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# BIOENERGY AND BIORESOURCES USAGE IN THE CONTEXT OF CIRCULAR ECONOMY PROMOTION

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**Abstract**. The circular economy, which minimises the level of environmental pollution, creates a promising background for sustainable development. The application of bioeconomics principles provides the use of by-products of agriculture, forestry, food waste, and wastewater as raw materials for electricity and heat. The objective is to analyse the prerequisites for bioenergy development as one of the circular economy areas. FGLS estimations are performed over the period of 2007–2018. The leading position in terms of bioenergy sphere growth is occupied by the European Union, followed by the countries of Asia and North America. The division of biomass into "traditional" and "modern" is discussed, where traditional biomass is mostly used for cooking and space heating in developing countries, while the EU is focusing on the development of second-generation (2G) biofuels when the biofuel is produced from non-food raw materials. It is estimated that the annual production of energy from renewable sources is about 225 thousand tons of o. e. in Ukraine. It is found that the legal field and the strategic directions of the bioeconomy in the European Union and Ukraine coincide, but the pace of development of bioenergy in Ukraine can be described as very slow. To increase the bioenergy potential, it is recommended to apply green tariffs, renewable energy certificates, and subsidies to energy producers.

***Keywords***: *Bioenergy potential, Biofuels, Biomass, Green tariffs.*

**JEL Classification**: Q01, Q20, Q25, Q42

## INTRODUCTION

The principles of resource reuse form the circular economy, which replaces the usual one. The traditional model of the production process is when resources went into production, the finished product came to the consumer, and the waste obtained at the stages of production and consumption was returned to the environment. This model has been replaced by the economics of recycling, which adds a stage of recycling after production and consumption, but much of the waste still enters the environment. In a circular economy, the level of waste is reduced to a minimum, because in addition to the recycling process, such processes as repair (prolongs the life cycle of goods), return (certain parts, parts are returned to the production process), reuse are widely used. The circular economy and the economy are closely intertwined, and their areas of intervention coincide, such as food waste, biomass and biological products, and so on. These two areas converge in terms of economic and environmental issues, research and innovation, and society's transition to sustainable development. The bioeconomy is designed to make the transition from non-renewable resources to the use of bioresources. First of all, the use of bioresources in the energy sector is required. The challenges of modern social and economic development require energy and related services on a growing scale. All national economic systems develop sectors of renewable and non-renewable energy to meet social needs (lighting, cooking, spatial comfort, movement, communication, etc.), as well as energy needs and maintenance of production processes. Bioenergy is an area that can meet existing needs while minimising negative effects on the environment.

The aim of the paper is to estimate the bioenergy potential of Ukraine for different kinds of renewable resources in the context of circular economy promotion.  A constant increase in production of biofuels and energy from waste is expected in Ukraine, while the reduction of hydropower generation is expected due to the climate change. The following tasks are set: to determine the place of bioenergy and bioresources in the concept of circular economy; to analyse the dynamics of the development bioenergy production in the world and Ukraine; to assess the prospects for the use of bioenergy resources in the context of circular economy development.

## 1. METHODS

To reveal the bioenergy potential of Ukraine, the general and specific methods are used. To be more specific, to estimate the production capacity of renewable energy sources using the grouping, a statistical method is used. To make the forecast of the development of hydroelectric, biofuels and waste, wind, and solar energy sectors, the ordinary generalized least squares methods are applied.

The ordinary least squares estimations would make efficient estimators, which produce the smallest possible variance. Efficiency estimators need the use of least squares with the following covariance structure: $y_i(T \times 1)$ vector of observations on $y$ for individual $i$. $X_i(T \times k)$ matrix observations on $X$ for individual $i$.

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_n \end{pmatrix}, X = \begin{pmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{pmatrix} v = \begin{pmatrix} v_1 \\ v_2 \\ \dots \\ v_n \end{pmatrix}. \quad (1)$$

Having known the covariance matrix for a full set of error terms, it is possible to estimate the fitted values of least squares estimators:

$$\hat{b}_{\text{OLS}} = (\acute{X}X)^{-1}\acute{X}Y. \quad (2)$$

Given the above concept of ordinary least squares estimations (2) and using the official state statistics of Ukraine, the values of bioenergy potential are predicted for different kinds of renewable sources in thousands of tons oil equivalent.

