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## ЕКОНОМІЧНІ ПРОБЛЕМИ СТАЛОГО РОЗВИТКУ НАЦІОНАЛЬНОЇ ЕКОНОМІКИ

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### THE PATH TO INDUSTRY 5.0: A GREEN ECONOMY EVOLUTION AND ENERGY INNOVATIONS FOR SUSTAINABLE DEVELOPMENT

### ШЛЯХ ДО ІНДУСТРІЇ 5.0: ЕВОЛЮЦІЯ ЗЕЛЕНОЇ ЕКОНОМІКИ ТА ЕНЕРГЕТИЧНІ ІННОВАЦІЇ ДЛЯ СТАЛОГО РОЗВИТКУ

*The article deals with the problem of the formation and development of the green economy in the context of sustainable development: insights from Industry 3.0, 4.0, and 5.0 technologies. This study focuses on the topic of the green economy, its evolution, legislative changes in European countries and the agenda of international organizations in relation to the European Green Deal. The authors emphasize the opportunities and challenges from a technological point of view for the countries of the European Union in transitioning to a green economy according to the European Green Deal. Comparison of the results with the trends identified in the literature review are given. The factors of innovative development in the modern green economy and sustainable development are described. The first priority tasks and new opportunities for innovation in the national economy under the influence of Industry 4.0 and the provisions of the European Green Deal are characterized. A study of papers devoted to the researched problem allowed for classification of historical periods of development, determination, and evaluation of the path of green growth. A comparative analysis of green growth indicators developed by the Organization for Economic Cooperation and Development was conducted. It was established that leaders in terms of criteria for the most efficient and sustainable use of resources in 2019 are Sweden and Denmark; level of protection of natural capital – Slovakia and Croatia; impact on environmental state and ecological assets – Czech Republic and Germany; effectiveness of green growth state policy – Sweden, Netherlands, and Denmark. The article noted that Ukraine had rather low results in terms of the most efficient and sustainable use of resources, and the impact of the state of the environment and ecological assets. At the same time, our country demonstrated high results in terms of the level of protection of natural capital and the effectiveness of the state green growth policy. The authors defined a system of effective tools for state regulation of innovative activity in the field of green economy, namely: tax incentives, increased state financing of technological and innovative activities, development of innovation-oriented culture. Also the role of energy innovations in relation to sustainable development and the green economy outlined by the authors in the concluding section of the article.*

**Keywords:** European Green Deal, Green Economy, Industry 5.0, Sustainable Development, Energy Innovations.

*У статті розглядається проблема становлення зеленої економіки в контексті сталого розвитку та технологій Індустрії 3.0, 4.0 та 5.0. Дослідження зосереджено на темі зеленої економіки, її еволюції, законодавчих змінах у європейських країнах та діяльності міжнародних організацій відносно Європейської зеленої угоди. Автори підкреслюють можливості та наявні проблеми технологічного характеру при переході до зеленої економіки країн Європейського Союзу*

із врахуванням умов Європейської зеленої угоди. Представлено порівняння результатів такого переходу із тенденціями, що були виявлені з огляду літератури. Описані чинники інноваційного та сталого розвитку в сучасній зеленій економіці. Охарактеризовано першочергові завдання та нові можливості для інновацій у національній економіці під впливом Індустрії 4.0 та положень Європейської зеленої угоди. Аналіз робіт, присвячених досліджуваній проблемі, дозволив провести класифікацію історичних періодів розвитку, визначити та оцінити шлях зеленого зростання. Проведено порівняльний аналіз індикаторів зеленого зростання, розроблених Організацією економічного співробітництва та розвитку. Встановлено, що лідерами: за критерієм найбільш ефективного та сталого використання ресурсів у 2019 році є Швеція та Данія; за рівнем захисту природного капіталу – Словаччина та Хорватія; за впливом на стан навколишнього середовища – Чехія та Німеччина; за рівнем ефективності державної політики зеленого зростання – Швеція, Нідерланди та Данія. У статті зазначається, що Україна має досить низькі результати щодо ефективного та сталого використання ресурсів, неефективно розпоряджається наявними екологічними активами та негативно впливає на стан навколишнього середовища. Водночас, за останні роки, Україна продемонструвала високі результати щодо рівня охорони природного капіталу та ефективності державної політики зеленого зростання. Визначено, систему ефективних інструментів державного регулювання інноваційної діяльності у сфері зеленої економіки, а саме: податкові пільги, збільшення державного фінансування технологічної та інноваційної діяльності, розвиток інноваційної культури. Також роль енергетичних інновацій для сталого розвитку та зеленої економіки, були окреслені авторами у статті.

