https://doi.org/10.15407/scine18.06.003

HEYETS, V. M. (https://orcid.org/0000-0002-2895-6114),
PODOLETS, R. Z. (https://orcid.org/0000-0002-3276-5505),
and DIACHUK, O. A. (https://orcid.org/0000-0002-3281-6536)
Institute for Economics and Forecasting, National Academy of Sciences of Ukraine,
26, P. Myrnoho St., Kyiv, 01011, Ukraine,
+380 44 280 1234, gvm@ief.org.ua

POST-WAR ECONOMIC RECOVERY OF UKRAINE IN THE IMPERATIVES OF LOW-CARBON DEVELOPMENT

Introduction. *Despite uncertain terms and conditions of the post-war economic recovery of Ukraine, the resource-intensiveness and complexity of this task, its successful realization will create unique opportunities for the implementation of essential institutional reforms and radical structural economic transformations. Priorities and effective implementation mechanisms of such recovery policy shall be formulated with a consideration of the regional and global trends in socio-economic and societal transformations, such as transition to the low-carbon (carbon-neutral) development model.*

Problem Statement. *The adoption of the national target on reducing GHG emissions in accordance with an updated Nationally Determined Contribution to the Paris Agreement has set quantitative targets for the low-carbon development for Ukraine. The next important task is to formulate the imperatives of thegovernment policy, as well as to identify the tasks and measures aiming at achieving the stated goal and the effective inclusion of Ukraine into the EU Green Deal during the post-war recovery.*

Purpose. *The purpose of this research is to estimate targeted transformations of the energy and electricity balances and corresponding macroeconomic effects.*

Material and Methods. *The effects ofachieving the climate goals have been evaluated in terms of economic factors, with the use of TIMES-Ukraine linear quasi-dynamic optimization energy system model.*

Results. *Energy efficiency and renewable energy deployment, technology modernization with the corresponding redirection of investments in low-carbon technologies, as well as development of competitive integrated energy markets have been proposed as the main pillars of decarbonization of Ukraine'seconomy.*

Conclusions. *Although the energy sector will play a key role in the post-war "green" recovery of Ukraine's economy, the attention of the government shall not be limited within the sectoral framework, as the relevant effects are closely related to financial, social, fiscal, competitive, and infrastructure policies.*

Keywords: economy, energy, climate change, low-emission development, decarbonization, and competitive ability.

Citation: Heyets, V. M., Podolets, R. Z., and Diachuk, O. A. Post-War Economic Recovery of Ukraine in the Imperatives of Low-Carbon Development. *Sci. innov.*, 18(6), 3—16. https://doi.org/10.15407/scine18.06.003

As a result of the war unleashed by the Russian Federation (RF) and the acute phase of hostilities, there has been reported a daily increase in the casualties, which is the most terrible, along with the mass suffering of the entire population, industry, and infrastructure of Ukraine. Currently, there have been no serious signs of ending or, at least, suspending the military intervention of the Russian Federation.

Consequently, there has been reported a reduction in the gross domestic product (GDP) of Ukraine, which is caused by:

- deteriorating quality of the human capital due to psychological injuries and the risk of loss of life;
- destruction of production facilities, housing stock, as well as nonresidential, transport, and social infrastructure;
- the limited use of the national land fund as a result of its partial occupation, as well as damages caused by mining, shelling, and pollution of Ukrainian territories;
- a reduction in the labor force employed in industry;
- a decrease in the consumer spending of the population;
- the reorientation of national budget expenditure in favor of areas that are not directly related to GDP production;
- growing inflation, debt, and devaluation of the national currency;
- direct and related investment losses;
- rising prices for energy resources.

Ukraine's direct and indirect losses will also be determined by global factors, such as a world economy recession as a result of the disruption of established commodity and sales chains, the rise in prices for energy resources and other raw materials, in particular, because of increasing general international risks, level of world confrontation, and defense costs.

Given these threats, international organizations and expert groups have estimated a decline in Ukraine's economy in 2022.

In its report for March, the International Monetary Fund (IMF) has projected that in 2022 the real GDP of Ukraine would drop by 10% [1], provided the war comes to end in a short run and the donors provide Ukraine with a significant financial aid. Otherwise, the annual GDP dropmight reach 25—35% (based on the data on real GDP decline during similar military conflicts in Iraq, Lebanon, Syria, and Yemen). According to the estimate of the IMF Deputy Executive Director for Ukraine, Ukraine's annual losses might account for 35% [2].

According to this IMF report, Ukraine's budget deficit is expected to increase by 3% of GDP, in 2022. The recession will lead to a drop in the tax revenues of about 4% of GDP, as compared with 2021. With such an increase in the budget deficit, given the already provided financial support from the IMF (USD 4.5 billion), there remaining budget deficit amountsto USD 7.4 billion (4% of GDP).

After the commencement of the military invasion of Ukraine, the international rating agencies have significantly downgraded Ukraine's sovereign ratings:

- Fitch Ratings (February 25, 2022): from "B" to speculative "CCC" (the highest is "AAA," the lowest is "D"), which worsens the investment rating of government bonds [3];
- Standard & Poor's (February 25, 2022): from "B" to "B-" (the highest is "AAA," the lowest is "D");
- Moody's (March 4, 2022): from "B3" to "CAA2", assuming that Ukraine's existing financial buffers and expected international financial aid are not sufficient to fully compensate for the liquidity risks associated with Ukraine's need of borrowings during the war [4].

This not only significantly complicates Ukraine's access to international capital markets, but also increases its economic losses because of significantly deteriorating business environment and growing capital outflow.

