Chapter 12

THE GREEN DIRECTION OF UKRAINE'S DEVELOPMENT – CURRENT STATUS AND PROSPECTS FOR POSTWAR RECOVERY

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INTRODUCTION

An analysis of research and publications on sustainable development shows that there is a rather long gap between the implementation of the provisions of the Sustainable Development Concept in Ukraine and the EU countries. The period of more than ten years has led to the fact that it has become mandatory for EU countries to pay special attention to the environmental aspects of ensuring sustainable development of regions. Research on the sustainability of regional development and the circular economy has intensified in the world. Despite the conditions of military invasion, researchers in Ukraine are also paying more attention to these issues.

In turn, within the framework of sustainable development, the issues of green recovery of Ukraine with the involvement of alternative energy sources are becoming relevant.

The world is witnessing a gradual transformation of traditional individualistic values based on the concept of sustainable development of society, which combines economic, social and environmental components. For Ukraine, the conclusions and recommendations on sustainable development remain relevant during the war, although it has become almost impossible to follow them.

There are many studies related to sustainable development in the world. Among the authors who deal with the issues of determining priorities and mechanisms for accelerating, improving the efficiency and effectiveness of economic and social development are Bogush L., Vatchenko O., Ilchenko V.[1].

The issues of sustainable development of Ukraine's regions have been paid attention to by many Ukrainian scientists, including: Korolchuk O[2]., Becker

[1] Ватченко О.Б., Ільченко В.М. Механізм забезпечення сталого розвитку регіонів України. "Економічний вісник НТУУ "Київський політехнічний інститут". Науковий вісник НТУУ. 2011. Вип. 21.19. С. 205-212.

[2] Корольчук О. Безпекові аспекти соціально-гуманітарної та економічної стабільності у формуванні національної стійкості України. Право та державне управління. 2021. № 2. с. 114-118. DOI: https://doi.org/10.32840/pdu.2021.2.17.

T., Eichengreen B., Horodnichenko Y., Guriev S., [3]Watchenko O., Ilchenko V[4]., Porudieieva T. [5]and others, Shvindina G., Petrushenko Y., Balahurovska I.[6]. However, nowadays, it is of particular relevance to address the question of how to ensure sustainable development of regions affected by military aggression, taking into account modern requirements for sustainable development and compliance with the trends of the EU countries.

Sustainable development in modern conditions is understood as a model of socio-economic development that meets the vital needs of the current generation without depriving future generations of such opportunities due to the exhaustion of natural resources and environmental degradation[7]. The concept of social responsibility became the basis for the implementation of such a strategy. And the driving force was the choice of the European vector of development and the emergence of Ukraine's current need for international support in connection with the full-scale invasion.

Sustainable development of Ukraine and its regions is one of the priorities of state and regional policy. It is characterized by its ability to ensure positive dynamics of socio-economic indicators, living standards and quality of life, and to use innovative factors and conditions for this purpose.

As a result, of European integration in the pre-war period, Ukraine, like other developed European countries, chose the European Green (sustainable) course of its development[8]. Since the beginning of the full-scale invasion, despite the revision of priorities, the country has not changed its views on green ideas. These beliefs are not only supported by the government. Civil society organizations and the country's population also support this choice despite the military events.

For Ukraine, green recovery is the process of overcoming the consequences of various kinds of emergencies and/or war by improving the

[3] Беккер Т., Айхенгрін Б., Городніченко Ю. та ін. Нарис відбудови України. Лондон: Центр досліджень економічної політики, 2022. 36 с. URL: https://cepr.org/system/files/2022-06/BlueprintReconstructionUkraine_ukr.pdf (дата звернення: 26.05.2025).

[4] Ватченко О.Б., Ільченко В.М. Механізм забезпечення сталого розвитку регіонів України. "Економічний вісник НТУУ "Київський політехнічний інститут". Науковий вісник НТУУ. 2011. Вип. 21.19. с. 205-212.

[5] Порудєєва Т.В., Міхневич В.О., Єдіна Ю.Г. Стратегічні цілі забезпечення сталого розвитку регіону. Економіка і суспільство, № 19. 2018. с. 785-790.

[6] Shvindina H., Petrushenko Y., Balahurovska I. Resilient management as an effective management tool for transformational changes in society. Bulletin of V. N. Karazin Kharkiv National University. Series “International Relations. Economics. Country Studies. Tourism”. 2022. № 15. pp. 54-59. DOI: https://doi.org/10.26565/2310-9513-2022-15-06.

[7] Порудєєва Т.В., Міхневич В.О., Єдіна Ю.Г. Стратегічні цілі забезпечення сталого розвитку регіону. Економіка і суспільство, № 19. 2018. с. 785-790.

[8] Європейський зелений курс. Режим доступу: https://ukraine-eu.mfa.gov.ua/posolstvo/galuzeve-spivrobitnictvo/klimat-yevropejska-zelena-ugoda (дата звернення: 25 березня 2025 р.).

living conditions of both the current and future population of the affected area in a way that mitigates climate change, helps to adapt to climate change, reduce negative environmental impacts, preserve biodiversity, and ensure clean air, water, and soil[9]. In 2022, Presidential Decree 266/2022 established the National Council for the Restoration of Ukraine from the Consequences of War[10].

Today, Ukraine faces large-scale and serious challenges: rebuilding or creating new critical infrastructure facilities, ensuring the country's energy security, accelerating further implementation of EU legislation, combating and adapting to climate change, etc. And despite the ongoing war, plans for the country's recovery are already underway. Although different regions will have different needs for reconstruction, at the national level, the basic principles of postwar life should be common to all.

1. Green direction of sustainable development of Ukraine – current state and prospects of post-war planning

The purpose of the study was to analyze the current state and prospects for sustainable «green» development of Ukraine as a whole and its regions, also to analyze the capabilities of remote sensing and GIS technologies for monitoring and visualization of renewable «green» energy facilities in Ukraine.

The following research methods were used to determine this. A comparative analysis was used to clarify different views on the problem of green (sustainable) recovery of Ukraine from the perspective of the Ukrainian authorities, the European Commission and the World Bank. Given that the planning of Ukraine's reconstruction is still ongoing[11], despite a number of legislative acts adopted, the current vision of Ukraine's post-war reconstruction by the government and its international partners (the European Commission and the World Bank) is still under development.

A comparison method was used to compare the possibilities of achieving the sustainable development goals related to the change in the priority of the sustainable development goals in the pre-war and post-war periods and to select possible concepts for post-war green reconstruction.