**Ключові слова:** Європейська зелена угода, зелена економіка, Індустрія 5.0, сталий розвиток, інновації в енергетику.

**Problem statement.** The revival of sustainable development theory and international scientific and technical cooperation coincides with the beginning of the XXI century. Technological advancements (Industry 5.0) are crucial in energy transitioning towards a green economy. The green economy encompasses various sectors such as renewable energy, sustainable agriculture, and waste management, among others. Technological energy innovations have played a significant role in developing new products, services, and processes that promote sustainable development. In this article the authors discussed the importance of a green economy evolution and energy innovations towards sustainable development.

In recent years, various factors have contributed to innovative energy development in the modern green economy. These factors include increased awareness of environmental issues, changing consumer preferences, and government policies promoting sustainable development. Technological advancements have also played a significant role in driving innovation in the green economy. For instance, the development of renewable energy technologies such as solar and wind power has revolutionized the energy sector and reduced reliance on fossil fuels.

Industry 5.0 and the provisions of the European Green Deal provide new opportunities for innovation in the national economy. Industry 5.0 refers to the fifth industrial revolution characterized by the integration of advanced technologies such as artificial intelligence, robotics, and the Internet of Things. The European Green Deal aims to make Europe climate-neutral by 2050 by promoting sustainable growth and reducing greenhouse gas emissions. These initiatives provide a conducive environment for innovation and technological advancements that promote sustainable development.

The utilization of renewable energy sources offers numerous advantages for Ukraine's economy. Firstly, it reduces dependence on imported energy resources, which has a positive impact on the country's foreign economic situation. Secondly, the adoption of renewable energy sources curtails the release of hazardous pollutants into the atmosphere, resulting in beneficial effects on public health and the environment. Thirdly, it fosters the advancement of domestic production in the renewable energy sector and facilitates job creation. In addition, the use of renewable energy sources contributes to a reduction in the cost of electricity and ensures a more stable and predictable energy supply to the country.

**Analysis of recent research and publications.** Review of existing literature on the evolution of the Green

Economy and legislative reforms in this field demonstrates that this issue is very important with a focus on the European Green Deal. Many scientists have been involved in the study of these key problems, in particular, Barbier E.B., Pearce D.W. and Markandya A. [1; 2], Brand U. [3], Söderholm P. [4], Koehring M. and Cornell Ph. [5] and others. Also we have to note the role of technological changes for sustainable development in papers Wenhan Ren, Jing Ni, Wen Jiao, Yan Li [6], Wei Chen, Zhuzhang Yang, Hang Yan, Ying Zhao [7]. Several scientists focus on a particularly important component of the green economy and sustainable development like energy efficiency and energy innovations (Licong Xing, Edmund Ntom Udemba, Merve Tosun, Ibrahim Abdallah, Imed Boukhris [8], Olena Trofymenko, Olha Ilyash, Serhii Voitko [9] and others). Acknowledging the contributions and efforts of researchers in advancing scientific and methodological approaches to the subject matter, it is worth noting that certain aspects remain underexplored in the existing scientific literature, necessitating further research in the field.

**Formulating the purposes of the article.** Based on the aforementioned considerations, the research objectives were formulated, and a comprehensive set of methods was established. The main idea of the article is the analysis, systematization and generalization of evolution of a green economy and sustainable development in the context of the European Green Deal, leading to Industry 5.0.

**Methodology.** The research design has limitations connected to only European countries' experience study including Ukraine. The quantitative research methods which involve the use of numerical data and statistical analysis (Eurostat) to answer research questions about the implementation of Green Economy provisions are used in this article. Also the authors used the qualitative research methods to analyze documents and grounded theories to explore complex phenomena and understand the social, ecological, technological and economic processes in the Industry 5.0 field. Tabular description methods are used to systematize the data. Graphical description methods are also used to visualize organized data related to a specific research question. The research base is the official reports, academic articles, materials of periodicals, official data of national and international statistics.