The national estimates of Ukraine's economic losses as a result of foreign intervention are also threatening. According to the estimates of the Minister of Finance of Ukraine, a half of the domestic GDP falls on the ten regions where active

hostilities are going on, as a result of which the losses might range from 33% to 50% [5]; so far, the one-time direct losses caused by the warhave exceeded USD 600 billion [6].

The economic losses from hostilities in the post-Soviet republics have been estimatedwith the use of 4 methods. The economic losses of Georgia as a result of the military conflict with the Russian Federation, which lasted eight days in 2008 and caused a limited damage to the Georgian infrastructure, are estimated at about USD 2 billion [7]. The complexity of more accurate calculations is explained by the global financial and economic crisis that took place shortly after the end of hostilities in Georgia. In 2009, its GDP dropped by 3.7% [8]; the GDP per capita fell by 15.7% [9]. Armenia's GDP declined by 7.4%, in 2020, as a result of both the six-week military conflict with Azerbaijan and the global decline in business activity because of the unfolding COVID-19 pandemic. In the first active phase of the Russian-Ukrainian war (March 2014 — February 2015), Ukraine's GDP decreased by 10.1%, in 2014, and by 9.8%, in 2015 [10].

UKRAINE' ECONOMIC LOSSES, AS ESTIMATED BY THE INSTITUTE FOR ECONOMICS AND FORECASTING OF THE NAS OF UKRAINE

The estimates are based on the extrapolation of the conditions and losses reported for the first active phase of the Russian-Ukrainian war (March 2014 — February 2015).

According to these estimates, in 2022, the real GDP may fall by 45%, the gross fixed capital formation may decrease by more than 80%, and the production in industry may decline by 52% [11].

All the options are extremely alarming, each leading to an unequivocal conclusion that, in addition to the existing humanitarian, military, and financial aid, Ukraine and its population need serious help from the international community in many areas of the country's life to restore the economy.

The estimates based on the scenario of a reduction in electricity consumption

The assumption of a high correlation between electricity consumption and Ukraine's real GDP has been used to estimate possible changes in the real GDP in 2022 under the two scenarios: 35% and 50% drop in electricity consumption.

The results have shown that the corresponding drop in the GDP of Ukraine in 2022 may amount to:

- 17.9—22.4% for the first scenario;
- 25.6—33.1% for the second scenario.

The estimates based on the assumption of some regions of Ukraine being prevented from the normal process of economic reproduction

Given the uneven spread of hostilities in the country, it has been assumed that 14 regions remain "conditionally unscathed." At the same time, 10 oblasts (Donetsk, Zhytomyr, Zaporizhzhia, Kyiv, Luhansk, Mykolaiv, Sumy, Kharkiv, Kherson, and Chernihiv) and the city of Kyiv are considered to be prevented from the normal process of economic reproduction. With the use of the mentioned approach it has been shown that the economic losses of Ukraine in annual terms may reach 46% of GDP.

Today, both national experts, researchers, employees of government bodies, and foreign specialists have been already making analytical preparatory effortsfor providing assistance to Ukraine. In particular, along with the recognition of the necessity of supporting Ukraine by the international community, attention is focused on the fact that in the world, in addition to the terrible consequences of the war, there are other equally important challenges for humanity. For example, Professor of the Kozminski University in Warsaw, Former Minister of Finance of Poland and foreign member of the National Academy of Sciences of Ukraine Grzegorz Kołodko, while saying that Ukraine recovery needs a debt write-off and help from the EU and China, alsonotes that the EU plans to spend hundreds of billions on the re-

covery of the EU countries' economy after the pandemic. The transformation of energy and the transition to renewable energy sources will be costly as well, because the EU shall not deviate from the agreements reached at the last COP26 summit to combat global climate change. Even in such an emergency situation as war, one cannot forget that climate change is the greatest challenge facing humanity [12].

Under such conditions, the expenditure on the transformation of the energy sector through its transition to renewable sources, which will be implemented in the EU in parallel with the recovery and restructuring of the economy in the post-war period, including at the expense of EU funds, shall be considered given Ukraine's contribution to the fight against climate change for recovery, which was made without taking into account both European and global practice. The restoration and restructuring of Ukraine's economy shall be harmonized with the global climate policy, first of all for Ukraine to be granted with the status of a candidate for accession to the European Union and to getthe membership in the future, in accordance with Ukraine's statement of February 28, 2022. Since the European Commission will analyze Ukraine's application in terms of its ability to meet the criteria established by the European Council in Copenhagen, in 1993, as well as those defined in Madrid, in 1995, it is expected that in this case the candidate country will develop administrative structures, thanks to which the EU will be able to integrate Ukraine, as a new member, into the EU. Obviously, their activities will be directly related not only to those processes that have been already taking place in the EU, but also to those that will take place in the course of changes, in particular, in the context of combating climate change and ensuring a low-carbon path of development, which has already been defined and will be implemented in the future. Insofar as this strategy is developed for the period up to 2050 and beyond, for Ukraine, it is a rather logical wayto restore and restructure its economy in the post-war period in accordance with this strategy.

In July 2021, Ukraine approved a national contribution to the Paris Agreement [13], which was developed on the basis of research carried out at the Institute for Economics and Forecasting of the NAS of Ukraine (IEF of the NAS of Ukraine) and presented at the UN Climate Change Conference (COP26) in 2021, in Glasgow (Scotland), which defined the climate agenda in the context of global trends and economic development imperatives.Such imperatives were also formulated as part of the research of the Institute for Economics and Forecasting of the NAS of Ukraine and presented by Full Member of the NAS of Ukraine Valerii Heyets as part of his report *Economy of Ukraine in the Imperatives of Low-Carbon Development* at the general meeting of the NAS of Ukraine on February 17, 2022.