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[9] Зелене відновлення України: керівні принципи та інструменти для осіб, які приймають рішення. URL: https://www.undp.org/sites/g/files/zskgke326/files/2024-04/undp–ua-green-recovery-ukr.pdf (дата звернення: 26.05.2025).

[10] Миколайчук М.М., Куспляк С., Лантратов М.С. Особливості забезпечення сталого розвитку регіонів України у післявоєнний період. Державне управління: удосконалення та розвиток. 2023. № 2. URL: https://www.researchgate.net/publication/369920819_Osoblivosti_zabezpecenna_stalogo_rozvitku_regioniv_Ukraini_u_pislavoennij_period_Derzavne_upravlinna_udoskonalenna_ta_rozvitok_2023_No_2 (дата звернення: 26.05.2025).

[11] Зелена повоєнна відбудова України. Екодія. Центр екологічних ініціатив. URL: https://ecoaction.org.ua/diyalnist/vidnovlennia (дата звернення: 26.05.2025).

The forecasting method was used to determine an acceptable model for further planning of Ukraine's green reconstruction – its future "green course", i.e., the definition of environmental goals and frameworks for green reconstruction of Ukraine.

Methods of systematization and generalization were chosen to formulate conclusions and recommendations.

To effectively manage the processes of sustainable development, it is necessary to identify the benefits and threats to the sustainable development of the region.

The main threat to the realization of the ideas of sustainable development of the regions of Ukraine is the continuation of military aggression by Russia. According to international experts, the war in Ukraine has led to a decline in the economy and a decline in sustainable development indicators[12]. The war has revealed sustainable development goals that Ukraine is currently not achieving by 100% compared to the pre-war period. An analysis of the interrelationships between the Sustainable Development Goals has shown their indivisibility and close interconnection, which directly depends on military actions. Thus, the achievability of the Sustainable Development Goal "Peace and Justice" is currently limited, and the likelihood of achieving such goals as "Quality Education," "Good Health and Well-Being," and "Decent Work and Economic Growth" is reduced. This situation has led to a change in Ukraine's priorities in achieving the Sustainable Development Goals for the regions. The priority goals of the pre-war period have been replaced by the following: poverty reduction (key); decent work and economic growth; clean water and proper sanitation (for some regions); industry, innovation and infrastructure[13].

Before the war, Ukraine had good prospects for green development. The war slowed down this process, but did not cancel it. To restore the process of green development to the pre-war level, it is necessary to launch new mechanisms that will ensure social norms, help implement political and restoration programs, and thus help launch a green economy.

We assume that sustainable development in Ukraine is primarily a socially oriented process of economic development that ensures economic and social stability and efficient reproduction of natural resources. And economic development, social growth and scientific and technological progress, in turn, should be combined with the processes of natural resource reproduction and environmental sustainability. Therefore, the systemic goal of sustainable

[12] Global Peace Index 2022. URL: https://www.visionofhumanity.org/wpcontent/uploads/2022/06/GPI-2022-web.pdf (accessed May 26, 2025).

[13] Державна служба статистики України. Цілі сталого розвитку: Україна-2021. Моніторинговий звіт. URL: https://ukrstat.gov.ua/csr_prezent/2020/ukr/st_rozv/publ/SDGs%20Ukraine%202021%20Monit oring%20Report%20ukr.pdf (дата звернення: 26.05.2025).

development for Ukraine is to achieve peace, which will also ensure the achievement of other goals[14].

The continuation of the active period of hostilities retains some uncertainty about their direct and indirect short-term and long-term consequences, which leaves the issues of both a comprehensive assessment of their impact on the prospects for socio-economic development of Ukraine and the justification of adequate rehabilitation and compensation measures systematized in long-term programs and strategies under discussion[15].

According to international experts, the war in Ukraine led to an economic downturn, which caused a decline in sustainable development indicators[16].

Despite the war conditions, Ukraine's economy did not stop, but remains in normal operation, despite a certain decline in many sectors of the economy. Ukraine almost immediately resumed its educational activities in a distance/mixed format, although with the loss of out-of-school and preschool education. Over time, full-time education became possible provided that bomb shelters were available, especially in the frontline regions. However, the results of the PISA international student achievement study showed some loss of quality of education, especially in reading and science[17]. To date, 15-year-olds from educational institutions in only 17 regions will participate in the PISA-2025 study, as due to the temporary occupation of certain territories of our country and security risks, educational institutions from some regions of Ukraine are not included in the sample of participants[18]. This is also an indicator of the failure to fully implement one of the Sustainable Development Goals, namely the quality of education.

In addition to the education sector, the war has identified other sustainable development goals that Ukraine is currently unable to achieve 100%.

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[14] Буряк Є.В., Редько К.Ю., Чорновол А.О., Орленко О.В., Соціально-економічні аспекти сталого розвитку України в умовах війни (євроінтеграційні аспекти) / Наукові записки Львівського університету бізнесу та права. Серія економічна. Серія юридична. Вип. 34, С. 18-24, 2022.

[15] Буряк Є.В., Редько К.Ю., Чорновол А.О., Орленко О.В., Соціально-економічні аспекти сталого розвитку України в умовах війни (євроінтеграційні аспекти) / Наукові записки Львівського університету бізнесу та права. Серія економічна. Серія юридична. Вип. 34, С. 18-24, 2022.

[16] Державна служба статистики України. Цілі сталого розвитку: Україна-2021. Моніторинговий звіт. URL: https://ukrstat.gov.ua/csr_prezent/2020/ukr/st_rozv/publ/SDGs%20Ukraine%202021%20Monit oring%20Report%20ukr.pdf (дата звернення: 26.06.2025).

[17] ПІЗА-2022. Українські студенти показали найнижчі результати з читання, найвищі – з природничих наук. URL: https://lb.ua/society/2023/12/05/587551_pisa2022_naynizhchi_rezultati.html (дата звернення: 26.05.2025 р.).

[18] Наказ Міністерства освіти і науки від 07.02.2025 "Про проведення основного етапу міжнародного дослідження якості освіти PISA-2025 в закладах освіти України". URL: https://testportal.gov.ua/wp-content/uploads/2025/02/PISA-2025_MS_Vybirka-zakladiv.pdf (дата звернення: 26.05.2025).

The analysis of the interaction of the Sustainable Development Goals showed their indivisibility and close interconnection, which is directly dependent on military operations (Fig. 1).