**Presentation of the main research material.** The European Green Deal (EGD) generates new opportunities and challenges for all member-states of the European Union (EU), technologically and economically, socially, politically, and legislatively. From a technological per-

Table 1

## Historical development of the "green economy" and phase transition of Industry 3.0, 4.0, 5.0

Years	Event	Organization / scientists / countries	Industrial revolutions and technological changes
1988	Brundtland Report	World Commission on Environment and Development 1987 [10]	III Industrial Revolution, Industry 3.0
1989–1994	Introduction of a green economy definition	Groups of the leading economists-ecologists (David Pearce, Edward B. Barbier and Anil Markandya) for the UK Department [1]	
1992	Green economy seems to have the potential to become the new leading strategy in political discourse – like sustainable development in Rio 1992	Ulrich Brand [3]	
1997	Kyoto Protocol	191 countries [11]	
2008	UN Green Economy Initiative	UNEP [12]; Green Economy Initiative (GEI) [13]	
2009	– New global green course – Green Economy Coalition – Taking a green economy as mainstream	As ordered by UNEP – Professor Edward B. Barbier [2] (Wyoming University) Green Economy Coalition [14]	
2010	Green economy is in the focus of the international community	United National General Assembly [15]	
2011	– Green economy report issued by UNEP in November 2011 within Green Economy Initiative – Sustainable definition of a green economy	UNEP [16; 17] ICC [18]	IV Industrial Revolution, Industry 4.0
2012	– New interpretation of a green economy definition as a transformation – Green Economy Guide Issue 1: Green economy, green growth and low-carbon development – Green Growth Knowledge Platform was officially launched	Danish Group 92 [19] European Bank for Reconstruction and Development [20] UN Department of Economic and Social Affairs [21] Global Green Growth Institute (GGGI) [22], Organisation for Economic Co-operation and Development (OECD) [23], United Nations Environment Programme (UNEP) [16] and World Bank [24].	
2015	Sustainable Development Goals are declared 2030 UN Agenda for Sustainable Development	UN Summit on Sustainable Development Millennium Declaration and its eight Millennium Development Goals (MDGs, 2000–2015) [25]	
2019	– Medium-term strategy, programme of work and budget, and other administrative and budgetary issues: proposed programme of work and budget for the biennium 2020–2021 – The European Green Deal was presented	United Nations Environment Assembly of the United Nations Environment Programme [26] European Commission [27]	
2020	The European Industrial Strategy was adopted	European Commission [28]	
2021	– For people and planet: UNEP strategy for 2022–2025 – 2030 Climate Target Plan was presented	UNEP [29] European Commission [30]	2017 marks a gradual transition from Industry 4.0 to Industry 5.0, but many companies and organizations remain at the level of Industry 3.0. A human-centered concept focused on achieving the goals of sustainable development based on technological achievements and innovations. "Industry 5.0" symbolizes the shift from prioritizing economic value to emphasizing social value, a principle deeply advocated by proponents of the green economy.
2022	Green Economic Recovery	Annual SDG Review 2022 [31]	
2023	The global energy crisis and war have hampered long-term climate mitigation efforts	World Economic Forum [32]	
2023 and further...	– International Conference on Circular Economy and Green Growth (ICCEGG) – International Conference on Green Economy and Sustainable Development (ICGESD) – International Conference on Green Economy and Sustainability (ICGES) and so on	Green Economy Conferences 2023/2024/2025 [33]	

Source: author's development based on [1–33]

spective, the transfer to a green economy involves major changes (in areas such as energy, waste management, transportation, agriculture, construction, but also in many other fields) to address global climate change.

The innovative development of the modern sphere of the green economy for sustainable development is primarily due to the action of the following factors: climate challenges (EGD stimulates innovations aimed at the development and implementation of environmentally friendly technologies and solutions), energy transformation (stimulates the development of new technologies in energy production, energy conservation, and energy efficiency), clean technologies (includes innovations in renewable energy, energy efficiency, eco-friendly construction, and other sectors), circular economy (stimulates the development of innovative methods for resource management and recycling), investment and financing (financial support has not only encouraged the growth of green industries but has also contributed to job creation, economic growth, and the overall transition to a more sustainable and low-carbon future).