The authors of this research are convinced that the main points of this report, its content and nature (of course, except for some absolute values of the forecast estimates) have been as relevant as before the Russian aggression, since in the post-war period, Ukraine's economy shall be restored and restructured in concordance with the changes expected in the world, Europe, and Ukraine.

CONCEPTUAL PRINCIPLES OF LOW-CARBON DEVELOPMENT FOR UKRAINE

Even in the pre-war period, the state of energy sector and environment in Ukraine was characterized by a problematic situation, which posed threats to the sustainable energy supply of the economy and the environment. The problematic situation may worsen in the future. In fact, it has aggravated because of the war, which has reduced the potential of Ukraine's economy and requires the intensification of the formation of low-carbon development.

Low-carbon development is fundamentally conditioned by the need to renew the global climate order as a common value of humanity, since, in fact, the ideology of low-carbon development and its implementation gives humanity the opportu-

nity to breakthrough into a safer future symbolized as climate stability. In order to achieve it and to stop the existing trends of climate change, which threaten the existence of all living things, it is necessary, while decarbonizing the economy, to achieve efficient energy consumption in most industries, agriculture, transport, infrastructure, including housing, as well as in the behavior of the population of cities and villages. As a result, the formation of a new behavior of business entities is expected to transform their activities, where the economy modernization will be basedon efficiency and social responsibility. A characteristic feature of such principles for the government, business, and citizens, along with profitable activities, is the focus on the formation of public goods as a common value.

The transition to carbon-neutral development foresees and stimulates the eventual formation of a carbon-neutral economy that is the imperative which reflects the content of the prescriptions in terms of general obligations, the implementation of which on a low-carbon basis will allow achieving climate neutrality in accordance with the sustainable development goals of the UN and the key requirements of the Paris Climate Agreement, to which 190 countries of the world have joined.

The Paris Agreement adopted in 2015 defines the goal of limiting the global increase in the average temperature to 1.5 °C, as compared with the pre-industrial period of development. As a means of achieving this result, it assumes to implement measures and technologies aiming at maximally reducing the manufacture of products and services, which requires the use of fossil fuel, and consequently, at reducing greenhouse gas (GHG) emissions.

The Paris Agreement became possible because, in general, it was in line with the development plans of the leading advanced economies, since they were the main consumers of energy and GHG emissions. In most cases, such plans were partially related to combating climate change; instead, they were aiming at reducing the dependence on conventional energy sources and local pollution, as well as at creating new jobs and so on.

The Paris Agreement sent a signal to the whole world about the inevitability of "low-carbon future". As a result, all economic agents were warned about the need to adapt themselves to such a future and to move to a new level of competitiveness, stimulating economic growth on a new technological basis.

Technological and technical conditionality of low-carbon development, at the same time, is a necessary but insufficient condition for its implementation. The sufficient condition is the creation of new forms of social reality, in which, first of all, the relationship between separate individuals and society should be transformed through changing the individual psyche and behavior of the individual with respect to the surrounding people and the environment as a whole.

This is conditioned by the results of the relationship between the individual and the people around him/her, who form his/her psyche that is determined by social reality and in which he/she is formed and develops both as an economic and as a social subject. Psyche, being a result of the existence of the individual, forms the ability to perceive the integrity of the surrounding environment, because, the personality is a socially determined, socially receptive, corporeal being endowed with all kinds of forces and abilities for socially conditioned action. Given that climate change has reached criticality in terms of the formation of a threat to existence, the preservation and renewal of life is a common value that is determined by the priority of the future life activities in the context of not only self-regulation, but also social inclusiveness, the achievement of which requires strong organization, careful long-term planning and implementation, consistent actions over many years, large-scale financing that is possible thanks to joined efforts and political power that can be obtained through joint actions [14].

Based on the above-mentioned ideology of success on the way to low-carbon development, as an imperative based on the key requirements of the Paris Climate Agreement, there were formed undertakings both to develop and to implement in

the signatory countries a long-term low GHG emissions development strategy, which covers both low-level emissions and absorption of those accumulated artificially and naturally.

Since the signing of the Paris Agreement, low-carbon development of the economy is an irreversible trend that marks *a new quality and style of life for all economic subjects*: individuals, households, firms, national economies (states), and global society. *Assuming the formation of new forms and the transition to a new level of competitiveness, unless appropriate material, social, and financial assistance is in place, low-carbon development may result in the further stratification of society within individual countries and at the global level, the growth of poverty, the emergence of new depressed regions, obstacles to the activation of economic growth, and the intensification of the competitiveness of economic entities at various levels.*

Low-carbon development, the strategic goal of which is to ensure that the global temperature increase does not exceed 1.5 °C by the end of the century, significantly reduces the risks of negative consequences, but is not able to completely prevent climate change. At the same time, solving the problem of climate change is a vital, but neither sufficient (nor even always main) condition for minimizing all environmental risks, as in a broad context, climate change reflects only part of the risks for economic growth and development, for people's lives and health. This is evidenced by the goals of sustainable development, as adopted by the world community, which, in addition to measures for combatting climate change and their consequences, include 16 more global objectives aiming at harmonizing its economic, social and environmental components. *Thus, unless they are achieved in coordination with other tasks, such as, in particular, promoting inclusive sustainable economic growth, full productive employment and decent work for all, neither the problem of climate change may be adequately considered, nor its solution may be realistic and effective.* Therefore, given the potential risks of negative manifestations of climate change in Ukraine and based on the "letter and spirit" of the Paris Agreement, we have proposed to formulate *the concept of low-carbon development in Ukraine as a policy aiming at reducing the climate risks of the socio-economic development of Ukraine, which combines the measures to adapt the population and the economy to the negative manifestations of climate change, as well as the measures to prevent man-made impacts both in terms of global climate-forming conditions and factors, and in certain types of activities, including the personalized activity of the population.*

