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# FACTORS INFLUENCING THE FORECAST OF ENERGY CONSUMPTION OF THE COUNTRY IN THE CONDITIONS OF WAR AND THE AMOUNT OF REDUCTION OF GREENHOUSE GAS EMISSIONS

**Abstract.** *The article highlights three main factors that influence the forecast of the consumption of energy in the economy of Ukraine. These are structural shifts in its economy, changes in the structure of energy consumption in Ukraine, and volumes and directions of reduction of greenhouse gas emissions (GHG) in the conditions of compliance with international emission limitations. The conservative scenario of the development of the country's economy is considered. It predicts a moderate recovery, with the economy growing at 2.5 % per year. This pace has been chosen under the condition of the continuation of russia's armed aggression against Ukraine and the end of the active phase of hostilities by the end of 2025. The change in the structure of the economy during russia's military aggression against Ukraine was studied. The directions of further development of key sections of the economy have been determined. Strategic measures to reduce GHG emissions are highlighted, primarily in industry and in the energy sector in particular. Reducing fuel consumption by types of industrial sectors in Ukraine will be achieved through the introduction of energy-efficient technologies and processes aimed at reducing energy consumption in production, by switching to the use of more ecological energy sources, such as renewable energy sources; modernization of industrial facilities and equipment to reduce fuel consumption; implementation of energy saving and energy efficiency promotion programs in industry; reforming the energy sector and increasing energy efficiency in general. According to the updated nationally defined contribution of Ukraine to the Paris Agreement in 2021, the country committed to achieving a reduction of greenhouse gas emissions by 35 % from the 1990 level by 2030 and switching to energy-efficient and low-carbon technologies.*

**Keywords***:* structure of the economy, energy resources, structure of energy consumption, forecasting, greenhouse gases.

## 1. Introduction

The climate problem is very relevant for the development of the whole world. Even 20 years ago, very hot summer months, especially July and August, were not typical for Ukraine. Nowadays, the situation has changed to the opposite, which contributed to the development of air conditioning systems in office and residential premises and led to an increase in electricity consumption in the summer [1]. Today, the lack of electricity is felt throughout the day, and it will increase in the winter period. This situation arose after large-scale shelling of energy facilities by the aggressor country, when about 9 GW of installed capacity was destroyed. The majority refers to heat generation, therefore it is necessary to determine the amount of electricity and thermal energy consumption that will be needed for the survival of the economy and the population of Ukraine. Of course, such survival does not exclude the observance of the Agreements on climate protection, that is, the study of the structure of consumed fuel at power plants in the energy, industrial and utility sectors of the economy remains important.

Among the researchers who contributed significantly to the understanding of the impact of energy consumption on greenhouse gas emissions and the development of strategies to reduce this impact, the works of foreign scientists should be noted: Michael Grubb [2], Nick Watts [3], J. Goldemberg [4], M. Ahmad [5], I. Khan [6], M.A. Baloch [7], S.A. Neves [8] and others, and Ukrainian scientists, in particular Vitalii

Babak [9–11], Mykhailo Kulyk [12–14], Iryna Leshchenko [15, 16], Natalia Parasyuk [17], Tetiana Nechaieva [17, 18], Vitalii Makarov [19], authors of the article [12, 13, 20–22], and others.

*The purpose and objectives of the research*

The purpose of this article is to determine the impact of structural changes in the economy of Ukraine on its energy consumption, changes in the structure of fuel consumption on the volumes and directions of reduction of greenhouse gas emissions for the development of forecasts of energy consumption.

The tasks of the research are:

- consideration of structural changes in the economy of Ukraine caused by economic, geopolitical and globalization factors;
- study of changes in the structure of energy consumption for the period 2010-2020, which are closely related to changes in the economic situation in the country;
- determination of directions for reducing greenhouse gas emissions from the industrial sector of the economy, as one of the main polluters of the environment.

## 2. Methods and statistical observations

The structure of the country's economy is an important factor for the formation of the forecast of the consumption of the main types of fuel and other energy resources. The situation in the economy of Ukraine for the decade 2010–2020 is presented in Table 1. The section "Agriculture" developed with a fluctuation of 7.4–12.1 % in the structure of the economy, the higher indicator is typical for the crisis period, for the period of stabilization of the economy it was at the level of 9.0–9.3 %, the sector "Industry" steadily declined, it fell from 22.6 to 18.0 %, this is especially characteristic of the "Manufacturing industry" section – to 10.1 %, although the "Extractive industry" section is also losing its positions – it decreased to 4.6 %, the section "Supply of electricity, gas, steam and air conditioning" and "Water supply" together stabilized around 3.3 %, the section "Construction" loses its share from 3.3 to 2.8 %, the section "Wholesale and retail trade, etc. develops steadily, its share is about 14 %, the "Transport" section reduces its share to 6.2 %, the "Information and telecommunications" section steadily grew to 5 %, the "Other Foreign Trade" section fluctuates between 26.1–31.3 % , supporting the employment of the population and the economy in general in difficult times.