New opportunities for innovations should be definitely implemented using provisions of Industry 4.0. We believe that the primary tasks within the agenda of the European Green Deal should be as follows: employment incentives in high-technology sectors of the economy; coupled with the minimization of reliance on finite natural resources (coal, oil and gas) and the considerable increase of renewable energy sources in the system for energy supply, as well as the implementation of energy-efficient, resource-saving technologies, and the advancement of hybrid vehicles development. The above will strengthen the national economy, enhance its competitiveness due to cost-cutting of domestic products, keeping currency within the country's borders, ensuring partial employment, as well as its increased role in fighting against the global challenges

to mankind such as COVID-19 pandemic and associated quarantine activities.

Analysis of the scientific works and annual reports of international organizations dedicated to the European Green Deal makes it possible to classify historic periods of development, identify and assess the green growth path. The findings are shown in Table 1.

The chronology table illustrates the development, definition, and assessment of the impact of the green growth trajectory and sustainable development, categorized by the type of technological advancements associated with 3, 4, 5 Industrial revolutions. Historical periods of development can be classified into two categories: industrial and post-industrial. Before the analyzing period societies relied on renewable resources such as wood and water for their energy needs. The industrial period (mostly Industry 3.0) saw the rise of fossil fuels and the development of new technologies that promoted economic growth. The post-industrial period (Industry 4.0-5.0) is characterized by a shift towards sustainable development and the use of renewable energy sources.

The international community has kept in sight green economy issues since the early XXI century. With economic tools available, the international organizations developed and produced step-by-step instructions enabling individual countries and the world as a whole to strike a balance between consumption and conservation of our planet.

Thus, for example, the Organization for Economic Cooperation and Development designed Green Growth Indicators [34] to assess the level of green course of countries in the world. The Indicators rest on the following parameters: Efficient and Sustainable Resources use, Natural Capital Protection, Green Economic Opportunities, Social Inclusion. According to OECD, the following EU member-states ranked top positions in the Indicators in 2019: Sweden (78.72), Denmark (76.77), Czech Republic (76.74), and Germany (75.8) [34].