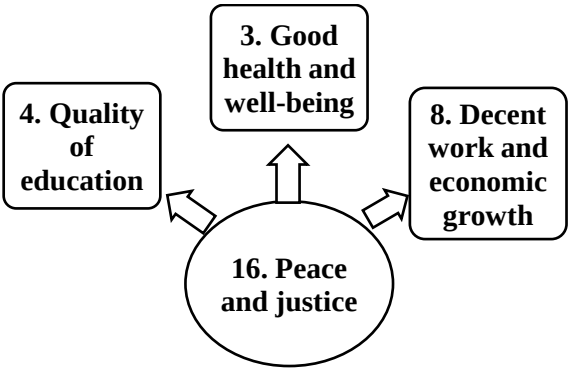

Fig. 1. Interaction of sustainable development goals

The limited possibility of achieving the Sustainable Development Goal "Peace and Justice" reduces the possibility of achieving such goals as "Quality of Education", "Good Health and Well-Being" and "Decent Work and Economic Growth", among others. These conditions have led to a change in priorities for achieving the Sustainable Development Goals for Ukraine (Table 1).

Table 1

Changing priorities of sustainable development goals in the pre-war and post-war period

Priority sustainable development goals in Ukraine before the war	Priority Sustainable Development Goals in Ukraine during the war and post-war period
Responsible consumption and production	Poverty reduction (key)
Quality education	Decent work and economic growth
Protecting and restoring terrestrial ecosystems	Clean water and proper sanitary conditions
Affordable and clean energy	Industry, innovation and infrastructure
Reducing inequality	
Industry, innovation and infrastructure	

In order to return the country to its pre-war trajectory, decisive steps must be taken to enforce social norms, implement the usual political and restoration programs that will help create "green" areas of the economy and develop social ties that will be resilient to new challenges.

Sustainable development of Ukraine is a socially-oriented process of economic development that ensures economic and social security, as well as efficient reproduction of natural resources. Economic development, social

growth, and scientific and technological progress must be combined with the process of reproduction of natural resources and ecosystem sustainability. The systemic goal of sustainable development for Ukraine is to achieve peace, which ensures the achievement of other goals[19].

After the end of the war, the priority should be to adjust the economic structure through the following components

– Creation of more energy-efficient and less polluting (low-carbon) industries and transportation systems;

– Reconstruction of existing social facilities by improving their energy efficiency with the necessary transition to the use of low-carbon materials.

The developed mechanism for regional sustainable development should cover the entire system and be integrated into national and global development strategies. The effectiveness of such a mechanism should be ensured by the following areas of regional development, namely: legal, organizational, financial, economic, innovation, social, environmental and informational[20].

Today, we already know about the varying degrees of damage to different regions and their strategic development goals. Regions can be divided according to the following characteristics: de-occupied (frontline), supporting (frontline) and rear regions. In accordance with the components of sustainable development (economic, social and environmental), they can be divided by the degree of damage into critical and acceptable. According to this division, the strategic goals and necessary measures to achieve them will be different in accordance with the current situation. And unfortunately, while the war is ongoing, it will be premature to talk about the final comparison of regions by the degree of damage.

However, there is a certain algorithm according to which we can already talk about ensuring strategic goals and taking the necessary measures to similarly divide the regions in the face of their critical damage[21] (Fig. 2). Regarding the acceptable degree of damage, the strategic goals of the development of such regions will mainly be to comply with the existing plans for their development. It should be noted that this algorithm is already being applied to the de-occupied territories (rebuilding Bucha and other regions).

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[19] Буряк Є.В., Редько К.Ю., Чорновол А.О., Орленко О.В. Соціально-економічні аспекти сталого розвитку України в умовах війни (євроінтеграційні аспекти) / Наукові записки Львівського університету бізнесу та права. Серія економічна. Серія юридична. Вип. 34, С. 18-24, 2022.

[20] Ватченко О.Б., Ільченко В.М. Механізм забезпечення сталого розвитку регіонів України. "Економічний вісник НТУУ "Київський політехнічний інститут". – Науковий вісник НТУУ. 2011. Вип. 21.19. С. 205-212.

[21] Миколайчук М.М., Куспляк С., Лантратов М.С. Особливості забезпечення сталого розвитку регіонів України у післявоєнний період. Державне управління: удосконалення та розвиток. 2023. № 2. URL: https://www.researchgate.net/publication/369920819_Osoblivosti_zabezpecenna_stalogo_rozvitku_regioniv_Ukraini_u_pislavoennij_period_Derzavne_upravlinna_udoskonalenna_ta_rozvitok_2023_No_2 (дата звернення: 26.05.2025).

Reconstruction should consist of a series of steps and should include planning for the short, medium, and long term as much as possible.

Therefore, it is worthwhile to outline the basic principles for green post-war reconstruction that would ensure a balanced development of the economy and communities: sustainable and systemic solutions; transparency, community and citizen participation in decision-making; use of the best available technologies and methods; sustainable and resilient development of cities and regions; decarburization and decentralization of energy; development of sustainable decentralized agri-food systems; and ensuring the conservation of ecosystems and natural resources of Ukraine[22].

These sustainable approaches are aimed at ensuring that all new infrastructures contributes to the abandonment of fossil fuels, and that the restoration of cities, rural areas and their communities takes into account social, economic and environmental factors. To this end, we help cities and communities develop a strategic vision of their sustainable development and prepare new green projects that will help improve the quality of life on the ground.

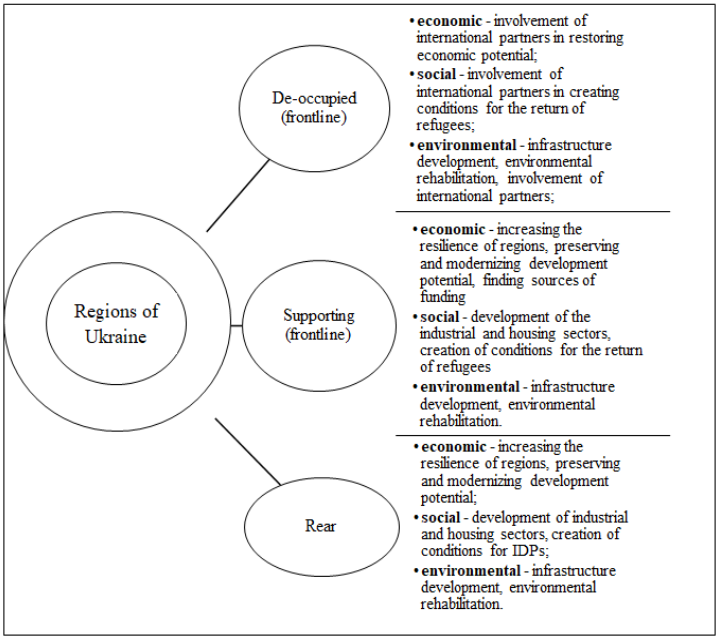

Fig. 2. Characteristics of the regions' compliance with the sustainable development goals in the wartime period

[22] Зелена повоєнна відбудова України. Екодія. Центр екологічних ініціатив. URL: https://ecoaction.org.ua/diyalnist/vidnovlennia (дата звернення: 26.05.2025).