**Table 1.** Structural changes in the economy of Ukraine for 2010–2020*

| **Indicators** | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 7.4 | 8.2 | 7.8 | 8.8 | 10.2 | 12.1 | 11.7 | 10.2 | 10.1 | 9.0 | 9.3 |
| Industry, including: | 22.6 | 22.1 | 21.8 | 20.1 | 20.5 | 19.8 | 21.2 | 21.1 | 20.9 | 19.9 | 18.0 |
| mining | 5.9 | 6.5 | 5.8 | 5.5 | 5.0 | 4.8 | 5.5 | 5.9 | 6.0 | 5.6 | 4.6 |
| processing | 13.2 | 11.9 | 12.4 | 11.3 | 12.2 | 11.9 | 12.2 | 12.0 | 11.5 | 10.8 | 10.1 |
| electricity, gas, steam and air conditioning supply, water supply | 3.5 | 3.7 | 3.6 | 3.3 | 3.3 | 3.1 | 3.5 | 3.2 | 3.4 | 3.5 | 3.3 |
| Construction | 3.3 | 3.0 | 2.8 | 2.5 | 2.3 | 1.9 | 2.0 | 2.2 | 2.3 | 2.7 | 2.8 |
| Wholesale and retail trade | 14.4 | 14.9 | 14.3 | 14.5 | 14.7 | 13.8 | 13.3 | 13.7 | 13.2 | 13.2 | 13.9 |
| Transport, warehousing | 7.7 | 7.9 | 7.0 | 7.1 | 6.4 | 6.8 | 6.8 | 6.4 | 6.4 | 6.6 | 6.2 |
| Information and telecommunications | 3.1 | 2.9 | 3.1 | 3.3 | 3.3 | 3.6 | 3.7 | 3.7 | 3.9 | 4.6 | 5.0 |
| Other types of economic activity | 29.9 | 27.3 | 29.6 | 31.3 | 29.7 | 27.0 | 26.1 | 27.3 | 28.0 | 30.0 | 30.7 |
| Total Airborne Forces | 88.4 | 86.3 | 86.4 | 87.6 | 87.1 | 85.0 | 84.8 | 84.6 | 84.8 | 86.0 | 85.9 |
| Taxes, subsidies | 11.6 | 13.7 | 13.6 | 12.4 | 12.9 | 15.0 | 15.2 | 15.6 | 15.2 | 14.0 | 14.1 |
| GDP | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

* – calculated according to the State Statistics Service of Ukraine [23]

During the period 2021–2024, significant structural changes took place in the economy of Ukraine. Now it can be stated that the economy of the country has changed significantly compared to the pre-war indicators in terms of the structure of its economy, when "... export of raw materials, mainly agricultural, IT sector, and transfers of labor migrants, in fact export of labor resources" determined the main sources of monetary income [24]. In the conditions of the war, the deterioration of logistics, the reduction of export potential and the export itself, the Agriculture section has reduced its share in the structure of the economy

over the past three years by 3.5 percentage points, which is surprising, since the giants of metallurgy, which have always competed with it for export volumes in monetary terms and shared 1-2 place. The Industry sector continued its decline by 3.2 percentage points, reaching 17.2 % in the structure of the Air Force only due to the fulfillment of military orders. The Extractive industry section fell by 2.4 percentage points. due to a sharp reduction in coal mining and the volume of exports of other raw materials, although recently there has been a recovery in the export of iron ore by rail and an increase in the mining of other minerals for the construction industry. The Processing industry section decreased by 2.1 percentage points, as its component Metallurgical production was seriously affected after the destruction of the giants of the industry in Mariupol, according to experts, up to 70 % were destroyed. Before the large-scale shelling of April-July 2024, the Electricity, Gas, Steam, and Air Conditioning Section, together with the Water Supply Section, increased their share in the structure of the country's Airborne Forces by 1.3 percentage points up to 5.0 %. The construction section, despite the necessity and importance of its services for the recovery of the economy after the destruction caused by hostilities, decreased to 1.6 % or 1.2 percentage points. The section of wholesale and retail trade maintains its high share in the structure of the country's GVA – 12.6 %, due to which the steady supply of sections of the economy and the population with the necessary types of production and consumer products and services continues. The Transport section proved itself quite well in the war, ensuring the evacuation of refugees under shelling, the transportation of commercial products, including grain through the grain corridor, ferrous metal ores, and construction raw materials and fuel. Its fall in the structure of GDP occurred by 1 p.p. «Information and telecommunications» decreased by 0.7 pp. to 3.9 %. Previously, this sector was the most developed among others in the economy of Ukraine and occupied a certain niche in the world trade in services. Currently, he has lost the volume of orders, and the number of specialists in the IT sector has decreased by 20 %, because some of the IT specialists joined the ranks of the Armed Forces of Ukraine [24]. The "Other Foreign Trade" sector, which includes a large part of this structure of the economy, increased from 28.2 to 40.6 %. These are the sections "Education", "Health care and provision of social assistance", "Arts, sports, entertainment, and recreation", "Operations with real estate", "Professional, scientific and technical activities", "Activities in the sphere of administrative and auxiliary service", "Provision of other services" and related activities. This sector is the largest in terms of the number of employed people and is a kind of trigger of the economy, providing both employment of the population and its financial support.

Table 2 presents the forecast of the structure of gross added value in Ukraine by the main types of economic activity according to our calculations. This is a conservative development scenario. It predicts a moderate recovery, with the economy growing at 2.5 % per year.

**Table 2.** Forecast of the structure of gross added value in Ukraine by main types of economic activity according to own calculations (conservative scenario),* %

| **Indicators** | 2021 fact | 2022 fact | 2023 fact | 2024 expected | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Agriculture | 10.9 | 8.6 | 7.4 | 8.0 | 8.5 | 10.0 |
| Industry, including: | 20.4 | 16.7 | 17.2 | 16.5 | 18.0 | 19.3 |
| mining | 6.4 | 4.4 | 4.0 | 3.9 | 4.5 | 5.3 |
| processing | 10.3 | 7.6 | 8.2 | 8.6 | 9.1 | 9.5 |
| electricity, gas, steam and air conditioning supply, water supply | 3.7 | 4.7 | 5.0 | 4.0 | 4.4 | 4.5 |
| Construction | 2.8 | 1.3 | 1.6 | 1.7 | 2.0 | 4.5 |
| Wholesale and retail trade | 13.6 | 12.3 | 12.6 | 13.1 | 13.9 | 15.5 |
| Transport, warehousing | 5.4 | 4.3 | 4.3 | 4.5 | 4.8 | 7.5 |
| Information and telecommunications | 4.7 | 4.0 | 3.9 | 3.8 | 4.1 | 5.9 |
| Other types of economic activity | 28.2 | 41.1 | 40.6 | 39.4 | 34.7 | 23.2 |
| Total Airborne Forces | 86.0 | 88.3 | 87.6 | 87.0 | 86.0 | 85.9 |
| Taxes, subsidies | 14.0 | 11.7 | 12.4 | 13.0 | 14.0 | 14.1 |
| GDP | 100 | 100 | 100 | 100 | 100 | 100 |

* – the forecast is based on the cessation of hostilities by the end of 2025

This pace has been chosen under the condition of the continuation of Russia's armed aggression against Ukraine and the end of the active phase of hostilities by the end of 2025. This rate of recovery was chosen taking into account the data of the Ministry of Economy, when due to blackouts, the GDP growth of Ukraine slowed down to 1.1 % in June 2024 [25].

