

WASTE MANAGEMENT SYSTEM: KEY DETERMINANTS OF GREEN DEVELOPMENT AND ENERGY BALANCE TRANSFORMATION

Yevheniia Ziabina,  ORCID: <https://orcid.org/0000-0003-0832-7932>

Assistant, PhD Candidate, Department of Marketing, Sumy State University, Ukraine

Andrii Iskakov,  ORCID: <https://orcid.org/0000-0003-3437-2550>

PhD Candidate, Department of Marketing, Sumy State University, Ukraine

Mavis Mensah Senyah,  ORCID: <https://orcid.org/0009-0008-3193-0522>

Garden City University College, Kumasi, Ghana

Corresponding author: Yevheniia Ziabina, e.ziabina@biem.sumdu.edu.ua

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Abstract: *This article summarizes the arguments and counterarguments within the scientific debate on the issue of the waste management system as a key determinant of green development and the transformation of the energy balance. The main goal of the research is to analyze the structure of energy production and its impact on the environment in the context of waste management as a key determinant of green development, taking into account the current realities of the war in Ukraine. The systematization of literary sources and approaches to solving the problem of changing the structure of the energy balance within the framework of the green development paradigm proved that the scientific community began to more actively explore alternative ways of changing the structure of the energy balance, also the results of the bibliometric analysis proved the formation of several scientific directions in the study of the waste management system as determinants of the impact on green development and the transformation of the country's energy balance. The urgency of solving this scientific problem lies in the fact that the production of primary energy produces about 75% of global greenhouse gas emissions. Accordingly, the main source of continuous work of all spheres of the national economy is one of the biggest sources of negative impact on the environment and climate change. The study of the issue of the waste management system as a key determinant of green development and the transformation of the energy balance in the article is carried out in the following logical sequence: the first stage – bibliometric analysis based on Scopus and Web of Science data; the second stage is a comparative analysis of the structure of the energy balance (production and consumption) of Ukraine; the third stage is scenario forecasting of the transformation of the energy balance based on the Brown model. The methods of bibliometric, comparative analysis and scenario forecasting became the methodical tools of the conducted research, the period of the study was 2000-2020. Ukraine was chosen as the object of the study, since it is important to study all possible ways of increasing economic, environmental and energy security, taking into account the war and post-war periods. The article presents the results of scenario forecasting, which proved that biofuels and waste are one of the promising sources of primary energy in the structure of the energy balance of Ukraine. The study empirically confirms and theoretically proves that the government of Ukraine needs to investigate promising directions for the modernization of the energy balance structure. The results of the conducted research can be useful for evaluating the transmission mutual effects of waste management, energy balance, public health, and the state of the environment.*

Keywords: waste management, energy balance, renewable energy, green development, transformation.

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Introduction

The economic development of the countries of the world today is characterized by the introduction of energy-efficient equipment, closed production cycles, secondary processing of raw materials, etc. However, not much attention is paid to the impact of energy production, which is subsequently used to support all spheres of life, from industry to households. According to the research results and data (Fig. 1) of the scientific online publication Our World in Data (2023), energy production itself (burning fossil fuels) produces about three quarters of global greenhouse gas emissions. Thus, the main source of uninterrupted work of all spheres of the national economy is one of the biggest sources of negative impact on the environment and climate change.