Energy, agriculture, active communities, clean air, and climate change are important areas of work for Ukraine's recovery.

Ukraine's green recovery should be a balanced recovery based on the use of the best available technologies and practices.

Despite a number of adopted legislative acts, planning for Ukraine's reconstruction is still ongoing[23]. The current vision of post-war reconstruction of Ukraine by the government and its international partners is still under development, although on some issues we can already talk about a common vision of post-war reconstruction of Ukraine. In particular, the reconstruction will require not only overcoming the direct consequences of the war, but also the development of a comprehensive plan (strategy) for the post-war reconstruction of Ukraine.

In addition, the Government of Ukraine and all partners share the view that the reconstruction process will be divided into three stages.

However, the vision of post-war reconstruction of Ukraine does not include sufficient and effective green elements. In the absence of sufficient green elements, post-war reconstruction could "close" certain sectors from modernization, greening, environmental protection, and sustainable development for decades.

The concept of post-war reconstruction of Ukraine consists of several components: the vision of the Ukrainian authorities, the European Commission, and the World Bank[24].

The Ukrainian authorities see postwar reconstruction as overcoming the consequences of the war and planning the country's strategic development in three stages. The European Commission interprets post-war recovery as a systemic process that includes rebuilding the state after the war, modernizing all sectors, implementing a wide range of European integration reforms, and supporting the medium-term development of the economy and society.

The World Bank has presented its preliminary vision of Ukraine's post-war recovery, namely: assistance, recovery and sustainable reconstruction to support Ukraine's medium-term economic needs. The report is the first step in a three-step approach to assessing the damage and needs in Ukraine as a result of the Russian invasion. The estimates of direct physical damage in this report are based on available information and data collected and assessed through March 31, 2022. It envisages both post-war reconstruction and the goals and objectives of the state's development in the medium term, and contains specific sectoral priorities and tasks[25].

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[23] Зелена повоєнна відбудова України. Екодія. Центр екологічних ініціатив. URL: https://ecoaction.org.ua/diyalnist/vidnovlennia (дата звернення: 26.05.2025).

[24] Зелене післявоєнне відновлення України: бачення та моделі. URL: https://dixigroup.org/wp-content/uploads/2022/08/green_recovery.pdf (дата звернення: 26.05.2025 р.)

[25] Оцінка фізичних збитків в Україні внаслідок російського вторгнення. URL: https://www.gfdrr.org/en/publication/assessment-physical-damages-ukraine-result-russian–invasion (дата звернення: 26.05.2025 р.).

At the same time, none of the analyzed approaches to Ukraine's post-war recovery proposes green goals as fundamental. Thus, it is unlikely that the recovery concept proposed by Ukraine, with the favorable support of its partners, will be "green" in terms of green development as a medium– or long-term goal for Ukraine's development. In other words, it is unlikely to be a Ukrainian "green course."

It is believed that the green recovery of Ukraine can have at least three models:

– ambitious: one that has general ambitious environmental goals and frameworks, for example, in the area of climate change, specific green sector goals and appropriate mechanisms and measures to achieve them (conditionally, the Ukrainian "green course");

– realistic: one that will promote green growth and at least includes specific goals, principles and mechanisms that will not impede such growth in the future; outlines "red lines" and ensures a link between economic transformation and future green development; ensures synergy, in particular, with elements of the green course (conditionally, the "green minimum");

– Inertial: one that provides for certain environmental and climate goals in accordance with current sectoral goals, but does not strengthen them and does not affect the implementation of other sectoral goals and objectives that do not affect the implementation of the sector ("business as usual").

However, despite the slowdown in green development due to military aggression, there are industries that already need to develop the green vector and are resolutely implementing it. This is the energy sector, the green component of which is renewable energy, which is already balancing the work of the energy complex.

Renewable energy is an energy industry that specializes in the production and use of energy from renewable sources. Renewable energy sources include periodic or steady flows of energy: solar radiation, wind, hydropower, and natural heat.

In recent years, the use of "green" energy has spread around the world and reached the peak of its popularity. This popularity is primarily due to the fact that the global environmental situation is becoming an increasingly pronounced problem, and green energy is one of the tools that can improve environmental conditions. This primarily concerns air pollution and greenhouse gas emissions.

For Ukraine, green recovery includes not only overcoming the consequences of emergencies, but also war[26].

[26] Зелене відновлення України: керівні принципи та інструменти для осіб, які приймають рішення. URL: https://www.undp.org/sites/g/files/zskgke326/files/2024-04/undp-ua-green-recovery-ukr.pdf (дата звернення: 26.05.2025 р.).

Since 2022, Ukraine has taken important steps both to commission alternative energy sources and to spread this idea in the information space[27].

However, today the main reason for the increased demand for green energy in Ukraine is Russia's terrorist actions against the energy sector of Ukraine, namely the targeted attack on critical energy facilities of our country. That is why the green energy sector is one of the leading sectors in the construction of the future energy complex of Ukraine. The main advantages of renewable energy in a time of war are that they can be installed near various infrastructure facilities throughout Ukraine. This will disperse the entire network of power plants in the country, which will significantly increase the security of the entire energy sector.

In times of war, energy security is one of the key factors for the proper functioning of government institutions and communications. This primarily concerns critical infrastructure facilities, medical and educational institutions, etc., which are very vulnerable. Ordinary citizens of Ukraine can also contribute to improving energy security. For suburban developments, solar panels can be installed in private estates or on the roofs of private houses. Solar panels can also be installed on the balconies or loggias of high-rise buildings, which is more relevant for the cities of our country. However, in order to increase the effectiveness of involving ordinary citizens in this process, it is necessary to properly inform them.

Wind energy is an equally important green energy tool, as well as a combination of wind and solar energy, which will greatly increase the efficiency of their use. If a wind generator and solar panels are properly combined into one power plant, it will have the best possible balance throughout the day. When the sun is shining, the wind is usually not strong, and at this time, solar panels are mostly working. And when there is no sun, the wind usually increases and at this time the wind generator works more. The wind generator also works at night, which accumulates energy for daytime use. That's why it makes sense to create power plants where solar panels and wind generators work together in one scheme.