The main factor slowing down the growth rate of the economy was power outages due to its shortage, but despite the negative factors, the economic recovery continues. Many factors influenced such dynamics. In particular: the high level of adaptability of the economy to difficult conditions; high rates of export of products of the mining and metallurgical complex; early start of harvesting of winter crops; stable operation of the Ukrainian maritime corridor; the ability of individual enterprises to ensure stable access to electricity thanks to direct imports. "Currently, high-security risks, as well as the consequences of the destruction of the energy infrastructure, remain the key unsolved problems. The restoration of the energy sector will require time and resources, which, according to forecasts, may hold back the pace of the recovery of industrial activity. Also, logistical problems and a difficult situation on the labor market remain negative factors for the economy" [26]. Another important factor for forming a forecast of the consumption of the main types of fuel and other energy resources is the structure of energy consumption in the country, both in the economy in general and taking into account the population.

The study carried out a comparative analysis of the structure of the total supply of primary energy (Table 3) and the final consumption of fuel and energy resources (Table 4) based on the data of energy balances of Ukraine in 2010, 2015, and 2020 [27]. The data for 2021 are given according to the source [28] in thousands of tons (conversion of natural fuel into so-called oil according to [29]).

**Table 3.** Dynamics of changes in the volume of total primary energy supply (TSPE) for 2010-2020, thousand tons of energy (% of TSPE) [27, 28]

| Year, indicators | Coal and peat | Crude oil | Petroleum products | Natural gas | Atomic energy | Renewable energy sources | Total supply of primary energy |
|---|---|---|---|---|---|---|---|
| 2010 | 38251 (29 %) | 11497 (8,7 %) | 1682 (1,3 %) | 55229 (41,7 %) | 23387 (17,7 %) | 2611 (2 %) | 132308 (100 %) |
| 2015 | 27344 (30,3 %) | 2851 (3,2 %) | 7700 (8,6 %) | 26055 (29 %) | 22985 (25,5 %) | 2700 (3 %) | 90090 (100 %) |
| 2020 | 22847 (26,4 %) | 4196 (4,9 %) | 9947 (11,5 %) | 23844 (27,6 %) | 19994 (23,0 %) | 5687 (6,6 %) | 86363 (100 %) |
| 2021 | 20561 | - | 5130 | 23337 | - | - | - |

As can be seen from the table 3, the volume of coal consumption decreased by 40 % while preserving the share of coal (about 30 %) in the structure of the UPP for 2010–2020. The volume of crude oil receipts decreased almost threefold while the volume of finished petroleum products for export increased by almost 6 times. The total share of oil and petroleum products in ZPPE increased from 10 % to 17 %, which reflects the activation of the development of the transport sector and agriculture. The volumes of natural gas consumption decreased by 22 %, the share in the structure of natural gas by 14 % (from 42 % to 27 %). The share of nuclear generation increased by 4 % while the absolute volume of electricity supply from NPPs decreased. The use of non-traditional and renewable energy sources, which are included in the combined energy balance in t.e. hydroelectricity, wind and solar energy, biofuels and waste, tripled in percentage terms and doubled in absolute terms. This direction of attracting non-traditional and renewable energy sources is extremely relevant for Ukraine in the conditions of war and especially post-war revival.

Analyzing fuel consumption in industry helps identify the main sources of energy consumption, identify opportunities to improve energy efficiency and reduce greenhouse gas emissions, and develop strategies for transitioning to more sustainable production (Table 4).

**Table 4.** Dynamics of changes in the volume of final energy consumption for 2010–2020 in Ukraine, thousand tons of energy (% of Total)

| Year | Coal and peat | Crude oil and petroleum products | Natural gas | Biofuel and waste | Electro-energy | Heat energy | Total |
|---|---|---|---|---|---|---|---|
| 2010 | 8372 (11.31) | 12244 (16.53) | 28396 (38.37) | 984 (1.33) | 11526 (15.57) | 12481 (16.86) | 74004 (100) |
| 2015 | 6302 (12.40) | 9463 (18.62) | 16022 (31.52) | 1283 (2.52) | 10233 (20.13) | 7527 (14.81) | 50831 (100) |
| 2020 | 5822 (12.19) | 9654 (20.21) | 13179 (27.59) | 2181 (4.56) | 9760 (20.43) | 7177 (15.02) | 47773 (100) |

The largest final consumers of fuel and energy in 2020 were industry and the household sector, which accounted for 33.4 % and 28.4 %, respectively. Non-energy consumption in 2020 amounted to 3.7 million toe, of which 2.2 million toe was used as a raw material for industry (Table 4).

According to the State Statistics Service of Ukraine [23], in 2015, fuel consumption by type by the industrial sector amounted to 22008.60 thousand t u.p. In 2017, consumption amounted to 19406.26 thousand t u.p. according to calculations, the absolute increase is -2602.3 thousand t u.p. If we compare the indicators of 2018 with 2017, we have an increase of 2120.1 thousand t u.p. and by 10.9 %. Since 2019, the volume of fuel consumption has decreased by 966.4 thousand t u.p., and in 2020 by another 277.4 thousand t u.p.