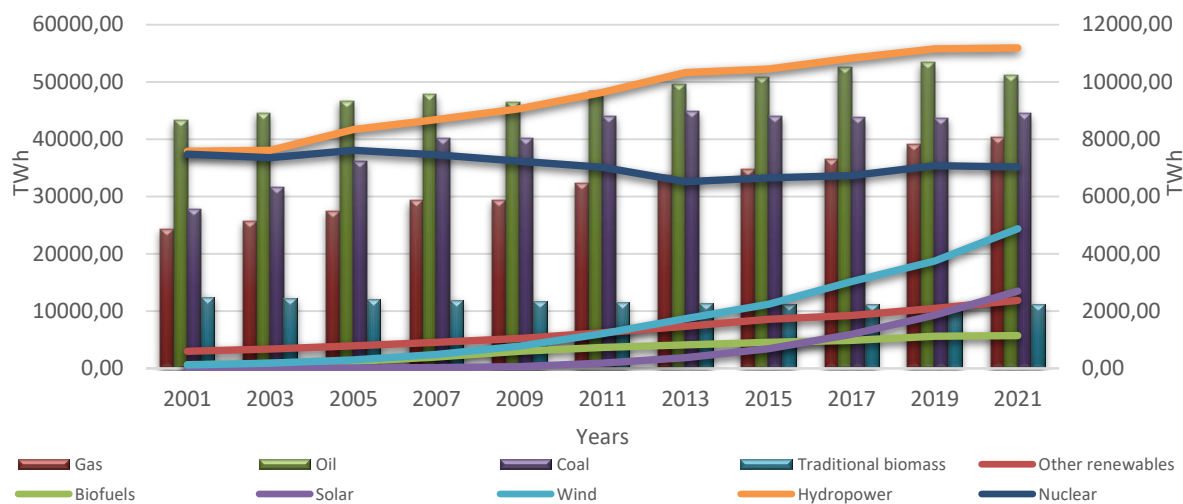


Figure 1. World consumption of primary energy by source, 2001-2021, TWh, substituted energy

Source: constructed by the authors based on Our World in Data (2023).

Taking into account the dynamics shown in Figure 1, it is possible to state certain trends towards changes in the structure of energy production sources. But the total volume of consumption is also increasing, which naturally provokes the stable use of fossil fuels as the main source of energy.

It is appropriate to pay attention to the fact that the key vectors of work to solve the above-mentioned problem have already been determined, in particular within the framework of the Sustainable Development Goals (2023) project and the European Green Agreement (2023). But changes in the world are quite dynamic, and already today some of the directions are quite difficult to implement. Therefore, within the scope of this study, the goal is to analyze the structure of energy production and its impact on the environment in the context of waste management as a key determinant of green development, taking into account the current realities of the war in Ukraine.

Literature Review

Today in the world much attention is paid to the solution of climatic, ecological, and economic problems. At the same time, all these issues are interconnected and have a high level of significance for each country. Taking into account the constant transformations in the energy sector, the search for new sources of energy that would not have a negative effect on the environment, it is advisable to consider the waste management system not only as a determinant of the impact on the environment, but also as a source of transformation of the energy balance by reducing the negative effect on the environment as a whole. As part of the literature review, we set certain restrictions for the search keywords "waste management" and "energy balance" in the scientometric databases Scopus and Web of Science. As a result, a sample of 344 publications was formed.

It was found that the first articles in the field of energy balance research and waste management systems date back to 1979. At the same time, for the next thirty years up to and including 2003, the lack of interest of the scientific community in this field of research can be traced, because on average 2-3 publications were indexed per year. However, since 2005, the dynamics of publication activity in the study of the structure of the energy balance through the prism of the waste management system has begun to grow.

Also, it is necessary to note the geography of publication activity by the researched topic (Fig. 2).



University	Number of publications
Politecnico di Milano	11
Università di Trento	8
Technical University of Denmark	7
University of Southampton	7
University of Surrey	6
Alma Mater Studiorum Università di Bologna	5
Università di Cassino e del Lazio Meridionale	4
Università degli Studi di Perugia	4
Cornell University	4
University of Leeds	4

Figure 2. Geography of publication activity and affiliation structure of the research articles, 2000-2022.

Source: compiled by the authors based on Scopus and Web of Science data

Considering the results shown in Figure 2, it can be concluded that the leader in the study of the structure of the energy balance through the prism of the waste management system is Italy (56 publications). This is confirmed by the largest number of publications affiliated with Italian universities - Politecnico di Milano (11 publications) and Università di Trento (8). It is also appropriate to pay attention to the subject areas of research (Fig. 3).