In 2022, Ukraine launched a loan program for the efficient use of electricity and the development of renewable energy sources. One of the top priority goals of this program is to encourage the population to install renewable energy facilities for heating and hot water supply by reimbursing part of the loan amount. Currently, there are many financial programs in Ukraine for obtaining loans for energy independence of consumers, including 0% lending to citizens for the purchase of energy equipment. Such actions encourage ordinary citizens to make themselves less dependent on the large electricity grid, which is directly related to improving their own living conditions during the war. In turn, this will reduce the load on the entire energy

[27] Мітрясова О., Смирнов В., Марійчук Р., Чвир В. Європейські зелені виміри: підручник / за ред. проф. Олени Мітрясової. Миколаїв: ЧНУ ім. Петра Могили, 2024. 471 р.

complex of Ukraine. In addition, initiative citizens who create sufficiently powerful solar or wind power plants can join the public grid of the energy sector, which will also contribute to the energy security of our country.

One example of citizen engagement is the Solar City project, one of the first cooperatives in Ukraine to build a solar power plant on the municipal roofs of Slavutych. Such initiative projects are increasingly supported by the state, which leads to an increase in the use of solar energy among ordinary citizens[28].

The scientific community is not sitting idle either. Today, there are many events dedicated to renewable energy sources, including energy webinars, forums, and hackathons, one of which is the IT hackathon "The SpaceTech Bootcamp: Reimagine Ukraine"[29].

2. Renewable energy sources in Ukraine – current state and prospects for post-war recovery

Ukraine's renewable energy sector (RES) was performing well before the war. According to the National Energy and Utilities Regulatory Commission (NEURC), as end 2021, the installed capacity of Ukraine's renewable energy sector reached 9,655.9 MW (including private solar installations (SPP)), or 8,450.8 MW without pSPP[30] (Fig. 3).

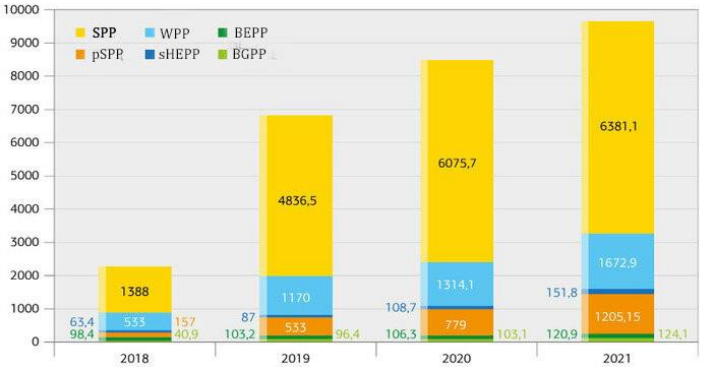

Fig. 3. The growth dynamics of the installed capacity of RES facilities operating under the «green» tariff, MW

[28] Славутич: сонячне місто в Україні з електростанцією на даху. URL: https://greentransform.org.ua/slavutych-sonyachne-misto-v-ukrayini-z-elektrostantsiyeyu-na–dahah/ (дата звернення: 26.05.2025).

[29] Участь в IT-хакатоні "The SpaceTech Bootcamp: Reimagine Ukraine". URL: https://pgf.sspu.edu.ua/novyny-fakultetu/1542-uchast-v-it-khakatoni-the-spacetech-bootcamp–reimagine-ukraine (дата звернення: 26.05.2025).

[30] Сектор відновлюваної енергетики України до, під час та після війни. Url: https://razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny#_ftnref11 (дата звернення: 26.05.2025).

According to 2021 data, solar power plants (SPP) took the first place, although there was an active growth in capacity only in the segment of home solar power plants (pSPP). In contrast to the residential sector, industrial solar power, on the contrary, did not demonstrate the best development indicators, but rather their reduction. Thus, the total installed capacity of all household solar systems reached 1,205.1 MW at the end of the year. The capacity of industrial solar generation, although not by much, increased its performance and amounted to 6381.1 MW. At the end of the year, the total installed capacity of the country's solar energy sector amounted to 7,586.3 MW (including pSPP).

Wind power was the second largest source of national renewable energy after solar energy in terms of total installed capacity. However, it should be noted that it was the wind energy sector of Ukraine that added the largest number of new capacities to the country's "green" energy mix in the pre-war years. The share of wind power capacities commissioned in 2021 amounted to 30.6% or 358.8 MW, which is 2.5 times more than the amount of new wind power capacities commissioned in 2020 (144.2 MW). Thus, the total installed capacity of the wind energy sector at the end of 2021 amounted to 1,672.9 MW. Before the start of the large-scale war, 34 wind farms or 699 wind turbines with an average unit capacity of 3.5 MW generated green electricity in Ukraine[31].

Thanks to the gas crisis and record high natural gas prices in 2021-2022, Ukraine's bioenergy sector (bioenergy) also showed good indicators of development prospects. There were 21 MW (almost 2%) of biogas plants commissioned, which is twice as much as in 2020, and 43.1 MW (or 3.68%) of biomass plants, which is twice the increase in bioenergy capacities in 2020.

Also, a share of small hydropower capacities was commissioned in 2021, which is 1.24% or 14.6 MW.

The location of RES facilities differs by renewable energy source, which is natural and corresponds to the natural RES potential of a particular region. Thus, wind power plants are characterized by their location in the southern and southeastern regions. The geography of wind facilities primarily gravitates to the coasts of the Black and Azov Seas -about a third. Unlike wind power, solar generation is much more widespread, although more than half of industrial solar power plants are also concentrated in the southern and southeastern regions of Ukraine.

According to total installed capacity with solar and wind generation, the leaders among all regions of Ukraine are the following (Table 2).

[31] Сектор відновлюваної енергетики України до, під час та після війни. Url: https://razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny#_ftnref11 (дата звернення: 26.05.2025).

Table 2

Regions – leaders in RES

№	Regions	потужності
1	Dnipropetrovska	1350,06 МВт
2	Khersonska	1139,65 МВт
3	Mykolaivska	1121,16 МВт

Unfortunately, since the beginning of the full-scale invasion, the Ukrainian renewable energy sector has undergone significant changes. For the past 3 years, Russian troops have been massively shelling not only Ukrainian cities and towns, but also trying to destroy critical energy infrastructure: high-voltage networks, transformer substations, control centers, as well as power plants, including renewable energy facilities. In general, after nuclear power facilities and power lines, renewable energy power plants have become the second highest priority for destruction by the Russian invaders.