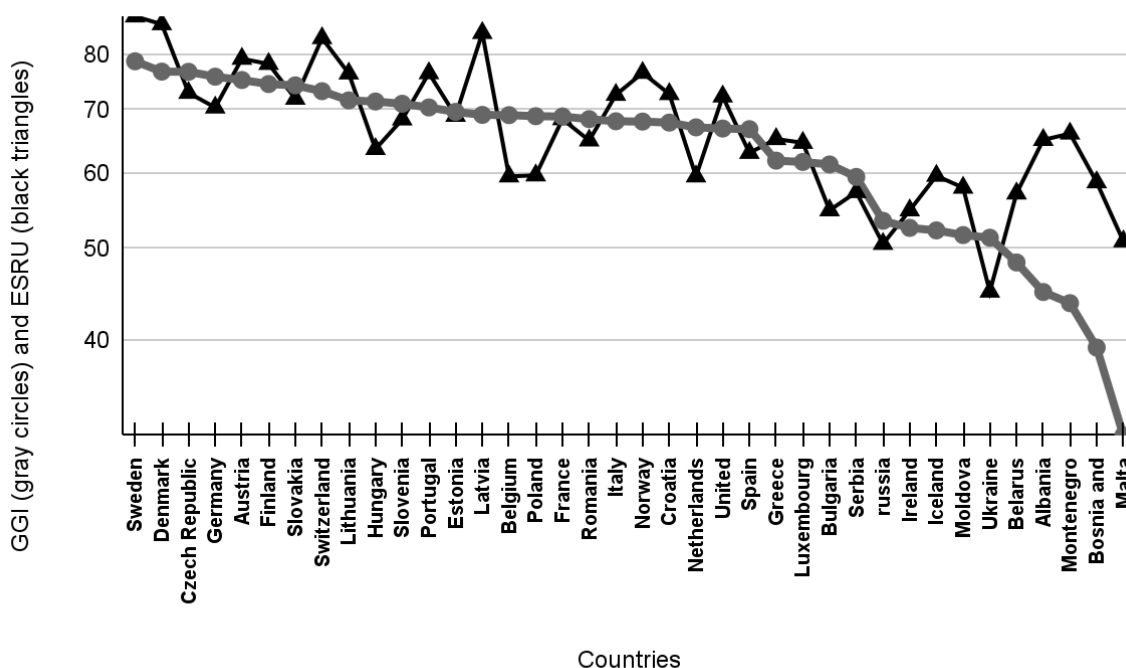


Figure 1. Ranked top positions in 2020 Indicators (Green Growth Indicator (GGI) and Efficient and Sustainable Resources use (ESRU))

Source: author's development based on [34]



Efficient and sustainable resource (Figure 1) use is a critical aspect of transitioning towards a green economy. Several European countries and territories have made significant progress in this area. Denmark (86.12), for example, has implemented policies to reduce its reliance on fossil fuels and increase the use of renewable energy sources such as wind power. Sweden (87.78) has also made significant progress in promoting sustainable development through the use of renewable energy sources and the implementation of effective green growth policies. Other countries such as Finland (78.21), Germany (70.37), and Norway (76.54) have also made significant strides in promoting efficient and sustainable resource use. These countries have implemented policies to reduce waste, increase recycling, and promote energy efficiency, among other measures.

Analysis of rating components reveals that the highest efficient and sustainable resources used in 2019 among EU member-states was demonstrated by Sweden – 87.78 and Denmark – 86.12. Ukraine scored modestly with 45.02 points [34]. It means that our country should develop and introduce policies focused on the sustainable use of natural sources and maximizing the use of renewable energy sources.

In respect of the second group of the Indicators – Natural Capital Protection – Slovakia (85.53) and Croatia (84.04) got the highest points. In 2019 Ukraine had a rather high indicator of 62.57 points. The third group of the Indicators measures impact of the environment condition and environmental assets for the benefit of mankind. The Czech Republic (65.49) and Germany (63.73) were the leaders in this group. Ukraine had a rather low value with 35.34 points [34].

Therefore, mitigation of the adverse impact of ecologically hazardous productions on the quality of life of Ukrainians remains among strategic lines for the country. With respect to the fourth group of the Indicators deserves closer scrutiny since they make it possible to assess the efficiency of the state policy with a green growth. In 2019 Sweden (94.06), the Netherlands (92.51) and Denmark (92.33) ranked top. These countries are absolute leaders of OECD rating. Ukraine enjoys a rather high result with 69.62 points [34]. This speaks for the country's intention to attain sustainable development of the national economy without disrupting ecological balance.

The geopolitics of energy consumption and energy production is now destabilizing because of the Russian-Ukrainian war. These challenges only reinforce the need to accelerate the transition to increased renewable energy production and reduced fossil fuel energy consumption. But multiple energy shocks are also driving up production and supply chain costs in energy innovation [9].

A comparative analysis of green growth indicators can help identify leaders in terms of efficient and sustainable resource use, natural capital protection, impact on environmental state and ecological assets, and effectiveness of green growth state policy. Countries like Denmark, Sweden, and Finland have made significant progress in promoting sustainable development through the use of renewable energy sources and the implementation of effective green growth policies.

As noted in paper by Patrik Söderholm: "Addressing climate and environmental challenges, clearly requires natural scientific knowledge as well as engineering expertise concerning the various technical solutions that can be

adopted to mitigate the negative impacts (e.g., carbon-free energy technologies). The pursuing sustainable technological change is also a societal, organizational, political, and economic endeavor that involves several non-technical challenges. For instance, the so-called transition literature recognizes that many sectors, such as energy generation, water supply etc., can be conceptualized as socio-technical systems and/or innovation systems" [4].

This perspective highlights the interconnectedness of social, technological, and economic factors in shaping sustainable transitions. A notable exemplification of such a holistic approach can be observed in the case of implementing a solution for the introduction of impact measurement systems for certain processes on climate change and energy efficiency. Swedish company Doconomy [35] coming third in the rating of innovative companies [36] found an easy way to track the adverse impact of people's spending on the environment. The credit card of DO White company using a cloud service to measure climate impact tracks CO<sub>2</sub> emissions produced as a result of the card owner's purchases. The company attracted 20 thousand clients in Sweden for several months after the launch of the DO card in mid-2 [35; 36]. This example of a responsible attitude to the social problems of mankind prepares the ground for development of similar technologies.