The decrease in fuel consumption by types of industrial sectors in Ukraine is associated with a number of factors, such as:

1. Implementation of energy-efficient technologies and processes aimed at reducing energy consumption in production.

2. Transition to the use of more ecological sources of energy, such as renewable energy (solar, wind, hydropower).

3. Modernization of industrial facilities and equipment in order to reduce fuel consumption.

4. Implementation of programs of energy saving and stimulation of energy efficiency in industry.

5. Reforming the energy sector and increasing energy efficiency in general.

These measures help not only to reduce fuel consumption, but also to reduce greenhouse gas emissions and improve the state of the environment.

Assessing the intensity of structural shifts in fuel consumption by the industrial sector helps in solving a number of issues:

1. Forecasting and planning: Understanding the intensity of structural changes in fuel consumption by industry makes it possible to predict future trends in fuel consumption and develop effective plans to adapt to these changes.

2. Effectiveness of energy strategies: Assessment of structural shifts in fuel consumption by industry helps to assess the effectiveness of measures and policies aimed at reducing fuel consumption, increasing energy efficiency, and transitioning to renewable energy sources.

3. Reducing emissions: Understanding structural shifts in industry can help establish strategies to reduce emissions of greenhouse gases and other fuel-related pollutants in the sector.

4. Energy security: Analysis of structural changes in fuel consumption helps to assess the country's energy security level, determine its dependence on imported energy sources and the diversity of their sources.

5. Investment planning: Knowledge of structural changes in fuel consumption helps investors and companies determine directions for investments in the development of new technologies and infrastructure

aimed at reducing fuel use and developing renewable energy sources and reforming the energy sector towards the development of distributed generation.

Therefore, assessing the intensity of structural shifts in fuel consumption by the industrial sector is important for decision-making and the formation of strategies in the field of energy and ecology.

The third studied factor affecting greenhouse gas emissions is Ukraine's participation in global measures to reduce greenhouse gas emissions and their implementation into legislation and practical implementation [30, 31].

The main aspects that take into account the reduction of greenhouse gas emissions include:

1. Types of energy: The use of coal, oil and natural gas to produce electricity and heat results in significant emissions of greenhouse gases such as carbon dioxide (CO2) and nitrous oxide (N2O). Switching to greener energy sources such as wind power, solar power and hydropower can reduce these emissions.

2. Energy efficiency: Improving the energy efficiency of energy production and consumption can help reduce greenhouse gas emissions. Reducing energy losses during production, transportation and use can reduce the need to use coal and other energy sources, which are the biggest emitters of these emissions.

3. Transport sector: A significant part of greenhouse gas emissions is associated with road transport, especially transport that runs on petroleum fuel. Reducing the use of internal combustion engine cars in favor of electric or hybrid vehicles can help reduce these emissions.

4. Industry: Industry is another important source of greenhouse gas emissions, especially carbon dioxide (CO2) and methane (CH4). The implementation of clean technologies and energy-efficient production methods can help reduce these emissions. Therefore, the transition to more ecological sources of energy and improvement of energy efficiency can significantly reduce the amount of greenhouse gas emissions, which is of great importance for the fight against climate change.

The National Inventory of Anthropogenic Emissions from Sources and Absorption by Sinks of Greenhouse Gases in Ukraine for 1990–2021 was developed in accordance with the requirements of the UN Framework Convention on Climate Change. After all, Ukraine is a party to the Convention and, even despite the war, strives to make its contribution to the global fight against the climate crisis. Submission of the National Cadastre to the Secretariat of the UN Framework Convention on Climate Change is part of our country's international obligations. According to the National Cadastre of Anthropogenic Emissions from Sources and Absorption by Sinks of Greenhouse Gases, which was prepared by the Ministry of Environment together with the National Center for Accounting for Greenhouse Gas Emissions. In 2021, greenhouse gas emissions in our country amounted to 341.5 million tons of CO2-eq. This is 62.5 % less than the volume of 1990, but 7.5 % more than in 2020.

In 2010–2013, the growth of GHG emissions was characterized by the general recovery of the economy from the consequences of the 2008 global crisis. During this period, the consumption of solid fossil fuels in the energy sector increased due to the gas conflict with the Russian Federation. In 2014–2015, a sharp reduction in emissions was caused by the fall in the economy due to the occupation of Crimea and the city of Sevastopol, as well as the start of hostilities in the Donetsk and Luhansk regions. In 2016–2019, fluctuations in GHG emissions were observed at the level of 337–362 million tons of CO2-equivalent. This period is characterized by the beginning of the active implementation of the energy efficiency policy (the "Warm Credits" program is being implemented) and the gradual bringing of tariffs for electricity, hot water and heat to market values. In 2020, emissions decreased by 11 % compared to 2019, due to the COVID-19 pandemic and measures taken to combat the virus. In 2021, the recovery of the country's economy led to an increase in greenhouse gas emissions by 7.5 % compared to 2020 [32].

Ukraine took part in a number of international agreements and initiatives aimed at reducing greenhouse gas emissions and combating climate change, in particular:

1. Association Agreement between Ukraine and the EU, the European Atomic Energy Community and their member states of 2014 (Chapter 6 – Environment) [33].

2. The Paris Climate Agreement of 2015, ratified in Ukraine in 2016 (from January 1, 2021, countries adopt their goals for reducing or limiting GHG emissions) [30].

3. Low-carbon development strategy of Ukraine until 2050 (SNVR), 2018 (Mindovkillya of Ukraine) [34].

4. The European Green Deal of 2019 (moving towards a climate-neutral European continent by 2050) [35]. Ukraine has undertaken to join initiatives and programs aimed at reducing greenhouse gas emissions and green economic growth supported by the European Union.