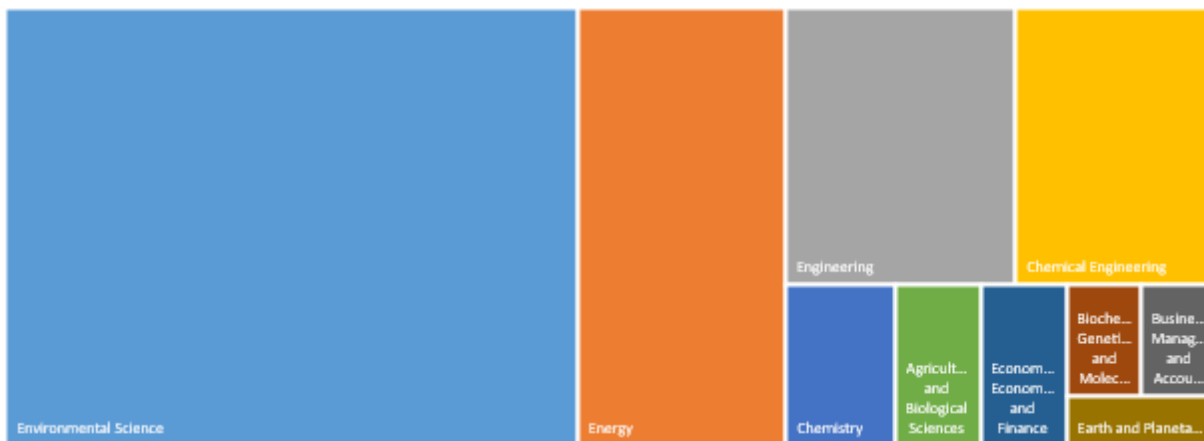


Figure 3. TOP-10 subject areas in which the scientific community publishes results on the subject under investigation, 2000-2022

Source: compiled by the authors based on Scopus and Web of Science data

The fourth yellow cluster has 48 terms characterized by the following keywords: “waste disposal” (occurrences – 101; total link strength – 2022), “environmental impact” (occurrences – 46; total link strength – 853), “sustainable development” (occurrences – 30; total link strength – 416).

The results of the built visualization map indicate a strong connection between the formed clusters (cluster density), this is a result of the integrity of the studied topic.

Also, in the course of the literature review, a number of scientific publications with the largest number of citations were singled out, the results of which remain relevant for the scientific community (Ghimire et al., 2015; Pöschl et al., 2010; Lundin et al., 2004; Bogner et al., 2008) and new prospective energy sources (Makaliuk et al., 2023; Pimonenko et al., 2021; Pryshlyak et al., 2020) and the possibility of their implementation in the future are being investigated.

Mishenin et al. (2020) substantiated the structural and functional scheme of creation and functioning of the ecological resource cluster of waste management. Previous studies (Boronos et al., 2016) confirm the relevance of the cluster approach to the waste management system within the energy balance of countries and environmental modernization. These results correlate with new research (Tambovceva et al., 2020) in the context of environmental protection, sustainable development of countries and green modernization.

Separately, it is necessary to note the direction of research (Matvieieva et al., 2023; Mastellone, 2019; Sekine et al., 2009; Arena et al., 2011) in the field of plastic waste management, as scientists analyze their impact on the health of the population.

Note that all measures related to modernization, innovation and investment activities must be regulated in the economic and legal field (Pysmenna et al., 2020). The more transparent and stable the political situation in the country (Vasylieva et al., 2019), the easier it is to encourage investors in various fields of activity, respectively, the authors (Brauweiler et al., 2017; Tregub O., 2021) consider various models of economic and legal regulation in the waste management system in the context of carbon-neutral development of countries. These statements are also based on the authors (Chygryn et al., 2019; Khalatur et al., 2022; Kolosok et al., 2020; Lyeonov et al., 2019) in their scientific works, where they analyze "green" finance as one of the tools of environmental innovation in the context of sustainable development (Kovtun T., 2020).

Many studies (Bedrii et al., 2021; Frolov et al., 2013; Shkarupa et al., 2014; Samusevych et al., 2021; Ziabina et al., 2020) are devoted to the analysis and implementation of new models for assessing the effectiveness of waste management in the framework of green development of countries.

Methodology and research methods (for research and theoretical papers)

The research was carried out in several stages. The first stage is a bibliometric analysis to summarize the prerequisites for researching the problems of energy balance transformation in the context of the waste management system. Data for analysis were collected from the scientometric databases Scopus and Web of Science. The main parameters for filtering works were keywords - "waste management" and "energy balance". After filtering, 344 documents were selected for analysis.