Climate regulation requires the unification of national and supranational approaches for the following reasons:

- the efforts of one country are not enough;
- there is differentiation in consumption, including excessive consumption both in individual countries and in individual social groups;
- there is property and resource stratification;
- there is and will becashless travel effect;
- supranational regulation has a priority over national regulation.

At the same time, the national climate policy is ineffective unlessit is directly requested by society, and the citizens consciously agree to certain financial losses for the sake of implementing specific environment and climate measures. Decisions imposed from above by international obligations or central authorities in the absence of public perception of the importance of the climate change problem may remain declarative and not implemented in everyday life.

The imperatives of low-carbon development of a global nature (Table 1) include the so-called "direct" imperatives corresponding to the Sustainable Development Goals of the UN and the "derived" imperatives specified in the Paris Agreement of 2015, as presented below.

Based on the direct and derived imperatives, targeted measures have been defined (column 3, Table 1), the implementation of which aims at fulfilling the obligations assumed by the countries that signed the Paris Agreement. These imperatives describe what needs to be done, i.e. ne-

cessary conditions. The imperatives that determine how this can be done are sufficient ones.

As part of the imperative to ensure low-carbon development in the world, the following measures were discussed at the UN Climate Conference in November 2021, in Glasgow:

- no subsidies and financing of fossil fuels;
- no construction of new coal-fired power plants;
- shifting the burden of paying for carbon emissions from taxpayers to polluters;
- mandatory disclosure of information about climate-related financial risks;
- integration of carbon neutrality goals into all economic and fiscal decisions.

Figure 1 presents the dynamics of obligations to reduce GHG emissions in the world, the EU, and Ukraine, given the updated NDC, which is Ukraine's obligation to the international community. The analytical data that are taken as a basis for formulating the updated NDC are developed at the IEF of the NAS of Ukraine, within the framework of *R&D, Economic and Environment Principles of Low-Carbon Development of Ukraine* joint project of the Department of Energy, the Department of Earth Sciences, and the Department of Economics of the NAS of Ukraine, in 2019—2021, and with the involvement of international experts within the framework of the EBRD project *Supporting the Government of Ukraine in Updating the Nationally Determined Contribution*. The information and analytical system based on the TIMES-Ukraine model developed at the IEF of the NAS of Ukraine has been used for the calculations. Regarding the later deadlines for reducing emissions for Ukraine, as compared with the EU countries, so far there has been only one statement at the highest political level, at the Summit of Climate Ambitions, about

Table 1. **Imperatives and Target Measures of Low-Carbon Development**

Direct imperatives (UN Sustainable Development Goals)	Derived imperatives	Target measures
To take urgent measures to combat climate change and its consequences (reduction of net GHG emissions (absorption can and should be increased)	Decarbonization in the sectors of final consumption: total technology modernization and upgrade of production facilities, premises, and vehicle fleet	Development of non-carbon energy (RES, nuclear)
To promote progressive, inclusive, and sustainable economic growth, full and productive employment and decent work for all (fair transition)	Abandonment of fossil fuels (or their use together with carbon capture, storage and use technologies). Large-scale electrification	Change of the investment policy of financial institutions, "low carbon" consideration in public procurement
To ensure access to inexpensive, reliable, sustainable and modern sources of energy for all	Increasing and redirecting investments in low-carbon technologies	Closing coal mines, decommissioning coal and other thermal generation
To ensure the transition to efficient models of consumption and production	Prioritization of R&D and innovation (to reduce the investment burden and to increase the competitiveness of the economy)	Use of the potential of energy efficiency
To create sustainable infrastructure, promote comprehensive and sustainable industrialization and innovation	Rationalization (reduction) of energy consumption	Introduction of strict control over emissions, introduction of administrative and market incentives to reduce GHG emissions
	Competitive integrated energy and fuel markets; developed market infrastructure	
	Sustainable carbon-neutral agriculture, land and forest use	Reduction of the personified carbon footprint

Source: developed by the authors.