Given that the vast majority of renewable energy facilities installed in the country were concentrated in the southern and southeastern regions of Ukraine, they are partially or completely under occupation or have become centers of active hostilities. According to various expert estimates, as of August 2022, 30-40% of RES power plants in these regions, or about 1120-1500 MW of installed capacity, were affected in one way or another[32].

Currently, the financial crisis in the RES market is deepening. This is due to the lack of sufficient funds to continue operations, which has become an urgent problem faced by all sectors of the Ukrainian energy system. However, the renewable energy sector has been particularly affected. The national renewable energy sector is facing the issue of survival within the state. First of all, this can be explained by the fact that in the first days of the war, the state's efforts were aimed at ensuring the stable functioning of base load generation and the reliable operation of the Ukrainian power system in isolation, which was disconnected from the networks of Russia and Belarus on February 24, 2022. Accordingly, addressing some of the problematic issues in the renewable energy sector was not a priority.

Despite the fact that renewable energy producers, in particular solar and wind power producers, did not receive full payment for the electricity supplied in 2021 [33] and continued to incur operating costs for the maintenance of their power plants, had financial obligations both to the state of Ukraine and their staff, as well as to international investors, they nevertheless challenged such

[32] Сектор відновлюваної енергетики України до, під час та після війни. Url: https://razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny#_ftnref11 (дата звернення: 26.05.2025).

[33] Сектор відновлюваної енергетики України до, під час та після війни. Url: https://razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny#_ftnref11 (дата звернення: 26.05.2025).

financial policies in the RES sector and the state's decisions, as they realized how important the stability and reliability of the power system and the electricity market in general were. However, this level of payments was frankly insufficient to maintain financial liquidity, especially for companies operating in the solar and wind energy sectors.

In addition to the above-mentioned financial problems, the national wind energy sector also faced the inability to complete some wind farms within the timeframe stipulated by the current legislation. At the beginning of the war, there were projects that had the appropriate permits. However, due to the outbreak of large-scale hostilities and the occupation of part of Ukraine, the construction of wind farms was suspended.

Despite the fact that the war is ongoing, there are certain decisions regarding the future development of the RES sector.

As already mentioned, prior to the war, Ukraine adopted a number of regulations and national strategies that define the future direction of renewable energy development in Ukraine during this and future decades (Figure 4).

These regulations do not set specific goals and do not address all issues.

Regulatory documents and national strategies that define the future direction of renewable energy development in Ukraine during this and future decades.	Energy Strategy of Ukraine until 2035 "Security, Energy Efficiency, Competitiveness"
	Economic Strategy of Ukraine until 2030 Concept of "Green Energy Transition of Ukraine" until 2050
	National Low-Carbon Development Strategy of Ukraine until 2050 and the Second Nationally Determined Contribution to the Paris Agreement
	Recovery Plan of Ukraine until 2032

Fig. 4. Regulatory documents and national strategies that define the future direction of renewable energy development in Ukraine during this and future decades

However, there are certain decisions regarding RES in the overall, short-term and long-term perspective (Fig. 5-7).

In the long run, to solve possible future problems associated with the development of a modern carbon-free energy sector in Ukraine, taking into account renewable energy sources, it is necessary to:	Approve a single fundamental strategic document that defines the direction of energy development and, in particular, RES in Ukraine.
	Approve an implementation plan for 5-10 years, which should be implemented by both the state (the President of Ukraine, the Verkhovna Rada of Ukraine, the Cabinet of Ministers of Ukraine, the Ministry of Energy of Ukraine, NPC Ukrenergo, NEURC, etc.) and market participants.
	Oblige all government agencies and state-owned enterprises involved in the energy sector to include measures from the plan in their activity/development programs and establish political/administrative responsibility for failure to do so.

Fig. 5. Necessary steps in the overall perspective to address possible future challenges related to the development of a modern carbon-free energy sector in Ukraine, including RES

For the long-term perspective, the following steps are required (Fig. 6).

In the short term, for the stable functioning of the RES sector, it is critical to:	1. Ensure that the legislation on the system of support for RES producers and gradual repayment of debts remains unchanged, and that existing guarantees provided to investors at the legislative level are respected;
	2. Amend the Order of the Ministry of Energy "On Settlements with Producers under the Green Tariff" of 15.06.2022 No. 206 to bring the level of payments to RES producers to an economically justified level to cover all operating costs;
	3. Fully repay the debt to "green" generation for previous years.
	4. Reduce the scope of systemic restrictions on RES by NPC Ukrenergo.
	Develop and adopt amendments to the NEURC Resolution "On Approval of Regulatory Acts Governing the Activities of the Guaranteed Buyer and the Purchase of Electricity at the Green Tariff" No. 641 of April 26, 2019, to introduce a mechanism whereby RES producers will be proportionally responsible for imbalances caused by electricity production forecasting.
	6. Ensure settlements with the SE Guaranteed Buyer for imbalances on the part of NPC Ukrenergo and stabilize payments to TSOs for services to increase the share of RES.
	7. At the legislative level, it is necessary to extend the term of validity of technical specifications for wind energy projects whose construction was interrupted by the war, as well as the term for their completion for the purposes of obtaining a "green" tariff, proposed by the Ministry of Energy of Ukraine, for at least 2 years.
	8. Establish a cash method of charging and paying VAT on load reduction services.
	9. Open up the possibility of exporting electricity to RES producers, create a transparent and non-discriminatory mechanism for setting tariffs and allocating transmission capacities, and simplify the procedure for organizing transit on the principle of free access to transit capacities.
	10. In order to stimulate the sale of electricity by RES producers in foreign markets, the export PSO requires the exclusion of RES producers from the list of exporters covered by such PSO.
	11. As soon as possible, a mechanism for issuing and circulating guarantees of origin of electricity from RES should be adopted at the legislative level and a national register of guarantees of origin for electricity produced from RES should be created.