At the second stage of the study, a comparative analysis of the structure of the energy balance (production and consumption) of Ukraine in the period 2000-2020 was carried out.

The third stage of the research is the scenario forecasting of the transformation of the energy balance based on the Brown model, which takes into account the retrospective nature of the distribution of its time series and eliminates the fluctuation of random variables.

Results

Today, Ukraine and the whole world face new challenges, primarily related to war. Questions regarding the irreversible negative impact on the environment due to war events (blow-ups of recreational facilities, burning of large areas of protected areas, harmful residues from rocket shells, etc.) are becoming more and more urgent. For

a more detailed analysis, figure 5 presents the dynamics of waste generation and its utilized share within Ukraine for 2010-2020.

The main conclusion that can be drawn considering the data from Figure 5 is that only a third of the generated waste is disposed of. At the same time, a significant decline in 2014-2016 was caused by the temporary occupation of the territories of Ukraine (AR Crimea, Luhansk and Donetsk regions). We can predict that, after all, in 2022-2023, the amount of generated waste will decrease, but this will be caused, first of all, by the mass forced migration of the population of Ukraine abroad, the closure of large and small enterprises, the temporary occupation of entire cities, and all this related to the war in Ukraine.

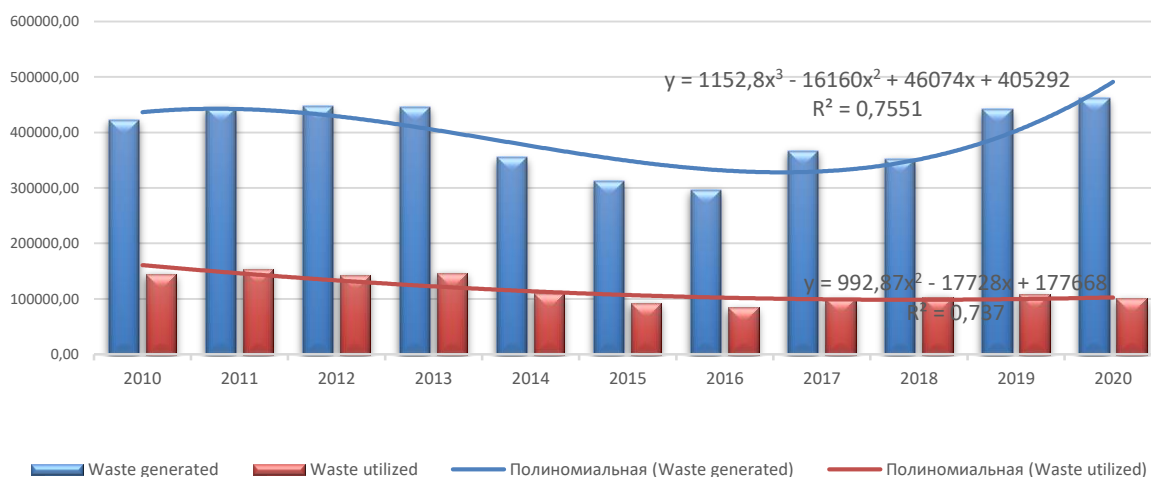


Figure 5. Dynamics of volumes of waste generated and disposed of in Ukraine, 2010-2020, thousand tons

Source: built by the authors based on Ukrstat data.

It is also necessary to pay attention to the structure of the energy balance and the role of the waste management system in this matter. As part of the study of the energy balance of Ukraine, the key stages of the decline in energy production were identified (Table 1).

Table 1. Energy production within the framework of the energy balance in Ukraine 2001-2022, in thousand tons of oil equivalent

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Production	76315	76746	75621	78262	79161	81147	84998	84260	79339	78712
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	85485	85247	85914	76928	61614	66323	58863	60883	60452	57017

Source: created by the authors based on Ukrstat data.

