bioenergy technologies, arrears regarding payments under the feed-in tariff to producers of electricity from biomass, etc.; • W7 availability of new promising bioenergy technologies that are not yet presented on Ukraine's market
Opportunities (O)	**Threats (T)**
• O1 creation of additional jobs in the bioenergy sector; • O2 development of the local economy and local fuel and resource base, implementation of bioenergy projects in households and small farms; • O3 development of networks of energy cooperatives with the aim of joint implementation of bioenergy projects by farms; • O4 increase in the amount of agricultural and municipal waste processing and reduction of landfill areas; • O5 development of new sectors of agriculture (growing energy crops) on limited suitable lands, rational use of agricultural lands; • O6 reduction of dependence on fuel imports, primarily from the Russian Federation and Belarus, in the electricity, heat and transport sectors, development of own production of biofuels; • O7 reduction of technical challenges related to balancing the United Energy System of Ukraine, due to the significant predominance of solar and wind electricity in the structure of green electricity generation; • O8 decentralization of power and heat supply sources, development of eco-transport based on biofuels; • O9 development of new areas of research at universities and research institutes specializing in renewable energy technologies; • O10 developed but not launched mechanism of green auctions; • O11 the increased interest of the world countries to Ukraine and broad international support against the background of the full-scale military invasion of the Russian Federation; • O12 ensuring a green energy transition, meeting state goals for renewable energy development and reducing greenhouse gas emissions under the Paris Climate Agreement; • O13 reducing the attractiveness of energy production and consumption based on conventional energy resources in the context of Ukraine's accession to the European Green Deal	• T1 further destruction of existing bioenergy facilities and the impracticality of building new ones due to the threat of their destruction as a result of prolonged military operations; • T2 a high level of mine-explosive danger at the objects of agriculture and forestry, which significantly reduces the possibilities of forming the raw material base of bioenergy, the reduction of the land area for growing agricultural crops; • T3 political and economic instability, additional restrictions on business caused by martial law; • T4 lack of investments for bioenergy development, problems with domestic investments due to the increase in the level of poverty of the population as a result of the war and the economic crisis; • T5 deterioration of the investment climate, undermining of confidence of foreign investors, curtailment of their activities on the territory of Ukraine; • T6 lack of personnel for bioenergy projects implementation as a result of prolonged military operations; • T7 priority state stimulation of the development of solar and wind energy; • T8 inefficient economic mechanisms for stimulating thermal energy and liquid biofuels production from bioenergy resources

Source: Developed by the authors

recommendations for the state policy improvement in the bioenergy sector (Table 8).

Thus, the main attention in the post-war period should be paid to improving the legislative and regulatory framework in the bioenergy industry, building a system of state strategic political, economic, and environmental goals for the sector development, strengthening the effectiveness of existing ones and introducing new motivational mechanisms for producers of electricity, heat and liquid biofuels, formation of new organizational forms of business in bioenergy, etc.

4. CONCLUSION

For Ukraine, bioenergy is one of the strategic directions for the renewable energy sector development, considering the country's high dependence on imported energy sources and the great potential of biomass available for energy production.

In 2009 the government began forming a state policy to support the development of renewable energy, introducing several economic instruments to stimulate green electricity generation in the country. However, the implemented mechanisms triggered the large-scale

Table 8: Strategic recommendations for the Ukrainian bioenergy sector development