## 2. RESULTS

The concept of circular economy has recently become increasingly popular, both among scientists and practitioners, because this concept is perceived as a way to put into practice the foundations of the concept of sustainable development. Murray, Skene, and Haynes (2017), Babbitt *et al.* (2018), and Hofmann (2019) define the circular economy (CE) as an economic model aimed at efficient use of resources through waste minimisation, reduction of primary resources, etc.; the circular economy has the potential to achieve sustainable development. According to Geissdoerfer *et al*. (2017), the circular economy is a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. Another definition says that CE is a simple but convincing strategy, which aims at reducing both inputs of virgin materials and the output of waste by closing economic and ecological loops of resource flows (Haas, Krausmann, Wiedenhofer, & Heinz, 2015). The central idea of the CE is to close material loops, reduce inputs, and reuse or recycle products and waste to achieve a higher quality of life through increased resource efficiency (Peters, Weber, Guan, & Hubacek, 2007; Kirchherr *et al*., 2017). Yang and Feng (2008) define that the fundamental goal of the circular economy is to avoid and reduce waste from sources of an economic process, so reusing and recycling are based on reducing. Mechanisms such as reclamation of water resources and energy production from bioresources are consistent with the basic principles of the circular economy (Forslund & Jonsson, 2009; Korhonen *et al*., 2018). Today, researchers are constantly looking for ways to produce biofuels from sustainable biomass, as it is an effective alternative to replacing fossil fuels (Gaurav, Sivasankari, Kiran, Ninawe, & Selvin, 2017; Gonzalez *et al*., 2011). The main advantages of biomass as a renewable energy source and its importance for the circular economy are pointed out in studies by Torrisi *et al*. (2018), Saldarriaga-Hernandez *et al*. (2018), Torreiro *et al*. (2020), and Sakiewicz, Piotrowski, and Kalisz (2020). According to Sheldon (2020), the CE is implicit in the bio-based economy, which is concerned with the use of renewable biomass to replace the unsustainable use of fossil resources as the raw material for the manufacture of fuels. Circular bioeconomy requires sustainable biomass as a guarantee that the restoration cycle is completed and can be completed indefinitely (Sherwood, 2020). According to Tambovceva and Tereshina (2018), there is a new frontier that forms the basis of sustainable development and is determined by the paradigms of the green and circular economy.

The circular economy is based on processing, repair, and reuse. These processes are satisfied by both the reclamation of water resources and the use of bioresources and bioenergy. Environmental taxation and green tariffs can serve as motivational tools on the road to CE (Diaz-Rainey & Tzavara, 2012; MacDonald & Eyre, 2018; Ringel, 2006; Yuan, Chai, & Song, 2020).

The circular economy and the bioeconomy are closely intertwined, and their areas of intervention coincide, such as food waste, biomass, and biological products. These two areas converge in terms of economic and environmental issues, research and innovation, and society's transition to sustainable development. The bioeconomy is designed to make the transition from non-renewable resources to the use of bioresources.

Usually, bioeconomics is defined in three directions, namely:

- biotechnological vision, which emphasises the importance of innovation and the use of biotechnology on a commercial scale;
- vision of bioresources, which focuses on the use of biomass as resources;
- bioecological vision, which indicates the positive consequences of optimising the use of energy and resources for the state of the ecosystem.

As inputs for the circular economy, the biological resources of the earth and ocean, waste from the production of food for humans, and animal feed for industrial production can be used. Bioeconomy covers the agricultural industry, as well as all industries engaged in the development, manufacture, processing, or use in any form of biological resources (plants, animals, and microorganisms). The following industries can be added to the areas of use: forestry, horticulture, fisheries economy, crop and livestock, food industry, woodworking, paper, leather, textile, chemical, pharmaceutical, and energy industries.

The technological component of bioeconomy is biotechnology – an industry that studies and develops methods of obtaining useful products for humans using microorganisms, animal cells, and plants. Biotechnology has a wide scope (Table 1).