Fig. 6. Necessary steps required for the stable functioning of the RES sector in the short term

In the long-term (post-war) perspective, the large-scale development of "green" generation and the creation of a new model of Ukraine's energy sector will be possible provided that:	1. Adoption of clear national strategies for the development of renewable energy sources, renewable hydrogen production, and offshore wind energy. Revision of the Energy Strategy until 2035, taking into account the replacement of retiring generation capacities with new ones and the concomitant increase in energy storage capacities. Adoption of the Energy Strategy of Ukraine until 2050;
	2. Adoption of clear national strategies for the development of renewable energy sources, renewable hydrogen production, and offshore wind energy. Revision of the Energy Strategy until 2035, taking into account the replacement of retiring generation capacities with new ones and the concomitant increase in energy storage capacities. Adoption of the Energy Strategy of Ukraine until 2050;
	3. Conduct international communication campaigns to encourage international strategic and financial investors to enter the Ukrainian RES market;
	4. Introduce new market mechanisms to stimulate RES development, including green auctions, corporate PPAs, contracts for difference, etc;
	5. Increase the use of biomass in electricity and heat generation;
	6. Ensure the development of the renewable hydrogen market, namely: - Provide guarantees of hydrogen origin, review the carbon tax and increase it; - Verify and technically justify the possibility of using the Ukrainian GTS, localize hydrogen production projects, connect them to the GTS; - Ensure the implementation of national hydrogen projects; - Build a reliable infrastructure for the production, consumption and export of renewable hydrogen; - Stimulate scientific organizations to research in the field of hydrogen technologies;
	7. Study the potential and develop an appropriate legislative framework for the construction of hybrid power plants with RES;
	8. Promote the development of local energy initiatives, including energy cooperatives, small and medium-sized enterprises in the energy sector, generation and supply of electricity with due regard to regional peculiarities, and development of distributed generation;
	9. Stimulating national production of equipment and components for renewable energy facilities, including wind turbines.
	10. Application of best practices in environmental protection;
	11. Developing legislation to introduce a greenhouse gas emissions trading scheme and other market and non-market instruments to reduce greenhouse gas emissions;
	12. Increase the share of installed automated electricity metering systems;
	13. Ensuring reliable operation of the energy infrastructure, taking necessary modernization measures, reducing breakdowns and accidents.

Fig. 7. Necessary steps required for large-scale development of "green" generation and creation of a new model of Ukraine's energy sector in the long-term (post-war) perspective

3. Opportunities of remote sensing and GIS technologies for monitoring and visualization of renewable "green" energy facilities in Ukraine

Renewable energy sources (RES) in Ukraine are one of the tools for reducing the negative anthropogenic impact, which is due, in particular, to the

reduction of carbon emissions into the atmosphere. RES are the key to Ukraine's energy security and independence, and they should contribute to building up the country's energy potential and security both now and in the post-war period. Unfortunately, current events make it impossible to fully record and control these objects. Therefore, the use of remote sensing and geoinformation technologies opens up new opportunities for monitoring and visualization of the VED objects.

Ukraine's energy system consists not only of nuclear, thermal and hydroelectric power plants. It also includes alternative “green” energy, such as wind turbines and solar panels.

Unfortunately, now that part of the country's territories are under occupation, some solar power plants (SPPs) and wind power plants (WPPs) have remained on the other side of the front. This had a negative impact on the overall picture of electricity generation in the country.

The possibility and timing of resuming the operation of such plants can only be discussed after the de-occupation of the territories and an assessment of the condition of the generating equipment and the state of the power lines in the region. Now we can only monitor their external condition.

Remote sensing and geoinformation technologies can be used as modern tools for visualization and monitoring of renewable energy facilities. Among geographic information technologies, both free and licensed resources can be used for such activities.

For visualization of objects, we use an accessible, simple, and free resource called My maps from Google. It allows you to put point and line objects on the map using predefined coordinates or addresses, as well as add the necessary information and images to the objects. This can be done by exporting or simply adding. An example of using this resource is the renewable energy map (Fig. 8). The legend shows the objects that produce electricity from renewable sources and have been assigned a “green” label (information as of June 1, 2017)[34].

[34] Map of renewable energy in Ukraine in 2017. 2017. URL: https://www.google.com/maps/d/viewer?mid=1XpUHYI597UcL3fLyH0dZMRM9bTY&hl=en_US&ll=48.21588892386554%2C28.190225569531236&z=7 (дата звернення: 26.05.2025).

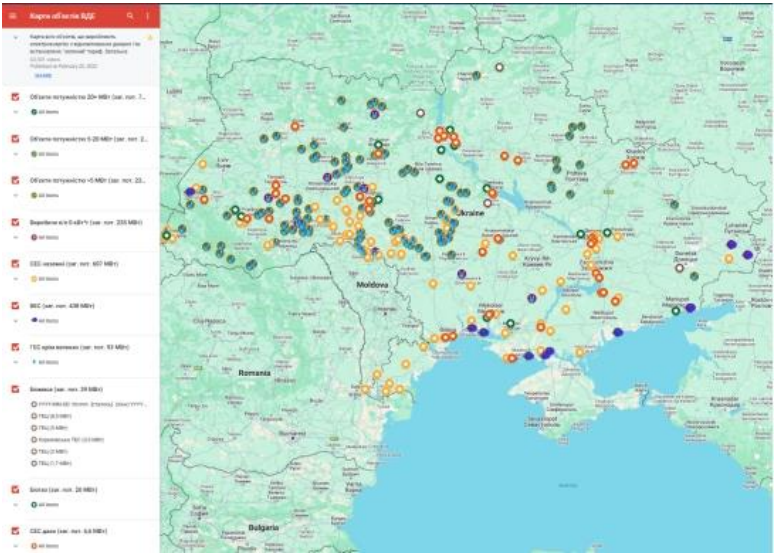

Fig. 8. Map of renewable energy in Ukraine in 2017

Another popular resource is ESRI's ArcGIS Online service. ArcGIS Online curates thousands of maps, applications, and datasets from authoritative and commercial sources and makes them available to users, ready to use through ArcGIS Living Atlas of the World. With ArcGIS Living Atlas, you can search for the content you need to visualize remote sensing imagery on maps, analyze images, and overlay imagery data with other spatial information.

The image data layers in ArcGIS Living Atlas include all the satellite, airborne, and remote sensing data needed for industry and research, as well as a range of current, forecast, and historical datasets. Datasets available for use include Landsat, Sentinel-2, MODIS, and other image archives.

This service allows you to not only view archived satellite images in ArcGIS Living Atlas, but also visualize and analyze them in various ways. Image analysis can be used for further research that demonstrates quantitative changes over time.

In addition to analyzing changes in natural phenomena, remote sensing methods and GIS technologies provide an opportunity to observe objects of anthropogenic origin. This also applies to renewable energy facilities. For this purpose, ArcGIS Online provides the ability to compare detailed satellite images in the World Image Wayback application.

The World Imagery Wayback application is not only a component of ArcGIS Living Atlas of the World, but also a digital archive that provides

access to the capabilities of the World Imagery layer, namely its various versions created in different periods. Each layer of this archive application is a satellite image for a certain date of the entire globe with a high spatial resolution (1 meter or more). The World Imagery application includes satellite and aerial images, which are constantly updated with more up-to-date data. Starting February 20, 2014, Wayback provides access to all published versions of World Imagery [35] (Fig. 9).