According to the data in Table 1, the decline of energy production in the structure of the energy balance is monitored, so in 2020, compared to 2001, energy production decreased by 25%, at the same time, the maximum volume of energy production falls on 2011-2012, in the period after the global economic crisis. But first of all, for a more detailed analysis of the dynamics and prospects of the country's green development in the context of the waste management system, it is advisable to consider the structure of the energy balance of Ukraine (Fig. 6).

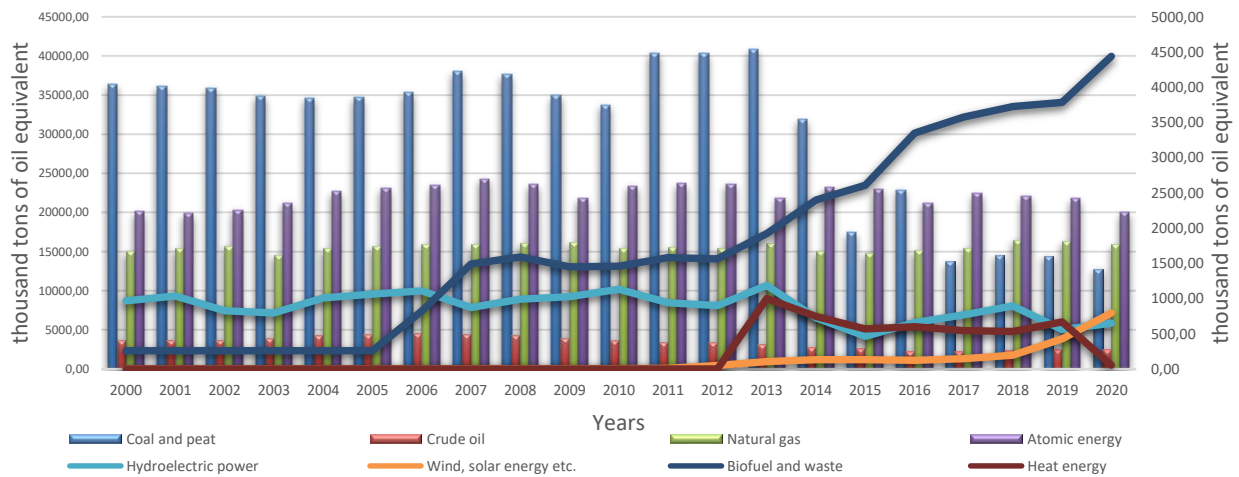


Figure 6. The structure of energy production in the energy balance of Ukraine in the period 2000-2020, in thousand tons of oil equivalent

Source: built by the authors based on Ukrastat data.

Analysis of data on the structure of energy production in the energy balance of Ukraine shows the following: the use of coal and peat as a source of energy has significantly decreased since 2014 due to the temporary occupation of Donetsk and Luhansk regions, which are the source of these resources. Such events usually caused certain burdens on other types of production, in particular, an increase in the use of natural gas, which at the same time was increased in price.

As part of all structural changes, attention should be paid to increasing the share of energy production with the help of renewable energy sources (solar, wind) and the use of biofuels and waste. It is appropriate to note that it is biofuel and waste that are steadily increasing in the structure of the country's energy balance. Since 2014, the specific weight of the use of biofuels and waste in the structure of the energy balance has been increasing, which is caused by the events mentioned above, as well as the mass transition of households to the use of solid fuel boilers to ensure independent heating in conditions of political and economic instability in the country.

It should be noted that today there is a significant decrease in the use of nuclear energy, due to the shutdown of the Zaporizhzhia nuclear power plant (from March 2022, after the occupation of the territory by Russian troops).