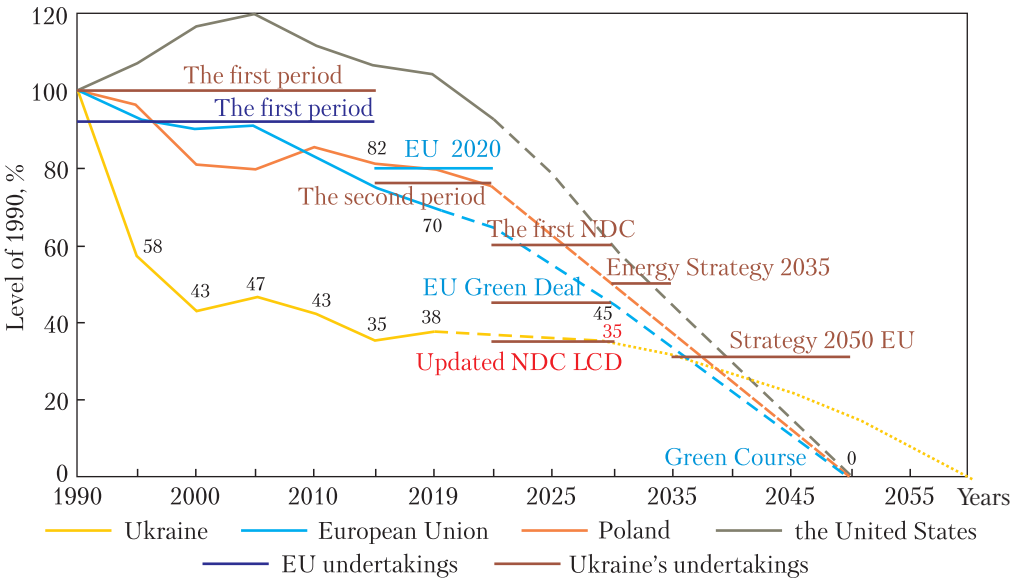

Fig. 1. International undertakings to reduce GHG emissions
Source: developed by the authors.

achieving the climate-neutral level of emissions by 2060 [15] (in the EU Green Deal it is expected to reach this level by 2050).

In low-carbon development, there should be related economic growth and reformatting of the energy system based on new technologies that today have a high level of capital intensity. Unless this capital intensity is reduced in the coordinates of the existing financial system, the implementation of low-carbon development is quite problematic.The current studies have shown that even with a dynamic decrease in the capital intensity of energy technologies, in the period 2035—2040, *the world energy costs will increase from the current 8% to almost 30% of world GDP* [16]. This will limit the possibilities of transition to low-carbon development while simultaneously ensuring the growth of the economy as a whole, since increasing the GDP capital intensity to such a level is quite problematic both in the world and in Ukraine. Thus, according to our estimates, for the implementation of the updated NDC, it is necessary to attract additional capital investments of about EUR 102 billion. At the same time, if according to the baseline scenario, the average annual capital investments for 2021—2030 will make up 18—20% of GDP, then given the goals of the updated NDC, the capital investments should increase to 23—25% of GDP.

This means that the mobilization of necessary capital investment in the energy sector and related activities requires an increase in the norm of accumulation in Ukraine, according to the NDC scenario, to 23—25%, i.e. by 6 percentage points, and given the additional costs for economic growth in the existing activities that are critically carbon-intensive, the norm of accumulation should reach, at least, 25—26% of GDP. Ukraine's GDP has not had such a level of capital intensity for a long time. Thus, for the period from 2016 to 2020, inclusive, the capital investments in Ukraine in terms of GDP amounted to 15.5% with a downward trend. In particular, in 2020, this index accounted for 12.1%. *As a conclusion, in Ukraine, the period of achieving economic growth on a low-carbon basis requires a change in both economic and energy policy*, thanks to which capital investments will increase, at least,by 10 percentage points in terms of GDP and bespent on low-carbon development of the economy and energy sector. Given

the need to ensure economic growth in carbon-neutral activities and, accordingly, investment in it, the above-mentioned share of capital investments in GDP will have to be raised to 28% and even 30%. This is a fairly significant level, and it will not be easy to reach it without special stimulating measures.

TARGET CHANGES IN THE ENERGY BALANCE

The main directions of decarbonization of the economy are energy efficiency and the development of renewable energy sources (RES). The energy efficiency potential in all sectors of the economy is estimated at 30—40% of the energy consumed; the realization of this potential will allow maintaining the consumption in 2050 at the level of 2020. Carbon-intensive fossil fuels (coal, oil) should be replaced by less carbon-intensive (gas), nuclear and hydropower, new synthetic and renewable energy sources (wind and solar energy, hydrogen, biofuel). The share of fossil fuels will decrease to 10—15% in the structure of total primary energy supplies (TPES), but their use will be limited to non-energy consumption (as raw materials) or will involve the use of carbon capture technologies.

According to our estimates, the target changes in the energy balance of Ukraine are as follows:

- the realization of the *energy efficiency* potential should ensure that the pre-war primary supplies will not be exceeded by 2050;
- *the role of natural gas, nuclear, and hydropower* will remain or even increase until 2030, which confirms the need to increase investments in increasing domestic production and infrastructure development;
- *the share of renewable energy sources* (together with hydro) should reach, at least, 17% in the TPES, by 2030 (6.6%, in 2020) and 33%, in 2050;
- the gradual abandonment of the use of coal *actualizesthe problem of employment and just transition in coal regions*;
- until 2030, *hydrogen and other new types of fuel will not play a significant role in the energy balance*.

Accordingly, the GHG emissions *in the fuel production and supply sector of Ukraine* by 2030 are expected*to decrease by 17%, as compared with 2019*, which will require additional investments of about *EUR 8 billion*. The directions of measures in this sector are as follows:

- relatively keeping demand for fossil fuels until 2030 will lead to increased attention towards sectoral measures on energy efficiency and decarbonization;
- preventing (reducing) methane leaks during extraction, processing, transportation, and storage of natural gas, oil, and coal (reducing natural gas losses during transportation by 80% as compared with 2015);
- modernizing underground gas storage facilities in accordance with standards and requirements;
- using geothermal energy of depleted oil and gas wells.