To ensure such directions of scientific and technological development put in practice (typical for developed countries in the world, namely for UN member-states) the Government of Ukraine approved a special programme on creation and introduction of all advanced technologies and innovative methods in all economy sectors which efficient implementation should accelerate the technological development of the country and ensure the increase of national wealth and its people's well-being.

In terms of legislation, virtually all aspects of mutually advantageous international scientific and technical cooperation of Ukraine with other partner countries are regulated. For the years of independence, a lot of treaties on cooperation in the area of science, technologies and innovations have been signed on intergovernmental level. These treaties are implemented not only between individual countries, but also under the auspices of international economic organizations and integration groups; however not all these aspects have a green growth path being up to date in the XXI century.

It should be noted that in previous publications the authors conducted a thorough analysis of the use of Industry 1.0, 2.0, 3.0 and 4.0 technologies in the utility sector in the context of building a green economy [37–39]. The findings of aforementioned analyses indicates that the shift towards a green economy necessitates the adoption of latest technologies enabling enhanced resource efficiency and diminished environmental repercussions. So, in the utility sector, this means the use of modern water supply and drainage management systems, the approbation of energy-efficient technologies in construction and heating, and the use of renewable energy sources and other innovative solutions.

However, under the legal regime of martial law, numerous utility enterprises in Ukraine face inadequate financial resources to implement new technologies, highlighting the necessity to attract investments and support from both governmental and relevant international organizations. Ukraine has some experience in attracting international assistance for the development of renewable energy. For example, within the framework of the United Nations Development

Programme (UNDP) in Ukraine, the project "Support for the Development of Renewable Energy in Ukraine" was initiated, aimed at attracting investments and technologies to support the development of the renewable energy sector. Ukrainian companies can also participate in programs and competitions that provide financial support for the development of renewable energy. For example, the "Horizon 2020" program of the European Commission provides financial support for research and innovation in the field of renewable energy. In addition, Ukraine has signed an Association Agreement with the European Union, which provides support for the development of renewable energy and the reduction of harmful emissions into the air.

**Conclusions.** The study of the processes of formation and development of the green economy in individual countries showed that the current status of innovations in Ukraine lags behind such solutions in technologically developed countries. There exist legal, economic and organizational foundations of innovations in Ukraine which are governed by the Constitution of Ukraine. A number of laws are enacted regulating public relations in this area however being insufficient in the environment of Industry 4.0 in case of stiffer international competition. The concept of the European Green Deal provide that Ukraine should:

1) not defy legal regulations pertaining to acceleration of scientific and technological activities, improvement of innovative infrastructure, maintaining stable political and economic situation in the country and a selected course to innovative development and their implementation for further green economy growth.

2) formulate a system for efficient instruments of government regulation of innovative activities providing incentives for enterprises to innovative and scientific-technological development in the area of a green economy.

3) develop schemes of tax incentives adjusted for various factors considering the available scope of finance for technological and innovative activities within the national economy framework, established innovation-oriented culture, political objectives etc.

In conclusion, energy technologies advancements are crucial in transitioning towards a green economy. The green economy encompasses various sectors that require innovative solutions to promote sustainable development. Industry 5.0 and the provisions of the European Green Deal provide new opportunities for energy innovation in the national economy. A comparative analysis of green growth indicators can help identify leaders in terms of efficient and sustainable resource use, natural capital protection, impact on environmental state and ecological assets, and effectiveness of green growth state policy. Continued energy innovation and technological progress are necessary to achieve a sustainable and environmentally-friendly future.

The systematization and generalization of green economy evolution and analysis of energy innovations and green policy for sustainable development are elements of scientific novelty in the results. The prospective direction of further research is an important question of the study. Discussion of the implications of the findings for the European Green Deal and the future of the Green Economy for the Ukrainian way of reconstruction after the war will be given in the next papers of authors.

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