**Table 1.** Areas of Biotechnology Application

| **Biotechnology** | **Field of application** |
|---|---|
| Green | Agriculture |
| Red | Healthcare |
| Yellow | Food biotechnology |
| White | Industrial biotechnology |
| Blue | Marine biotechnology, aquaculture |
| Gold | Bioinformatics, nanobiotechnology |
| Brown | Biotechnology of deserts and arid areas |
| Black | Bioterrorism, bioweapons |

Although biotechnology has a downside (black biotechnology), the transition to a bioeconomy is expected to reduce our dependence on fossil fuels and provide a higher level of sustainability, as well as protect the environment and climate. To this classification, it is expedient to add bioenergy as a separate sector of the bioeconomy, as well as the scientific sector (scientific institutions, centres in the field of bioeconomics). The bioenergy sector is one of the most promising industries. The basis of bioenergy is biomass – a renewable resource that is formed from plant and animal raw materials, as well as microorganisms. According to the Law "On Amendments to Certain Laws of Ukraine on Ensuring Competitive Conditions for Production of Electricity from Alternative Energy Sources" (Zakon, 2019), biomass is a non-fossil biologically renewable substance of organic origin, capable of biodegradation, in the form of products, waste and residues of forestry and agriculture (crop and livestock), fisheries and technologically related industries, as well as a component of industrial or domestic waste, capable of biodegradation. In this case, biomass can be used as a ready-made fuel (e.g., wood pellets, etc.) or converted into liquids or gases. The main advantages of biomass are the availability of opportunities for its distribution and relative exhaustibility. There are many options for converting biomass to biofuel or bioenergy. In particular, thermochemical transformation is carried out by burning biomass (often from solid – wood, nuts, etc.). Another method is biotechnological conversion, during which biomass is decomposed and a dry matter of combustible gases (70 % methane) is released. By processing vegetable and animal oils, biodiesel is obtained, which is completely environmentally-friendly, does not emit sulphur dioxide during combustion, and carbon dioxide emissions are minimal, almost completely decomposes when entering the soil, biodiesel is not harmful when entering the water for its inhabitants.

The EU has long taken a course to increase the share of renewable energy sources in the structure of the energy sector. For this reason, some incentives are taken, among which are the following: green tariffs and certificates for energy from renewable sources, subsidies for the organisation of the technical process (purchase of equipment, etc.). Ukraine needs similar mechanisms, given the existing potential, in particular in the field of bioenergy (Table 2) (Stratehiia, 2020).

**Table 2.** Bioenergy Potential of Ukraine

| **Type of biomass** | **2015** | | **2050** |
|---|---|---|---|
| | **Theoretical potential, million tons** | **Economic potential, million tons o. e.** | **Economic potential, million tons o. e.** |
| Agropotential | 91.64 | 11.28 | 15.86 |
| Wood | 14.80 | 3.45 | 4.44 |
| Biofuels | – | 1.04 | 1.04 |
| Biogas | 3.2 billion $m^3$ of $CH_4$ | 1.50 | 4.81 |
| Energy crops | – | 9.96 | 33.56 |
| Peat | – | 0.40 | 0.40 |
| In total, million tons of c. f. | – | 27.63 | 60.10 |
| In total, million tons o. e. | | 19.34 | 42.07 |

One can also observe a high potential in terms of wood as a biofuel, but there is a downside: there is an increase in the rate of self-procurement of firewood by Ukrainian households. Such procurement even exceeds the volume of official procurement, so the issue of regulating these processes is acute. Wood fuel for the population should be sold on legal biofuel markets.

Therefore, the potential for the development of bioenergy is there, according to statistics. However, to compete with traditional energy, it is necessary to accelerate growth. As Ukraine is an agrarian country, it is advisable to focus on the use of waste and agricultural by-products. Today the country's biopotential is used weakly and unevenly. The largest share is solid biofuels (firewood, wood chips, pellets, briquettes, and straw). Thus, productions of such raw materials are located in the territory of the country unevenly and tend to regions where there is a weighty raw material base. Therefore, it is also important to find other sources for production, such as growing so-called energy crops, which are not too demanding and do not need fertile land (e.g., miscanthus, willow, and poplar). Regarding the prospects in the field of biofuel production, it is also important to focus on energy crops that are processed into biomass, from which further liquid fuel (biodiesel and bioethanol) is obtained. In addition to those listed above, such crops are also corn, rapeseed, sunflower, wheat. The plant potential for this in the country is available, as well as the necessary land resources.