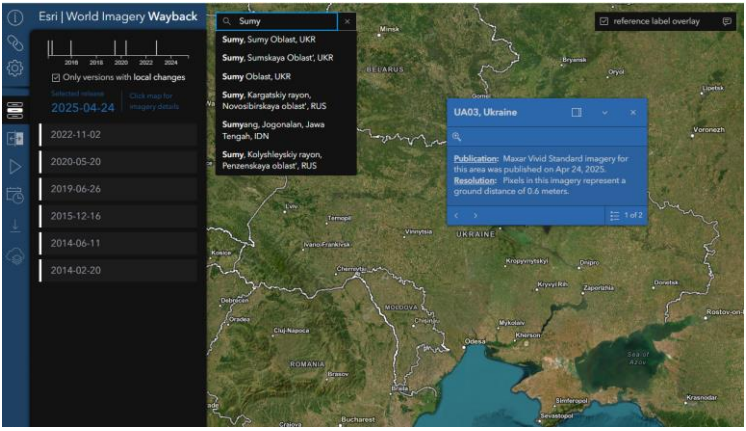

Fig. 9. Setting up the World Imagery Wayback resource

Monitoring of wind energy facilities in the World Imagery Wayback application can take place in the form of comparing detailed satellite images of the SPP appearance on satellite images "before" and "after" construction, or 'before' and "after" damage or destruction. An example is the image of one of the larger solar power plants (SPP) "before" and "after" construction (Fig. 10).

[35] Dynamics of SPP construction in Ukraine. URL: https://arcg.is/5eDj11 (дата звернення: 26.05.2025).

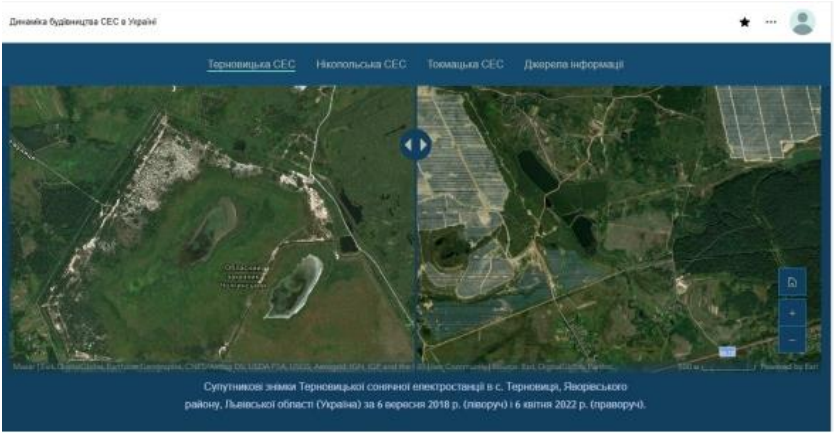

Fig. 10. Satellite images of the Ternovytsia solar power plant in the village of Ternovytsia, Yavoriv district, Lviv region (Ukraine) for September 6, 2018 (left) and April 6, 2022 (right)

ArcGIS StoryMaps is another of the ArcGis online applications. Publishing a story in ArcGIS StoryMaps is an effective way to communicate information using text, photos, maps, etc. in an interactive and engaging way. With ArcGIS StoryMaps, you can create your own stories that can be part of a separate project or study. It is a very convenient resource for sharing your maps in the context of narrative text and other multimedia content. ArcGIS StoryMaps helps you tell great stories through storytelling that inform, motivate, and inspire. These maps are an integral visual part of the story. ArcGIS StoryMaps can illustrate spatial relationships and add visual appeal to your ideas.

With the help of such approaches, you can not only compare the construction process, but also the process of damage to certain objects that can be recorded using satellite images.

CONCLUSIONS

The green (sustainable) recovery of Ukraine should be considered as one of the possible concepts of postwar reconstruction. The concept of green reconstruction is based on an overall vision of social, economic and overall national development. Ukraine can use the opportunities created by postwar reconstruction to lay the groundwork for future green growth. If the vision of post-war reconstruction is green, then this is a reasonable and achievable goal. We are convinced that one of the two possible models of green reconstruction can be implemented in this case: ambitious or realistic.

The study analyzed the current state and prospects for sustainable development of Ukraine's regions. The primary task for both the Ukrainian government and domestic scientists is to develop a mechanism to ensure the balanced development of all sectors of the economy based on the rational use of resources to address economic, social and environmental problems. This mechanism, on the one hand, will allow the introduction of new models of the eco-socio-economy aimed at improving the quality of life. On the other hand, it is the basis for Ukraine's European integration process, as the standards of sustainable development and environmental safety are of paramount importance. European integration will allow Ukraine to change the priorities of its national policy and rethink the priority of sustainable development goals and ways to achieve them.

The study also addresses the issue of renewable energy sources (RES). This is the key to Ukraine's energy security and independence, which contributes to building the country's energy potential and security both during the war and in the post-war period.

The paper considers remote sensing and GIS technologies that can be used as modern tools for visualizing and monitoring renewable energy facilities both in peacetime and under occupation, when the fate of these RES remains unknown.

Thanks to these technologies, it is possible to compare not only the process of reconstruction (construction), but also the process of damage, which can be recorded using satellite images.

SUMMARY

The research is based on the scientific developments of scientists who deal with the sustainable development of Ukraine and its regions, namely, mechanisms for ensuring sustainable development of regions affected by military aggression, taking into account the requirements of sustainable development and compliance with the development trends of the EU countries. It is found that there are different views on the problem of green (sustainable) recovery of Ukraine through the eyes of the Ukrainian authorities, the European Commission and the World Bank. On their basis, the relevant conclusions and recommendations are formulated. The article also identifies acceptable models for further planning of Ukraine's green recovery and compares the possibilities of achieving sustainable development goals related to the change in the priority of sustainable development goals in the pre-war, war and post-war periods.

Renewable energy sources (RES) are considered as the key to Ukraine's energy security and independence, and they should contribute to building up the country's energy potential and security in the postwar period.

Remote sensing and GIS technologies can be used as modern tools for visualizing and monitoring renewable energy facilities remaining in the occupied territory to determine their condition. Among GIS technologies, both free and licensed resources can be used for such activities. Image analysis can be used to study objects of natural and anthropogenic origin that show quantitative changes over time. This also applies to renewable energy facilities

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