The decarbonization of *Ukraine's electricity sector* has ambitious goals: reducing GHG emissions by 30% as compared with 2019 will require capital investments of *EUR 26 billion*. Table 2 provides the estimated structure of electricity production in Ukraine in comparison with the global trends and the goals of the Green Deal declared in the EU for the period until 2050, according to the baseline scenario and the scenario of low-carbon development (or the scenario of the updated NDC for Ukraine). While doing the estimates, we assumethat the decarbonization of electricity and heat production is the key to achieving carbon neutrality in the final consumption sectors; in turn, the decarbonization in the final consumption sectors and the development of the production of synthetic fuels imply*a multiple increase in power generation*: 2.7 times in the world, 1.3 times in the EU. It is expected that by 2030, the share of carbon-free electricity generation in the world will reach 70%, and the increase in the share of RES generation will require a redesign of the electric power system (the creation of necessary

amount of reserve capacities, energy storage systems, the development of distributed generation, "smart grids", etc.).

The challenges on this path will be as follows:

- ensuring the readiness of the energy system for a multiple increase in electricity production;
- decommissioning of coal-fired thermal power plants after 2030 until 2050;
- intensively developing solar and wind generation;
- maintaining (building up) the potential of nuclear and hydropower;
- priority development of highly efficient cogeneration;
- building energy conservation systems (industrial electricity storage) for primary regulation, frequency equalization, and integration of RES generation;
- developing "smart grids" and distributed generation.

Private investments should be the main source of financing for the development of the electricity and heat energy sector. The green tariff (perhaps, revised) should continue stimulating investment in small renewable energy. Increasing private investments in the development of renewable energy of Ukraine shall ensure:

- the further improvement of the electricity market operation;
- the abolition of price subsidies for energy production and supply, while maintaining targeted subsidies for vulnerable consumers;
- the introduction of market tariffs for electricity and heat;
- the introduction of predictable and competitive auctions for the construction of RES facilities;
- the creation of a reliable financing environment for investors in Ukraine.

DEVELOPMENT OF ENERGY MARKETS

Achieving the goals of a carbon-neutral economy necessitates the continuation of energy policy regarding the formation of liberalized, integrated, competitive, and efficient energy markets.

Efficient prices are an important feature of competitive markets, which provides appropriate

Table 2. **The Current and Prospective Structure of Electricity Production by Type of Primary Fuel, in the World, the EU, and Ukraine,** *%*

	World			European Union		Ukraine		
	2020	2050[i]	2050[2]	2020	2050[3]	2020	2050[4]	2050[5]
Coal	35.4	13.5	0.9	13.7	0.6	27.0	27.6	0.0
Natural gas	23.4	18.1	1.3	20.1	16.6	9.6	6.8	7.2
Petroleum products	2.8	0.7	0.0	1.8	0.1	0.2	0.0	0.0
Nuclear power	10.1	7.9	7.7	24.6	22.0	51.4	44.8	40.3
Hydropower	16.2	14.4	11.9	13.5	41.9	5.1	4.5	3.3
Wind energy	6.0	18.9	34.8	14.3		2.2	1.3	26.7
Solar energy	3.1	20.7	33.0	5.2		4.0	9.4	16.2
Biofuel	2.6	4.0	4.6	6.8	11.3	0.5	1.6	5.0
Other fuel	0.4	1.8	5.8	0.0	7.5	0.0	4.0	1.3
Power generation, bln kW	26 762	46 703	71164	2 904	3 612	148	266	372

Source: [1] Baseline scenario (Stated Policies Scenario) [17]. [2] Carbon-neutral scenario (Net Zero Emissions by 2050 Scenario) [17]. [3] EU Green Deal scenario [18]. [4] Baseline scenario. Estimates of IEF of the NAS of Ukraine. [5] Low-carbon development scenario. Estimates of IEF of the NAS of Ukraine.

signals for changing the behavior of market participants. Effective prices on competitive markets require an increase in the transparency of pricing conditions, the abolition of established approaches to subsidizing fossil energy resources, and the consideration of harm to the environment and human health. This leads to a change in the pricing model and, ultimately, to an increase in the competitiveness of RES. At the same time, such a model provides effective signals for market entities who, in competitive markets, are always interested in maximizing their income or minimizing costs by rationalizing energy consumption, implementing energy-efficient measures, investing in innovation and R&D. An integral part of the development of competitive energy markets in the context of decarbonization is the development of the emission trading scheme, which also contributes to the growth of effective competition. Ultimately, effective competition is able to provide the necessary signals to all market actors regarding the decarbonization of other sectors that are more difficult to decarbonize (heat supply, transport, industry), at this stage of technological development.

Competitive integrated markets of energy resources are a necessary condition for the effectiveness of market mechanisms. As sufficient conditions, it is necessary to form effective pricing of energy resources, which provides appropriate signals to optimize the behavior of market entities; to ensure competition between energy sources (energy technologies), which allows optimizing investments in innovation and the development of clean energy sources, as well as ensuring competition in the field of reducing GHG emissions by implementing energy efficiency measures. It is also necessary to provide expanded coverage of the components of the price of energy resources by taking into account the costs caused by the impact on the environment, human health, and adaptation to climate change.

In the last years of the reform of Ukraine's energy market according to the European model, the national markets have undergone significant transformations caused both by therevision of the rules of trade and by the changes in political conditions, which actualized the need for diversifying, increasing the security of supply and the need to fulfill international commitments made in previous periods, primarily of ecological nature. As part of the reform of national energy markets in accordance with international obligations, Ukraine has largely implemented the norms of the Third Energy Package (TEP) into the primary legislation and continues efforts towards the harmonization of the secondary legislation with the TEP requirements. New models of electricity and natural gas markets in which competitive operating conditions are introduced in many segments have been formed.