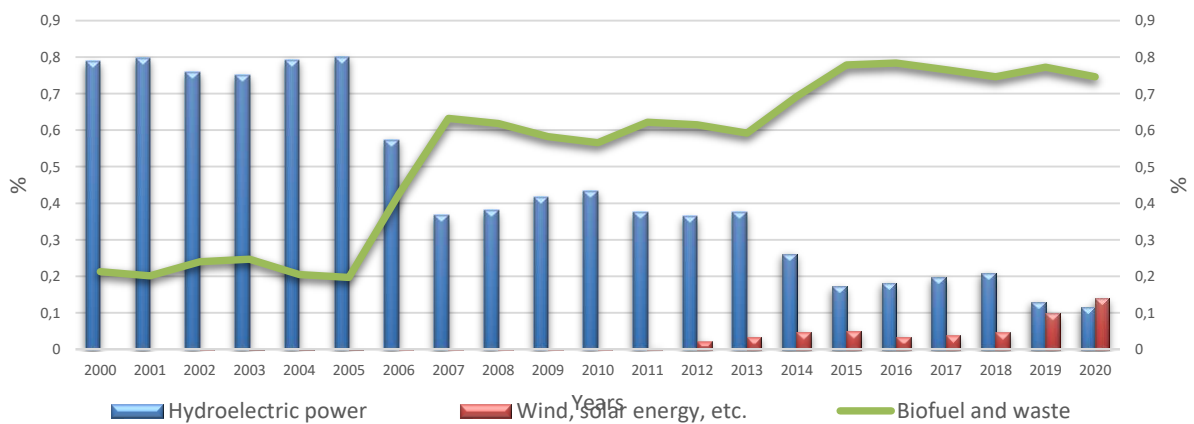


Figure 7. The structure of renewable energy sources in the total supply of primary energy in Ukraine, 2000-2020, in percentage

Source: built by the author on the basis of Ukrstat data.

Analyzing the data displayed in Figure 7, we can conclude that today the prospects of using waste and biofuel in the structure of the country's energy balance have high chances. Given that the country supports the vector of green development, this is an excellent direction in the transformation of the country's energy balance. We carried out a scenario forecasting of the transformation of the energy balance based on the Brown model, which takes into account the retrospective nature of the distribution of its time series and eliminates the fluctuation of random variables:

$$\widehat{ep}_0 = \alpha ep_t + (1 - \alpha)\widehat{ep}_t, \widehat{ep}_0 = ep_0, \quad \alpha \in (0,1), \tag{1}$$

Where $\widehat{ep}_0, \dots, \widehat{ep}_t$ – the projected volume of energy production in the structure of the country's energy balance; ep_0, \dots, ep_t – the actual value of the volume of energy production in the structure of the country's energy balance; t – forecasting period; i – forecasting time interval; α – confidence coefficient of prediction. Two determinants were chosen as the object of scenario forecasting - the volume of energy production in the structure of the energy balance of Ukraine and the share of the use of biofuels and waste in energy production in the structure of the energy balance. Given that statistical data for 2021-2022 are currently unavailable, 2020 was chosen as the start of the forecast. The results of scenario forecasting of the production volume are shown in Table 2 and Figure 8.

Table 2. Scenario forecasting of the volume of energy production in the structure of the energy balance of Ukraine

Forecast year	Lower confidence limit (pessimistic forecast)	Foresight	Upper confidence limit (optimistic forecast)
2021	57017,04	57017,04	57017,04
2022	46995,24	62665,31	78335,39
2023	45944,41	61740,35	77536,29
2024	44892,61	60815,39	76738,17
2025	43839,84	59890,42	75941,00

Source: calculated by the authors

Scenario forecasting within the framework of the study makes it possible to analyze possible factors that will affect the structure of the energy balance in the future. The main parameters of the forecast: confidence interval - 95%, interpolation filling, combination of repeated values - average value (Fig. 8).