Ukraine also has the potential for the development of biogas produced by biomass fermentation. The raw material base for biogas is vegetable raw materials (silage) and waste (organic agricultural or household). Obtaining energy from biogas does not harm the environment, does not increase greenhouse gas emissions, production is independent of weather conditions, has a high renewable potential as opposed to fossil sources. However, today the biogas sector is still at a low level of development.

Although the growth rate of bioenergy in Ukraine is still low, the prerequisites for the development of this area should focus on incentive mechanisms (the initial incentive elements can be called the existence of a green tariff for biogas in Ukraine, which will remain unchanged until 2030 sales of green energy). The effectiveness of the green tariff as a motivational mechanism can be seen by analysing the dynamics of alternative energy in Ukraine. Starting from 2012, one can see a growth trend (due to the introduction of the green tariff, and in 2018 the share of renewable energy increased by almost 6 % compared to 2012).

According to statistics in 2017, energy from renewable sources amounted to 5 % (4481.25 thousand tons o. e.) of the total volume in the structure of the total supply of primary energy in Ukraine. In 2018, this percentage did not change in percentage terms, in physical units amounted to 4658.25 thousand tons o. e. (+177 thousand tons o. e.). At the same time, in the structure of electricity production from renewable sources, biofuels account for 1.7 % in 2017 and 2.1 % in 2018 (Palyvno-enerhetychni, 2020).

According to the State Agency for Energy Efficiency, at the end of 2018, there were 33 biogas plants in Ukraine (with a capacity of 46 MW). For example, this figure in Germany reached 10 000 plants at this time. From 2009 to 2017, the capacities for bioenergy production almost doubled (Fig. 1).

The growth rate of the bioenergy sphere in the world is really fast, the leading position in terms of growth is occupied by the European Union, followed by the countries of Asia and North America. Although South America lags in terms of production, the growth rate has been rapid since 2012. A similar trajectory can be traced in countries belonging to Eurasia (Biohazovi, 2020). Dynamics similar to that shown in Fig. 2 can be observed in bioenergy in particular (Fig. 3).

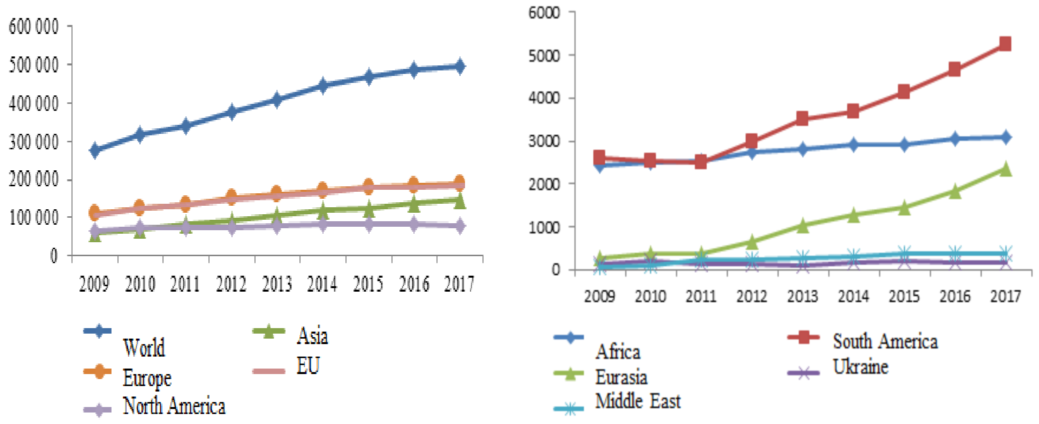


**Fig. 1.** Bioenergy production, GW, global trends.

The development of bioenergy in Ukraine became possible after 2009 when a law was passed that allowed the production of bioethanol by private individuals (before that the production of this type of fuel was a state monopoly). It should be noted that the biofuel market in Ukraine is very difficult to analyse because there are many small producers of this type of fuel statistically.