5. Ukraine's updated nationally determined contribution to the Paris Agreement (NAP2), 2021: Ukraine committed to achieve a 35 % reduction in greenhouse gas emissions from 1990 levels by 2030 and to switch to energy-efficient and low-carbon technologies. The very first NPP provided for Ukraine to reduce CO2 emissions by 40 % by 2030, excluding the agricultural sector and forestry. The indicator of reducing emissions by 65 % by 2030 was obtained based on the calculation that in 1990 Ukraine's emissions amounted to 884 million tons, taking into account land use and forestry. And already in 2019, according to the cadastre, CO2 emissions amounted to 37.6 % of the 1990 level, namely 332 million tons [36, 37].

6. Law 3220-IX "On Amendments to Certain Laws of Ukraine Regarding Restoration and Green Transformation of the Energy System of Ukraine", 2023 [38].

These obligations require Ukraine to develop and implement emission reduction strategies and transition to more environmentally friendly technologies and practices in all sectors of the economy.

General measures that will contribute to the reduction of greenhouse gas emissions in industry:

1. Increasing energy efficiency in the industrial sector (sections "Processing industry", "Mining industry", "Supply of electricity, gas, steam and air conditioning, Water supply") both at thermal power plants and industrial block stations, and in the heat supply system: reduction of losses during extraction, transportation and distribution of various types of organic fuel, the introduction of cogeneration units based on highly maneuverable HTUs and GPUs into energy supply systems, in particular in the city of Kyiv, etc.).

2. Transition to alternative (burning solid household waste at waste incineration plants with a cogeneration scheme) and renewable energy sources, in particular in heat supply systems (bioboilers, solar panels for the production of electricity that will be consumed by electric boilers, heat pump installations).

3. Technological modernization of industrial and energy technologies to increase the coefficient of use of fuel heat, the coefficient of useful action. In addition to technological energy saving, it is necessary to pay attention to structural energy saving not only at the country level (reduction in the use of fossil fuels in the processing industry) but also in intra-sectional structural changes (increasing the effectiveness of energy saving measures in energy-intensive industries in sections, groups, classes of the Classifier of types of economic activity).

4. Reforming the energy sector towards the development of distributed generation, including at industrial enterprises.

Effective tools that stimulate the reduction of greenhouse gas emissions include the following:

1. Market (emissions trading systems). The European Emissions Trading System (EU ETS) is based on the EU Emissions Trading Directive 2003/87/EC. Energy enterprises fall under it: thermal power plants with a capacity of more than 20 MW; mining industry: coal mining (mine methane), gas mining; processing industry: oil refineries, coke ovens, enterprises for production and processing of ferrous metals, production of cement, bricks, glass, ceramics, pulp and paper industry.

2. Tax (fuel taxation, CO2 emissions tax are paid by enterprises that are not part of the EU ETS).

3. Regulation and subsidies (environmental standards, support policy for innovative sectors of the economy).

## 3. Results

Analysis of research results. In the table 5–8 shows the calculated volumes of forecast demand for energy resources according to the structure of the base year 2020 and according to the forecast structure for 2025–2030.

**Table 5.** Forecast of demand for electricity in Ukraine until 2030, taking into account structural and technological energy savings, million kWh

| **Indicators** | 2020 (fact) | 2021 (fact) | 2022* (fact) | 2023* (expected) | 2024 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Gross electricity consumption by GDP electricity capacity in 2022 | 120324.6 | 125654.8 | 106200 | 102507 | 84000 - 90560 | 95000 - 100800 | 111780 - 118600 |
| Gross electricity consumption by GDP electricity capacity in 2022, before large-scale shelling and the loss of part of the capacities | | | | 108307 | 112965 | 120085 | 162990 |
| Gross electricity consumption by the power capacity of the Airborne Forces together in 2022 before large-scale shelling and the loss of part of the capacities, million kWh | | | | 108457 | 114406 | 121609 | 165063 |
| Total gross electricity consumption (gross) | 147801.4 | 156601 | 127440 | 123000 | 100800 - 108670 | 114000 - 121000 | 134140 - 142320 |
| Total gross electricity consumption (gross), before large-scale shelling and the loss of part of the capacities | | | | 129968 - 130148 | 135558 - 137287 | 144102 - 145931 | 192328 - 194774 |

* – operational data of Ukrenergo, calculated based on monthly consumption

**Table 6.** Forecast demand for thermal energy in Ukraine until 2040, taking into account structural and technological energy savings, thousand GCal [39]

| **Indicators** | 2020 (fact) | 2025 | 2030 |
|---|---|---|---|
| Consumption of thermal energy in the country according to the structure of the economy of the base year 2020, taking into account the needs of the population (2020 structure) | 75449.4 | 58670 | 76501 |
| Thermal energy consumption by country according to the forecast structure of the economy (forecast structure) | 75449.4 | 56202 | 74791 |

**Table 7.** Forecast of demand for coal in Ukraine until 2040, taking into account structural and technological energy savings and emissions of greenhouse gases from their burning, million tons of coal, million tons of $CO_2$-eq

| **Indicators** | 2020 (fact) | 2025 | 2030 |
|---|---|---|---|
| Coal consumption by country according to the structure of the economy in 2020 and technological energy saving (structure of 2020) | 39.29 | 40.4 | 37.5 |
| Coal consumption by country taking into account structural and technological energy saving (forecast structure) | 39.29 | 24.03 | 23.98 |
| Estimated GHG emissions from coal combustion – total, million tons of $CO_2$-eq (2020 structure) | 78.38 | 80.59 | 74.81 |
| Estimated GHG emissions from coal combustion – total, million tons of $CO_2$-eq (forecast structure) | 78.38 | 49.96 | 49.85 |
| Change in GHG emissions due to changes in the structure of the economy, million tons of $CO_2$-eq | 0 | 30.63 | 24.96 |