However, the existing barriers and threats do not allow the final formation of competitive, liberalized, integrated energy markets (Table 3), mainly because of:

- administrative interference in the conditions of pricing and the absence of market pricing for all categories of consumers in all segments of the energy markets gives rise to abuses in the rules of the supply of energy resources, which leads to an increase in the burden on state finances;
- the lack of transparency in economic relations, which is a significant barrier in the implementation of government plans and programs for self-sufficiency with energy resources of domestic production.

Consequently, the consistent institutionalization of the mechanisms for achieving the goals of the Paris Agreement at the global level and the EU Green Deal at the regional level has testified to the inevitability of the transformation of the world economy to the low-carbon development model and the need for the appropriate adaptation of all economic agents to it for the transition to a new level and form of competitiveness. At the same time, without proper material, social, and financial support, proper management capacity, and scientific and expert support, the "greening" of government policy can become an obstacle on the way to revitalizing economic growth.

Determining the ways of transition to low-carbon development should be a multi-purpose complex process that, along with the tasks of reducing GHG emissions, ensures the simultaneous economic growth and social justice. In this context, the socio-economic effects of the implementation of certain processes embody the criteria for ordering the relevant decarbonization measures. The positive nature of the economic consequences should be the main indicator of adequate choice of policies, the implementation of which should aim at increasing energy efficiency and energy saving, and reducing GHG emissions, in an economically and socially acceptable way. Based on these considerations, the authors have proposed basic provisions for low-carbon development of Ukraine until 2050, given the need to expand its sectoral coverage and organizational and legal mechanisms for its implementation, in particular, taking into account the principles of technology development, fairness, environmental friendliness of investments, and inclusiveness of socio-economic reforms.

As the analysis has shown, the priorities and effects of the low-carbon development policy go far beyond the energy sector of Ukraine and are closely related to the financial (in the context of attracting funds), the social (creation of new jobs, training of highly qualified personnel), the fiscal (targeted use of tax incentives), the competitive (in particular, the production of "green" technologies), and the infrastructure (the renewal of domestic energy networks) policies. Considering such a set of interrelationships of climate, energy and related policies makes it expedient to use a complex approach to their study, including with the use of model tools, which can be observed by the examples of methodological framework for the development of program and directive documents of the EU and individual European countries. Given this experience, the authors have used a complex of adapted economic and mathematical models created at the Institute for Economics and Forecasting of the NAS of Ukraine to analyze the new climate goal of Ukraine in accordance with the approved updated nationally determined con-

Table 3. **Continuation of Market Reforms in Ukraine's Energy Sector**

	Administrative and political	Economic	Technical/engineering
Barriers	• preserving the practice of paternalistic policy; • delay in adopting the necessary regulatory and legal support (Natural Resources Code, continuation of the practice of Public Service Obligations); • delay in certification and establishment of property rights on networks; • reduction in gas transit	• non-market pricing for certain categories of consumers; • lack of incentive pricing for network operators, non-transparency of tariff formation and lack of an investment component; • debt crisis of non-payments for the feed-in tariff and imbalances; • ineffective subsidy system that does not encourage energy efficiency	• wear and tear of networks and significant production and process losses; • unpreparedness of the energy system of Ukraine to growing share of variable renewable generation; • the need for redesign of networks for current and expected consumption; • synchronization of Ukraine's energy system with ENTSO-e
Threats	• outflow of foreign counterparties from energy markets of Ukraine; • decreasing trust in Ukraine and support from European and international institutions; • freezing of Ukraine's European integration aspirations and rollback of reforms	• breach of energy supply rules and the practice of discriminatory pricing; • redistribution of network maintenance costs between domestic consumers and transit ones; • energy poverty and the growth of non-payments for communal services	• increase in the number of emergency situations; • unbalancing of Ukraine's power system and emergency power cut-offs; • growing pressure of network maintenance costs on consumers

Source: developed by the authors.

tribution to the Paris Agreement. The use of such a model complex in the future makes it possible to formulate consistent goals, tasks, and a package of sectoral measures for decarbonization, given the inter-industry relations in the energy sector, as well as the identified priority areas and macroeconomic regulatory measures aiming at the development of Ukraine's economy.