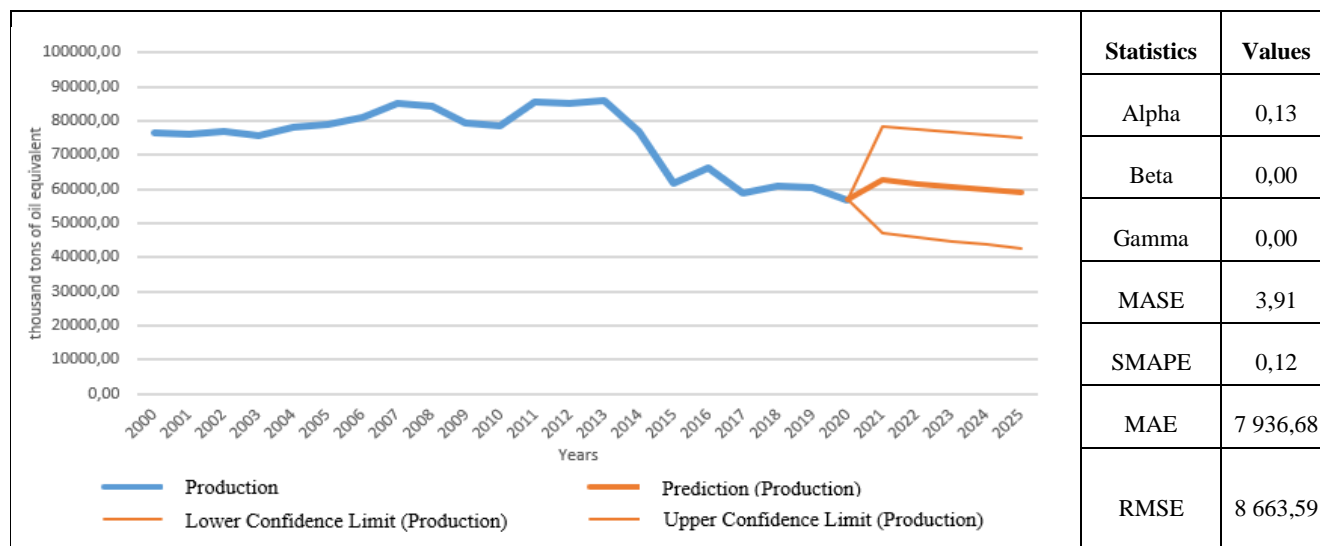


Figure 8. Forecast of the level of energy production in the structure of the energy balance of Ukraine 2000-2025

Source: constructed by the authors.

If there is no war in the country, we would take the results of the "Prediction" as the reference values, but taking into account all the circumstances - the seizure of the Zaporizhzhya nuclear power plant, the blowing up of the Kakhovskaya hydroelectric power plant, constant shelling of the energy infrastructure, etc., in our opinion, the optimal data for today are the predicted data according to the lower confidence limit (pessimistic scenario). At the same time, it should be noted that a decline in energy production is predicted under all scenarios.

For a comprehensive analysis of the impact of the waste management system on the structure of the energy balance, a scenario forecasting of the share of the use of biofuels and waste in energy production in the structure of the energy balance of Ukraine was also carried out (Fig. 9).