**Table 8.** Forecast of demand for oil products in Ukraine until 2040, taking into account structural and technological energy savings and emissions of greenhouse gases from their burning, million tons of oil*, million tons of $CO_2$-eq

| **Indicators** | 2020 (fact) | 2025 | 2030 |
|---|---|---|---|
| Consumption of petroleum products by country according to the structure of the economy in 2020 and technological energy saving (structure of 2020) | 10 | 13.6 | 16.9 |
| Consumption of petroleum products by country, taking into account structural and technological energy saving (forecast structure) | 10 | 13.5 | 18.4 |
| Estimated GHG emissions from the combustion of petroleum products - total, million tons of $CO_2$-eq (2020 structure) | 30.5 | 41.3 | 51.4 |
| Estimated GHG emissions from the combustion of petroleum products - total, million tons of $CO_2$-eq (forecast structure) | 30.5 | 41.1 | 56.1 |
| Change in GHG emissions due to changes in the structure of the economy, million tons of $CO_2$-eq | 0 | 0.2 | -4.7 |

*without taking into account the replacement by electric vehicles, but taking into account the overspending of oil fuel with an increase in the share of the GDP of the agriculture section and the transport section in the country's economy.

## 4. Conclusions

The work examines the impact of three main factors on the forecast of demand for fuel and energy resources: the structure of the country's economy, the structure of the country's energy consumption, and international obligations regarding the reduction of greenhouse gas emissions. It is shown that changing the structure of the economy can both reduce greenhouse gas emissions (due to fuel savings) and increase their emissions (due to increased fuel consumption). In the second case, it is expedient to consider measures to replace volumes of organic fuel with alternative types of fuel (for example, burning coal together with biofuel in boiler plants) or renewable energy sources (electricity from the sun, wind turbines). In addition to structural changes, a significant projected decrease in greenhouse gas emissions when using coal was facilitated by a decrease in coal consumption in the metallurgical complex (by 45 %) due to the destruction caused by military operations, the large-scale transfer of boiler plants operating in agriculture and in sections of the "Other VED" group to renewable energy sources: biogas, biofuel boilers, electric boilers and heat pump installations with solar and wind power generation installations and storage batteries (due to inaccessibility to own coal deposits in the occupied territories). The forecast for greenhouse gas emissions from the burning of petroleum products gives a small increase due to the revival of the country's economy by 2030 and an increase in transportation.

**Authors' Contributions.** O. Maliarenko reviewed the literature, analyzed primary energy supply based on Ukraine's reported energy balances for 2010–2021, and developed forecasts for thermal energy, coal, and petroleum products, including calculations for greenhouse gas emission reductions under economic structure changes through 2030. N. Maistrenko reviewed domestic literature, analyzed structural shifts in Ukraine's economy during 2010–2020, and provided a conservative scenario for forecasting the structure of gross value added by key economic activities and Ukraine's gross domestic product. Additionally, a forecast of electricity demand in Ukraine through 2030 was developed, considering structural and technological energy savings. T. Yevtukhova conducted a comparative analysis of the structure of total primary energy supply and final consumption of fuel and energy resources. She identified factors contributing to fuel consumption reduction across industrial sectors in Ukraine, analyzed the intensity of structural shifts in fuel consumption by the industrial sector, and outlined key aspects for reducing greenhouse gas emissions in the industrial sector.