Combination of S, W, O, T	A strategic recommendation meeting the combination of S, W, O, T
S1, S2, S8, S10, S11 O6, O12, O13	Review and correction of strategic documents regarding the vectors of bioenergy development and the share of energy produced from bioenergy resources in final energy consumption, national and regional goals for decarbonization regarding bioenergy contribution: the Energy Strategy of Ukraine, the National Action Plan for the Development of Renewable Energy, the National Transport Strategy, the National economic strategy
S4, S5, S9 W2, W4 O11 T3, T4, T5	Conducting negotiations with donors and international organizations regarding attracting foreign funding for the implementation of bioenergy projects in Ukraine, continuing cooperation within the framework of existing programs, in particular credit lines of the European Bank for Reconstruction and Development, creating a platform for legal, public, and financial support of bioenergy reforms in Ukraine
W4, W6 T3, T5	Fixation of clear norms at the legislative level and their strict observance by the state. In the case of the need to make changes to the regulatory framework, legislative innovations should take into account the interests of investors and not fundamentally change the conditions of doing business in the bioenergy sector
S6, S7 W1, W2, W6 O1, O10 T3, T5, T8	Revision of the annual quotas that determine the total capacity of renewable energy facilities, which claim state support within the framework of the green auction mechanism, in terms of their increase for bioenergy projects, launch of green auctions for the bioenergy industry
S6, S8, S9 W6 O2, O6, O8	The spread of the feed-in tariff, the green auctions mechanism, tax and customs benefits for thermal energy produced from biomass, the liberalization of the thermal energy market, the introduction of a blending mandate to stimulate the domestic liquid biofuels production
S10 W2, W3 O2, O6, O7, O8, O13	Improvement of current state and regional methods of calculating the cost of energy generation by taking into account external costs in the cost of energy production from various energy resources, reducing subsidies for fossil fuels production and benefits for the purchase of solid fossil fuels and natural gas by households
S4, S9 W5 O2, O3 T3, T4, T7	Implementation of periodic information campaigns to inform territorial communities, commercial institutions, industrial enterprises, households about the benefits of using bioenergy technologies
S3, S4, S5, S7 W6, W7 O5, O8, O9 T1, T3, T7, T8	State support for the implementation of pilot projects the bioenergy sector, the development of the infrastructure of bioenergy market, decentralized heat and electricity supply based on bioenergy technologies, state funding or co-financing of research and development in the bioenergy field
W1, W2, W5 O2, O3 T3, T7	Improvement of the current regulatory framework regarding the formation of energy cooperatives, elimination of barriers to the formation of a cooperative model in the bioenergy sector
S2, S3, S4, S5 W1, W2, W3 O2, O4, O5 T2, T7	Introduction of state economic stimulation of the cultivation of energy crops on limited agricultural lands, processing of agricultural and municipal waste
S3, S5, S10 O1, O2, O7 W1, T1, T2, T3, T6, T8	Creation of a single electronic platform for the biofuels thade in Ukraine, involving suppliers of raw materials for the biofuels production, producers and consumers of biofuels, primarily those who use state benefits (feed-in tariff, green auctions, etc.)

Source: Developed by the authors

development of only certain renewable energy technologies. Although the same incentives were introduced for all renewable energy technologies in the electricity sector, electricity generation from biomass has not become widespread. Its share in the total electricity mix of renewable energy resources as of 2020 was only 6.8%, significantly inferior to solar and wind generation, the share of which was 61.4% and 29.9%, respectively. At the same time, even slight progress in bioenergy in the power sector emphasizes that the main driver for its development remains the state support policy.

Its absence in terms of bioenergy resources involvement in sectors of heat energy and liquid biofuels at the initial stage of these industries formation and its fragmentation in subsequent years led to the lack of progress in developing these areas. As a result, modern types of biomass in the heat energy sector is almost not used today; the main contribution to heat energy production is provided by traditional biomass. The situation is identical with liquid biofuels, which are practically not produced in Ukraine today.

Thus, further bioenergy sector development requires a review of state policy, a significant improvement of the current motivational mechanisms and the implementation of new support schemes considering the diversity of types of bioenergy resources and the specifics of energy production based on them. Special attention should be paid to removing the key barriers to bioenergy development and the use of new opportunities, which are discussed in detail in this study under SWOT-analysis. Implementing the proposed strategic recommendations meeting the current strengths, weaknesses, opportunities, and threats in the sector will help significantly improve the bioenergy facilities development in the country.

The limitations of the study deal with the uncertainty of bioenergy development in Ukraine due to the ongoing hostilities on its territory. Reliable and complete information on the actual damage and destruction of bioenergy capacities in the occupied regions is unavailable. Moreover, predicting the exact consequences of hostilities for the bioenergy sector is impossible. Due to the uncertainty of the war end, the reformation of the state incentives

for bioenergy development is in question. However, the results of the conducted analysis on energy policy in the sector and SWOT analysis help identify the perspectives and policy instruments for the post-war development of bioenergy in Ukraine.

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