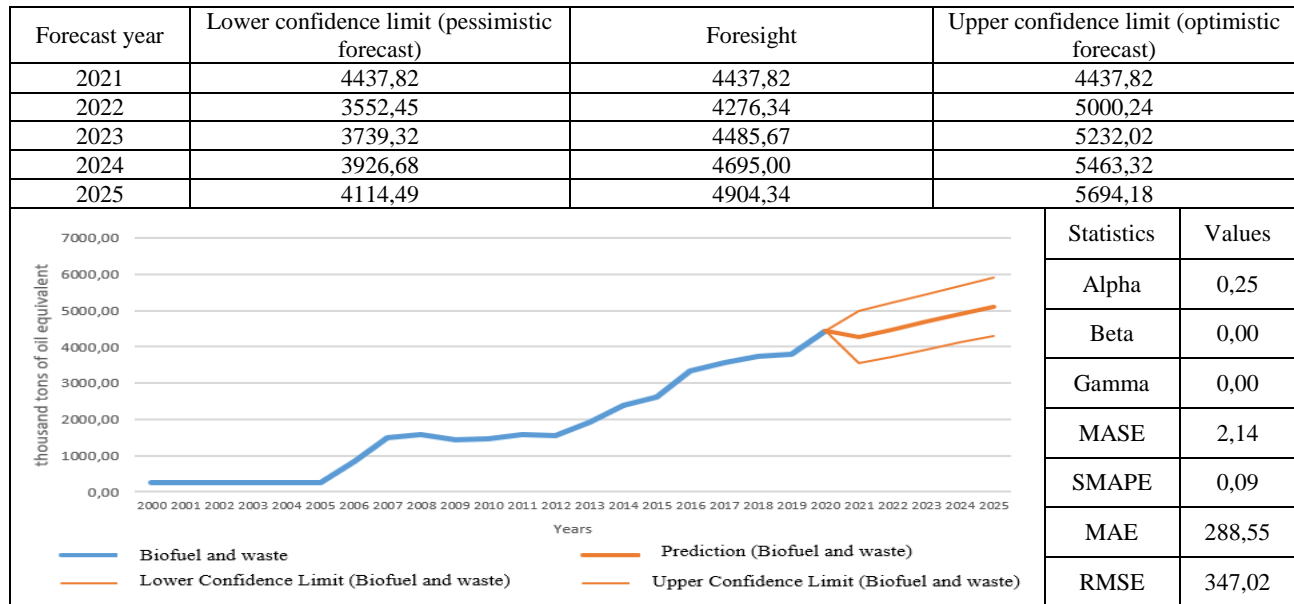


Figure 9. Forecast of the share of the use of biofuels and waste in energy production in the structure of the energy balance of Ukraine in 2000-2025

Source: constructed by the authors.

In general, the results of the scenario forecast indicate a positive trend of increasing the share of biofuel and waste use in the energy production system. At the same time, Ukraine can become an ecological and economic hub in this area, taking into account the problems with which we had to work. After all, even with a pessimistic scenario, the production of 4 114.49 thousand tons of oil equivalent is possible, which is close to the values of 2020 and the most for the entire period from 2000-2020.

Taking into account the results of the scenario forecasting, it can be noted that in today's military conditions, the country is quite stable withstanding all the problems that arise in the energy sector. We can predict structural changes in the energy system of European countries, which is connected with a number of sanctions against the Russian Federation.

According to the research results, it should be noted that scenario forecasting does not include the influence of external unpredictable factors, but only states conditional possibilities with a certain probability. But taking into account even such results and the high probability of uncertainty in the country caused by the war, the state has the opportunity to implement new strategies for the development of the energy sector. After all, other EU countries are now interested in Ukraine's energy stability.

Today, the country's government needs to research and develop certain programs to attract investments in the fields of waste processing as a source of alternative energy. Such measures must be created under the financial auspices of the UN and various international organizations. Integration in the creation of energy and

environmental hubs with Moldova may be appropriate. In general, today one of the main tasks of the government is the need to use all opportunities to strengthen the country's energy front.

Conclusions

Taking into account the results of the research, it is possible to state an increase in the interest in the researched topic of both foreign and domestic scientists. At the same time, the authors reveal problems from different angles, with appropriate conclusions and proposals. In general, the results of the bibliometric analysis proved the formation of several scientific directions in the study of the waste management system as determinants of the impact on green development and the transformation of the country's energy balance.

The results of a comparative analysis of the structure of the energy balance (production and consumption) of Ukraine in the period 2000-2020 characterize structural shifts. There is an increase in the specific weight of renewable sources in the structure of the energy balance, as well as a significant decrease in the use of fossil fuels, which reduces the powerful negative impact on the environment in the country.

The conducted scenario forecasting of the transformation of the energy balance based on the Brown model testified to a possible decline in energy production for the next 3 years. At the same time, the results indicate a possible increase in the specific weight of the use of biofuels and waste in the structure of the country's energy balance. As part of the results of scenario forecasting, we have proposed the following ways of increasing the efficiency of the use of biofuels and waste in the structure of the energy balance: to integrate the waste classification system with the international one, for the possibility of participation in joint projects on waste processing and disposal; work on joint ecological and energy hubs even on the territories of other countries (under conditions of military operations on the territory of Ukraine); introduction and support of start-ups, regarding the search for alternative use of waste and recycling of secondary raw materials.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “conceptualization, Y.Z., M.S. and A.I.; methodology, Y.Z., M.S.; software, Y.Z.; validation, Y.Z., M.S. and A.I.; formal analysis, Y.Z.; investigation, M.S.; resources, A.I.; data curation, Y.Z.; writing-original draft preparation, Y.Z., A.I.; writing-review and editing, M.S.; visualization, Y.Z., A.I.; supervision, Y.Z.; project administration, Y.Z.; funding acquisition, Y.Z.

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