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## References


1. Maliarenko, O.Ye., Teslenko, O.I., & Maistrenko, N.Yu. (2022). Mathematical model of forecasting demand for electricity for the country and the industrial sector by months of the year. *Achievements of Ukraine and EU countries in technological innovations and invention*. Izdevnieciba "Baltija Publishing", Riga, Latvia (36 p.).
2. Grubb, M., Lange, R.-J., Cerkez, N., Sognnaes, I., Wieners, C., & Salas, P. (2024). Dynamic determinants of optimal global climate policy. *Structural Change and Economic Dynamic*, 71, 490–508. https://doi.org/10.1016/j.strueco.2024.07.005
3. Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., & Cai, W. (2015). Health and climate change: policy responses to protect public health. *The Lancet*, 386, 1861–1914. https://doi.org/10.1016/S0140-6736(15)60854-6
4. Goldemberg, J. (2020). The evolution of the energy and carbon intensities of developing countries. *Energy Policy*, 137, 111060. https://doi.org/10.1016/j.enpol.2019.111060
5. Ahmad, M., & Wu, Y. (2022). Natural resources, technological progress, and ecological efficiency: does financial deepening matter for G-20 economies? *Resources Policy*, 77, 102770. https://doi.org/10.1016/j.resourpol.2022.102770
6. Khan, I., Hou, F., & Le, H. P. (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: fresh evidence from the United States of America. *Science of The Total Environment*, 754, 142222. https://doi.org/10.1016/j.scitotenv.2020.142222
7. Baloch, M. A., & Suad, S. (2018). Modeling the impact of transport energy consumption on CO2 emission in Pakistan: evidence from ARDL approach. *Environmental Science and Pollution Research*, 25, 9461–9473. https://doi.org/10.1007/s11356-018-1230-0
8. Neves, S. A., Marques, A. C., & Patrício, M. (2020). Determinants of CO2 emissions in European Union countries: does environmental regulation reduce environmental pollution? *Economic Analysis and Policy*, 68, 114–125. https://doi.org/10.1016/j.eap.2020.09.005
9. Babak, V., Scherbak, L., Kuts, Yu., & Zaporozhets, A. (2021). Information and measurement technologies for solving problems of energy informatics. Proceedings of the 1st International Workshop on Information Technologies: Theoretical and Applied Problems. *CEUR Workshop Proceedings*, 3039, 24–31.
10. Babak, V., Dekusha, O., & Burova, Z. (2021). Hardware-Software System for Measuring Thermophysical Characteristics of the Materials and Products, Proceedings of the 1st International Workshop on Information Technologies: Theoretical and Applied Problems. *CEUR Workshop Proceedings*, 3039, 255–266.
11. Babak, V. (2024, June 12). Changes in the structure of the power system and peculiarities of the energy market in the period of Ukraine's recovery. According to the materials of scientific report at the meeting of the Presidium of the NAS of Ukraine. *Visnyk of the National Academy of Sciences of Ukraine*, 8 [in Ukrainian]. https://doi.org/10.15407/visn2024.08.010
12. Kulyk, M.M., Malyarenko, O.E., Maistrenko, N.Yu., Stanytsyna, V.V., & Spitkovskyi, A.I. (2017). Application of the complex forecasting method to determine the prospective demand for energy resources. *The Problems of General Energy*, *1*(48), 5–15 [in Ukrainian]. https://doi.org/10.15407/pge2017.01.005
13. Kulyk, M.M., Malyarenko, O.E., Maistrenko, N.Yu., Stanytsyna, V.V., & Kuts, G.O. (2021). Energy efficiency and forecasting of energy consumption at different hierarchical levels of the economy: methodology, forecast estimates until 2040. Kyiv, Naukova Dumka (234 p.).
14. Kulyk, M., Nechaieva, T., Zgurovets, O., Shulzhenko, S. & Maistrenko, N. (2023). Comparative Analysis of Energy-Economic Indicators of Renewable Technologies in Market Conditions and Fixed Pricing on the Example of the Power System of Ukraine. In A. Zaporozhets, V. Artemchuk (Eds), *Systems, Decision and Control in Energy IV. Studies in Systems, Decision and Control*, 454 (pp. 433–449). Springer, Cham. https://doi.org/10.1007/978-3-031-22464-5_26
15. Leshchenko, I.Ch. (2022). Assessment of the greenhouse gases emissions reduction by the coal sector of Ukraine to meet international climate agreements. *The Problems of General Energy*, *1-2*(68-69), 139–149 [in Ukrainian]. doi.org/10.15407/pge2022.01-02.139
16. Leshchenko, I., Shulzhenko, S., Kaplin, M., Maistrenko, N., & Shcherbyna, E. (2023). Assessment of the greenhouse gases reduction by the oil and gas sector of Ukraine to meet international climate agreements. In A. Zaporozhets, V. Artemchuk (Eds.), *Systems, Decision, and Control in Energy IV. Studies in Systems, Decision, and Control*, 456 (pp. 199–212). Springer, Cham. https://doi.org/10.1007/978-3-031-22500-0_13
17. Parasyuk, N.V., Nechaieva, T.P., & Lebid, M.V. (2020). Evaluations of benchmarks for greenhouse gas emission in engineering under the emissions trading system of Ukraine. *The Problems of General Energy*, *4*(63), 50–57 [in Ukrainian]. https://doi.org/10.15407/pge2020.04.050
18. Nechaieva, T.P. (2022). Modeling ensuring demand-supply balance of the power system in conditions of significant renewable generation. *The Problems of General Energy*, *1–2*(68–69), 42–99 [in Ukrainian]. https://doi.org/10.15407/pge2022.01-02.042
19. Makarov, V., & Perov, M. (2023). Assessment of the prospectiveness of operating coal mining enterprises. *System Research in Energy*, *2*(73), 18–29 [in Ukrainian]. https://doi.org/10.15407/srenergy2023.02.018