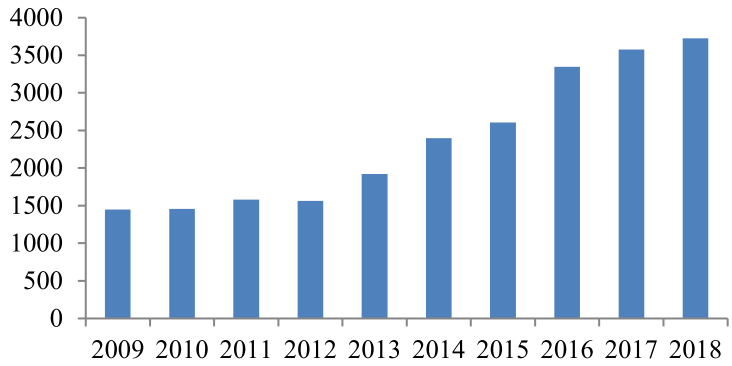


**Fig. 2.** Production of biofuels and energy from waste, thousands of tons of conventional oil (Palyvno-enerhetychni, 2020).

At the same time, Ukrainian biofuel producers mostly work for export. Raw materials from which biofuels are produced are also exported, as the consumption of biofuels in the European countries is constantly growing. In 2018, the export of solid biofuels amounted to 2.38 million tons per year, which was equivalent to 0.7 billion $m^3$ of natural gas per year (Stratehiia, 2020).

Many Ukrainian entrepreneurs produce and use biofuels for their own needs (maintenance of their production facilities, heating of shops, etc.), so the potential of this market in Ukraine is high. If one considers the structure of thermal energy production separately by type of fuel, then biofuel is already 7.19 % in the overall structure in 2017 and 8.39 % – in 2018. The share of thermal energy from biomass in Ukraine was about 97 % of all renewable thermal energy for the period from 2014 to 2018. Biomass thermal energy is mainly used by the household sector (domestic boilers and stoves) for heating and water heating, as well as for industrial heating facilities. Wood biomass is mostly used for thermal energy production, as well as waste from agricultural products (plant and animal).

In general, the structure of the primary energy supply according to the Energy Strategy of Ukraine until 2035 is given in Table 3.

**Table 3.** Bioenergy Potential of Ukraine, million tons o. e.

| Source | Forecast for 2020 | Forecast for 2025 | Forecast for 2030 | Forecast for 2035 |
|---|---|---|---|---|
| Coal | 18 | 14 | 13 | 12 |
| Natural gas | 24,3 | 27 | 28 | 29 |
| Petroleum products | 9,5 | 8 | 7,5 | 7 |
| Atomic energy | 24 | 28 | 27 | 24 |
| **Biomass, biofuels, waste** | **4** | **6** | **8** | **11** |
| Solar and wind energy | 1 | 2 | 5 | 10 |
| HPS | 1 | 1 | 1 | 1 |
| Thermal energy | 0.5 | 1 | 1,5 | 2 |
| TOTAL, million tons o. e. | 82.3 | 87 | 91 | 96 |

According to the forecasts of the “Concept for the implementation of state policy in the field of heat supply” (Rozporiadzhennia, 2017), it is expected that the share of the use of alternative energy sources in the overall balance of heat supply systems will increase to 30 % for the period up to 2025, and up to 40 % for the period of 2026–2035. Such indicators can be achieved mainly through biomass energy. The development of renewable energy, in particular, bioenergy in its composition, is shown in more detail in Fig. 3. As you can see from the Fig. 3, biofuels show the highest rate of development in the structure of renewable energy production for the study period, and the forecast is likely to grow in the coming years. The Energy Strategy of Ukraine for the period up to 2030 states that development in the direction of biofuels should take place with a focus on the basic principles contained in the “EU Strategy for Biofuels”.

The ordinary least square predicts growing trends of biofuel and waste energy generation. To be more exact, the annual increments in biofuels and waste energy are expected to be at the level of 225 thousands of tons o. e. The last is coherent with our hypothesis, since the increase in efficiency and availability of proper technologies as well as the rise of public awareness make the biofuels and waste energy one of the most prominent sources for the agrarian countries like Ukraine. The circular economy principles are the most applicable in agricultural sectors, since all byproducts and waste are the key inputs for bioenergy generation.