REFERENCES

1. Ukraine: Requestfor Purchase under the Rapid Financing Instrument and Cancellation of Stand-by Arrangement-Press Release; Staff Report; and Statement by the Executive Director for Ukraine. IMF Country Report. No. 22/74. March, 2022. URL: https://www.imf.org/en/Publications/CR/Issues/2022/03/10/Ukraine-Request-for-Purchase-under-the-Rapid-Financing-Instrument-and-Cancellation-of-Stand-514148 (Last accessed: 04.07.2022).
2. What happens to the Ukrainian economy during the war — radio NV interview. URL: https://biz.nv.ua/ukr/economics/shcho-vidbuvayetsya-z-ukrajinskoyu-ekonomikoyu-pid-chas-viyni-interv-yu-nv-50226235.html (Last accessed: 04.07.2022).
3. Ukraine CreditRatings: Fitch Ratings. URL: https://www.fitchratings.com/entity/ukraine-80442268#ratings (Last accessed: 04.07.2022).
4. Moody's downgrades Ukraine's ratings to Caa2 from B3, ratings remain on review for downgrade. 4 March, 2022. URL: https://www.moodys.com/research/Moodys-downgrades-Ukraines-ratings-to-Caa2-from-B3-ratings-remain--PR_463451(Last accessed: 04.07.2022).
5. Interview of Minister of Finance Serhiy Marchenko to Forbes (14.03.2022). URL: https://mof.gov.ua/uk/news/interviu_ministra_finansiv_sergiia_marchenka_vidanniu_forbes_14032022-3361(Last accessed: 04.07.2022).
6. Losses for Ukraine due to the invasion of the Russian Federation exceed $500 billion — Shmyhal (16.03.2022). URL: https://interfax.com.ua/news/economic/814088.html(Last accessed: 04.07.2022).
7. Economic consequences of the Georgian-Russian conflict conflict: Press Release. Vienna Institute for International economic studies. URL: https://wiiw.ac.at/press-release-economic-consequences-of-the-georgian-russian-conflict-english-pnd-19.pdf(Last accessed: 04.07.2022).
8. World Bank national accounts data. URL: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=GE (Last accessed: 04.07.2022).
9. How military conflicts affect the economy. Mind.ua. URL: https://mind.ua/openmind/20173685-yak-vijskovi-konflikti-vplivayut-na-ekonomiku (Last accessed: 04.07.2022).
10. World Bank national accounts data. URL: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=UA (Last accessed: 04.07.2022).
11. After estimation of losses, it is necessary to start developing a strategic plan for the reconstruction of the country. Director of the Institute for Economics and Forecasting, NASU, Valeriy Heyets spoke at the meeting of the Presidium of the National Academy of Sciences of Ukraine on March 30, 2022. URL: http://ief.org.ua/?p=12018(Last accessed: 04.07.2022).
12. Grzegorz Kolodko. Ukraine recovery needs a debt write-off and help from the EU and China. Financial Times, April 8, 2022. URL: https://www.ft.com/content/58b74ced-fed6-4fc4-978e-d54f7ada4c41 (Last accessed: 04.07.2022).
13. On the approval of the Updated Nationally Determined Contribution of Ukraine to the Paris Agreement: Resolution of the Cabinet of Ministers of Ukraine from 30.07.2021. No. 868. URL: https://zakon.rada.gov.ua/laws/show/868-2021-%D1%80#Text (Last accessed: 04.07.2022).
14. Rebecca Henderson. (2020). *Reimagining capitalism in a world on fire*. New York: PublicAffairsPress.
15. Ukraine plans to achieve climate neutrality by 2060 — Zelenskyi. URL: https://www.dw.com/uk/ukraina-planuie-dosiahty-klimatychnoi-neitralnosti-do-2060-roku-zelenskyi/a-59689062 (Last accessed: 04.07.2022).
16. Porfiryev, B., Shirov, A., Kolpakov, K. (2020). Low-Carbon Development Strategy: Prospects for the Russian Economy. *World economy and international relations*, 64(9), 15—25. https://doi.org/10.20542/0131-2227-2020-64-9-15-25 [in Russian].
17. IEA (2021).World Energy Outlook 2021. OECD Publishing, Paris. https://doi.org/10.1787/14fcb638-en
18. EU Reference Scenario 2020. URL: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en (Last accessed: 04.07.2022).

Received 01.08.2022
Revised 01.08.2022
Accepted 01.08.2022

В. М. Геєць (https://orcid.org/0000-0002-2895-6114),
Р. З. Подолець (https://orcid.org/0000-0002-3276-5505),
О. А. Дячук (https://orcid.org/0000-0002-3281-6536)

ДУ «Інститут економіки та прогнозування НАН України»,
вул. Панаса Мирного, 26, Київ, 01011, Україна,
+380 44 280 1234, gvm@ief.org.ua

ПОВОЄННА ЕКОНОМІКА УКРАЇНИ В ІМПЕРАТИВАХ НИЗЬКОВУГЛЕЦЕВОГО РОЗВИТКУ(МАКРООЦІНКА)

Вступ. Попри невизначеність термінів та умов повоєнного відновлення України, ресурсоємність та комплексність цього завдання, його успішне виконання створюватиме унікальні можливості для проведення необхідних інституційних реформ та радикальної структурної трансформації економіки. Пріоритети та ефективні механізми реалізації такої політики відновлення повинні бути сформульовані з урахуванням регіональних та глобальних напрямів соціоекономічних і гуманітарних перетворень, одним з основних серед яких є перехід до низьковуглецевої (вуглецевонейтральної) моделі розвитку.

Проблематика. Ухвалення цілі зі скорочення викидів парникових газів відповідно до оновленого Національно визначеного внеску до Паризької угоди задало кількісний вимір низьковуглецевого розвитку України. Актуальним завданням постає як формулювання базових імперативів державної політики, так і визначення завдань і заходів, спрямованих на досягнення заявленої мети та ефективного долучення України до Зеленого курсу ЄС в умовах повоєнного відновлення.

Мета. Оцінювання цільових змін структурних пропорцій енергетичного та електробалансів, а також відповідних макроекономічних ефектів.

Матеріали й методи. Оцінювання наслідків досягнення кліматичної цілі виконано з використанням прикладної лінійної квазідинамічної оптимізаційної моделі енергетичної системи TIMES-Україна.

Результати. Магістральними напрямами декарбонізації економіки запропоновано розглядати енергоефективність, розвиток відновлюваних джерел енергії, технологічну модернізацію з відповідним переспрямуванням інвестицій в розвиток низьковуглецевих технологій, а також формування конкурентних інтегрованих енергетичних ринків.

Висновки. Хоча енергетичний сектор відіграватиме ключову роль у післявоєнному «зеленому» відновленні економіки України, увага держави не може обмежуватися галузевими рамками, оскільки відповідні ефекти також пов'язані з фінансовою, соціальною, фіскальною, конкурентною та інфраструктурної політиками.

Ключові слова: економіка, енергетика, зміна клімату, низьковуглецевий розвиток, декарбонізація, конкурентоспроможність.