20. Maliarenko, O.Ye., & Maistrenko, N.Yu. (2015). Forecasting fuel and energy consumption levels taking into account energy saving potential in the context of structural changes in the economy. *System Research in Energy*, *2*(41), 5–22 [in Ukrainian]. https://doi.org/10.15407/pge2015.02.005
21. Maliarenko, O., Maistrenko, N., Stanytsina, V., & Bogoslavska, O. (2020). Improved complex method of forecasting energy consumption on a long-term perspective. *Power engineering: economics, technique, ecology*, *3*(57), 53–64 [in Ukrainian]. https://doi.org/10.20535/1813-5420.3.2019.196383
22. Maliarenko, O., Maistrenko, N., Horskyi, V., Leshchenko, I., & Ivanenko, N. (2023). Mathematical Simulation of Projecting Energy Demand for Ukraine's Budget Institutional Buildings. *Studies in Systems, Decision and Control V*, 481 (pp. 57–70). https://doi.org/10.1007/978-3-031-35088-7_4
23. State Statistics Service in Ukraine. (n. d.). URL: https://www.ukrstat.gov.ua/ (Last accessed: 05.08.2024) [in Ukrainian].
24. Kush, O. (2024, June 25). The three whales on which our economic model rested turned out to be paper and burned in the flames of war. *TRUEUA.info*. URL: https://trueua.info/news/kutsh-tri-kiti-na-yakih-trimalasya-model-ekonomiki-viyavilisya-paperovimi-i-zgorili-u-polumi-vijni (Last accessed: 05.08.2024) [in Ukrainian].
25. As a result of blackouts, Ukraine's GDP growth slowed to 1.1% in June. *Telegraf.in.ua*. URL: https://www.telegraf.in.ua/kremenchug/10130540-vnaslidok-vidkljuchen-svitla-zrostannja-vvp-ukrajini-u-chervni-spovilnilosja-do-11.html (Last accessed: 05.08.2024) [in Ukrainian].
26. The Ukrainian economy has grown by more than 4% since the beginning of the year: what was the reason. *TRUEUA.info*. URL: https://trueua.info/news/ukrainska-ekonomika-z-pochatku-roku-zrosla-na-ponad-4-tsho-stalo-prichinoyu (Last accessed: 05.08.2024) [in Ukrainian].
27. Energy balances of Ukraine for 2010, 2015, 2020. URL: https://www.ukrstat.gov.ua (Last accessed: 05.08.2024) [in Ukrainian].
28. Annual consumption of gas, coal and other fuel products in Ukraine. *Minfin.* URL: https://index.minfin.com.ua/ua/economy/energy/ (Last accessed: 05.08.2024) [in Ukrainian].
29. A ton of oil equivalent. URL: https://uk.wikipedia.org/wiki/Tonne_of_oil_equivalent (Last accessed: 05.08.2024).
30. Paris Climate Agreement. URL: https://greendeal.org.ua/paryzka-klimatychna-ugoda/ (Last accessed: 05.08.2024) [in Ukrainian].
31. On the approval of the Updated Nationally Determined Contribution of Ukraine to the Paris Agreement. Decree of the Cabinet of Ministers of Ukraine dated July 30, 2021 No. 868. URL: https://zakon.rada.gov.ua/laws/show/868-2021-%D1%80#Text (Last accessed: 05.08.2024) [in Ukrainian].
32. How the amount of greenhouse gas emissions in Ukraine changed over 30 years. Ministry of Environmental Protection and Natural Resources. URL: https://www.facebook.com/EnvironmentalofUkraine/posts/563957175840064?ref=embed_post (Last accessed: 05.08.2024) [in Ukrainian].
33. Association agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their member states, on the other hand. Editorial office dated 11.30.2023. Verkhovna Rada of Ukraine. URL: https://zakon.rada.gov.ua/laws/show/984_011#Text (Last accessed: 05.08.2024) [in Ukrainian].
34. Low-carbon development strategy of Ukraine until 2050. Ministry of Environmental Protection and Natural Resources of Ukraine. URL: https://mepr.gov.ua/diyalnist/napryamky/zmina-klimatu/pom-yakshennya-zminy-klimatu/strategiya-nyzkovugletsevogo-rozvytku-ukrayiny-do-2050-roku/ (Last accessed: 05.08.2024) [in Ukrainian].
35. The European Green Deal. URL: https://ecoaction.org.ua/zaoshchadzhuj-u-majbutnomu.html?gad_source=1&gclid=Cj0KCQjwgrO4BhC2ARIsAKQ7zUnXUWrnDIPAZa4dgi5V0bPy4rITfAtfw5BDxtze8up0vrKMgfb6Xx4aAo-8EALw_wcB (Last accessed: 05.08.2024) [in Ukrainian].
36. Sudarikov, O. (2024). Analysis of factors influencing electricity consumption upon the implementation of the "green" energy transition concept in Ukraine by 2050. *Systems Research in Energy*, *3*(79), 70–79 [in Ukrainian]. https://doi.org/10.15407/srenergy2024.03.070
37. Ukraine must reduce CO2 emissions by 65% by 2030: A resolution of the Cabinet of Ministers. *Interfax.ua.* URL: https://ua.interfax.com.ua/news/greendeal/758991.html. Name from the screen. (Last accessed: 20.05.2024) [in Ukrainian].
38. On Amendments to Certain Laws of Ukraine Regarding the Restoration and Green Transformation of the Energy System of Ukraine: Law of Ukraine. (2023). Information of the Supreme Council, 82, 301. URL: https://zakon.rada.gov.ua/laws/show/3220-20#Text (Last accessed: 05.08.2024) [in Ukrainian].
39. Malyarenko, O.E., Maistrenko, N.Yu., & Stanitsyna, V.V. (2024). Predictive scenarios of heat energy consumption in the economy of Ukraine in wartime realities. A collection of scientific papers of the 20th International Scientific and Practical Conference "Heat Energy: Ways of Renovation and Development" (pp. 176–181). Kyiv. https://doi.org/10.48126/conf2024

# ФАКТОРИ ВПЛИВУ НА ПРОГНОЗ ЕНЕРГОСПОЖИВАННЯ КРАЇНИ В УМОВАХ ВІЙНИ ТА ОБСЯГИ СКОРОЧЕННЯ ВИКИДІВ ПАРНИКОВИХ ГАЗІВ

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**Анотація.** *У статті виділено три основні фактори, які впливають на формування прогнозу споживання ПЕР в економіці України. Це структурні зрушення в її економіці, зміна структури енергоспоживання (споживання палива) в Україні, обсяги та напрями скорочення викидів парникових газів (ПГ) в умовах дотримання міжнародних угод стосовно обмежень їх викидів. Розглянуто консервативний сценарій розвитку економіки країни. Він передбачає помірне відновлення, коли економіка буде зростати до 2,5 % на рік. Такий темп вибраний за умови продовження збройної агресії росії проти України та закінчення активної фази бойових дій до кінця 2025 року. Досліджено зміну структури економіки за час російської військової агресії проти України. Визначено напрями подальшого розвитку ключових секцій економіки. Висвітлюються стратегічні заходи для зменшення викидів ПГ, в першу чергу в промисловості та в енергетичному секторі зокрема. Зменшення споживання палива по видах промислових секторів в Україні буде досягнуто через впровадження енергоефективних технологій та процесів, спрямованих на зменшення енерговитрат у виробництві, перехід до використання більш екологічних джерел енергії, таких як відновлювані джерела енергії (сонячна, вітрова, гідроенергія); модернізацію промислових об'єктів та устаткування з метою зменшення витрат палива; впровадження програм енергозбереження та стимулювання енергоефективності в промисловості; реформування енергетичного сектору та підвищення енергетичної ефективності в цілому. За Оновленим національно визначеним внеском України до Паризької угоди (НВВ2) у 2021 р. країна зобов'язалася досягти зменшення до 35 % від рівня 1990 року викидів парникових газів до 2030 року та перейти до енергоефективних і низьковуглецевих технологій. Найперший НВВ передбачав скорочення Україною викидів $CO_2$ на 40 % до 2030 року, не враховуючи агросектор та лісове господарство.*

**Ключові слова:** структура економіки, енергоресурси, структура енергоспоживання, прогнозування, парникові гази.

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