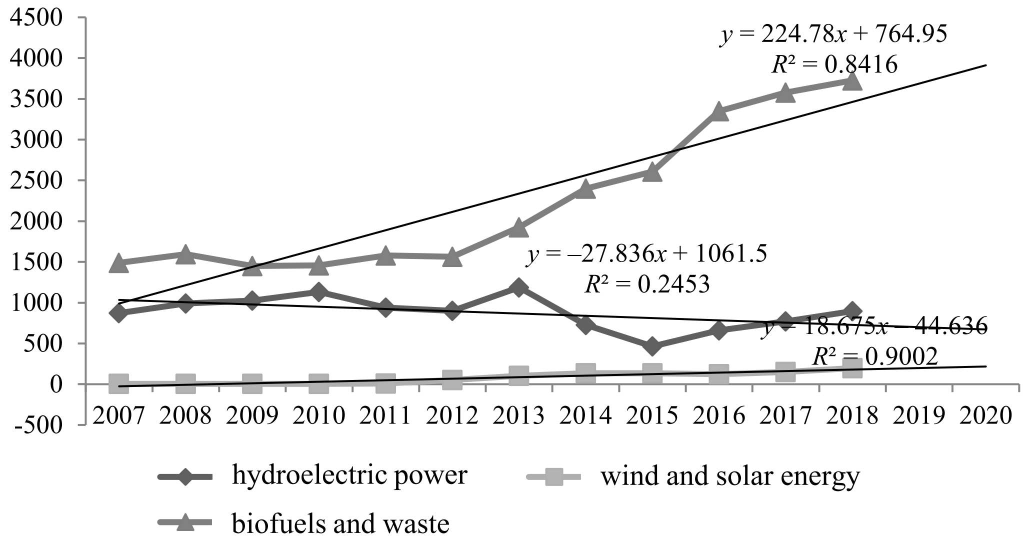


**Fig. 3.** Production of energy from renewable sources, thousands of tons o. e.

One of the tasks of the circular economy is to reduce the negative impact on the environment. The resources used in the production process must be environmentally friendly. The global bioenergy sector is constantly evolving, and related to the division of biomass into “traditional” and “modern”. Traditional biomass is mostly used in developing countries. Such raw materials are used for cooking and space heating in inefficient boilers and furnaces. Traditional use of biomass is gradually declining due to the provision of access to cleaner biomass sources.

Although Ukraine has not yet caught up with a rapid pace of development, it still focuses on the course of bioenergy development. This is evidenced in particular by the concept of the green energy transition of Ukraine until 2050. Its creation is dictated by the global transformation of energy approaches with a focus on sustainable economic development and overcoming climate change. The concept consists of maximum harmonization of the provisions contained in the programme documents of the European Union, in particular, the Strategic Concept for Reducing Greenhouse Gas Emissions, which has seven strategic components, namely: maximising energy efficiency; maximum deployment of renewable energy sources and electrification; transition to environmentally-friendly transport; introduction of circular economy (closed-cycle economy); development of smart networks and communications; expansion of bioenergy and natural carbon sequestration; absorption of other $CO_2$ emissions due to carbon absorption and storage technologies. Anyway, Ukraine has a significant potential for circular economy development based on energy from renewable sources. From year to year, the agricultural crops become more and more dependent on climate change (especially on hydrological regime and precipitations); therefore, all organic waste should become input for circular economy sectors.

## 3. DISCUSSION

The growth of biofuel production is important not only in terms of domestic consumption but also because of the high demand for it in the EU, which creates opportunities for biofuel exports and closes the production cycles through the practical application of the circular economy principles. Europe widely uses biofuels for transport, from motor vehicles to aviation. The strategy envisages the transition to the production of diesel using biodiesel fuel in the amount of 7 % and gasoline using 15 % ethanol by 2030.

It is also important to pay attention to certain contradictions regarding this type of renewable energy because today there are discussions about its impact on climate change and the environment in general. As already mentioned, today in Ukraine, the most used type of biomass is solid biomass, e.g., wood used for heating, both individual households and enterprises, and the export of wood pellets is also growing. On the one hand, all biomass inputs are completely suitable for circular economy, leaving no production wasted. On the other hand, there are some concerns about the rate of deforestation and other possible ways of unsustainable use of renewable resources, which can lead to climate change, biodiversity loss, affect soil quality, etc. The raw material for solid biofuels can be wood waste; the use of by-products from forestry replaces the use of fossil resources: gas, oil, coal. The use of waste is economically feasible because obtaining energy from wood, even if its transportation does not cost anything, will be much more expensive than obtaining energy from traditional fossil resources. In addition to wood, straw, seed husks, etc., livestock by-products and waste are used as biomass; therefore, they are 100 % circular. When burning wood, harmful substances enter the atmosphere, leading to air pollution. At the same time, due to the reduction of forest plantations, there are not enough trees to absorb carbon from the air. Forest plantations do not have time to recover.

However, precisely because the use of wood waste as a bio raw material leads to the substitution of fossil fuels, it reduces $CO_2$ emissions into the atmosphere. According to the Bioenergy Association of Ukraine, almost all plants created in Ukraine on solid biomass and biogas plants meet the requirements contained in the EU directives, and the reduction of greenhouse gas emissions during their operation exceeds 60 %. Given the growing popularity of bioenergy in the world, there is an opinion that Ukraine's growth rate will be too rapid, which also threatens forest resources.

Besides, Europe is focusing on the development of second-generation biofuels. This is biofuel produced using new technologies (from non-food raw materials). In the EU, after 2020, it is planned to finance only second-generation biofuels, which reduce greenhouse gas emissions. After all, when biofuels are produced from food raw materials, it leads to increased demand for them and, accordingly, to rising food prices. The raw material base is certain types of energy crops, forestry waste, and household waste. Moreover, third-generation biofuels are also being developed. This is a new technology for the production of biofuels, which use algae as raw material. During their processing, more fuel is formed than from other raw materials. In the United States, the technology of growing algae on emissions from thermal power plants was introduced. This technology reduces emissions that occur during the operation of CHP and ultimately produces quality animal feed. “Modern” biomass provides more efficient and cleaner energy production for heating. Bioheat can be used where it is produced, including through combined heat and power systems.

However, statistics show that solar and wind energy significantly exceed the use of biomass. Therefore, there is competition in the renewable energy market, with solar and wind energy having more support from the state (the availability of credit benefits, the green tariff for these species is much higher than biomass). Another worrying issue is the possible reduction of biodiversity. The basis for this, again, is deforestation, as well as planting in the same species of plants for a significant period, which can displace other species from these areas. Therefore, it is important to use different types of raw materials, alternating their plantings in the same areas, attracting land with infertile soils.

To increase the bioenergy potential as well as to stimulate the circular economy, it is recommended to apply green tariffs, certificates for renewable energy, and subsidies to energy producers. These actions will help realise the existing bioenergy potential in Ukraine and, at the same time, follow the concept of sustainable development.

## CONCLUSION

For the circular economy, the use of bioresources in general, and biomass in particular, is one of the main strategic directions, since these resources are renewable. At the same time, even bioresources can affect the environment to varying degrees; therefore, preference should be given to more modern sources (for example, the use of second-generation biofuels). The analysis of the current state of the bioenergy sector in Ukraine shows the inability to perform its main function, namely, the stimulation of sustainable development promotion. New motivational mechanisms that promote sustainable use of nature need to be introduced or improved. The issues of introduction of motivational mechanisms for the development of alternative energy sources, in particular, bioenergy are closely related to the problem of ecological modernisation. It is found that the legal field and the strategic directions of the bioeconomy in the European Union and Ukraine coincide, but the pace of development of bioenergy in Ukraine can be described as very slow.

Bioenergy is a unique source of energy, as it completely coincides with circular economy that can provide energy in three areas: heat/cold, energy, and fuel, leaving no industrial waste. One of the main renewable energy sources is biomass, which is formed from plant and animal raw materials and microorganisms (grass, wood, cereals, marine plants, algae, wastewater, manure, etc.). Having predicted the annual increments in biofuels and waste energy in Ukraine at the level of 225 thousands of tons o. e., it is expected that waste energy generation would be given the key priority, since it reduces the amount of municipal waste, promotes sustainability through the application of the circular economy principles to real life.

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