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Ukraine's Green Economy Growth in the Context of Industry 4.0: Challenges and Solutions

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Abstract. The research highlights the importance of prioritizing new sources of economic growth for the world, with a specific focus on Ukraine. The information base of the study included data from the statistical and managerial reporting of enterprises, the State Statistics Service of Ukraine, and information-analytical materials from international organizations. The authors analyze scientific works associated with the European Green Deal (EGD) to identify historic periods of green economy growth and establish growth trends. The authors argue that favorable conditions are necessary to achieve sustainable green growth within the framework of the EGD. The study aims to introduce an improved economic definition, namely the efficiency of green (natural) capital, aligned with the provisions of the EGD in the context of Industry 4.0. The analysis demonstrated that the coefficient of green (natural) capital (GNC) efficiency is crucial in decision-making processes by enterprises, taking into account ecological and green (natural and resource) factors. The analysis also includes a flowchart of Ukraine's green economy growth in the environment of Industry 4.0 as of 2022. The research results have led to the improvement of scientific and methodological approaches to assessing the eco-economic efficiency of advanced green technologies. The introduced green (natural) capital indicator allowed to display of the theory of achieving more products and services with fewer resources, including natural and ecological ones.
Keywords: Green Growth Indicators, European Green Deal, efficiency of green (natural) capital, Industry 4.0.

Introduction

The world population became more concerned about the fact that the Western model of economic growth (Crafts, 1995; Friedland, R., & Sanders, J., 1985; Rodríguez-Pose, A., Tselios, V., 2010; Ekelund Jr, R.B. and Hébert, R.F., 2013) with its extreme anthropogenic

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burden on the environment, over-exploitation of natural resources, and dehumanization of society proved vulnerable to the global issues associated with the aggravation of raw material, ecological and demographic problems. In the view of intensification of technological globalization processes, Ukraine in its international scientific-technical cooperation should focus primarily on putting into practice the latest achievements of science and technology (Industry 4.0) to ensure the basis of the „green economy" (i.e., tackling challenges in the area of ecology, energy, transport of XXI century, information technology etc.). In the paper (Galushkina, T., 2011) considers trends and ways of creating «green» economy and Investigating stages of development of «green» economy and transformation processes taking place towards the reorientation of «brown» economy to «green». (Vargas-Hernandez, J., Rakowska,Jo. and Vargas-González Omar C., 2022) put attention that Green Economic Development could be the Framework for Green Finance and Green Investment.

Following the authors, building and introducing globally the model of a green economy sustainable growth should be regarded as the only option to overcome the above problem. Such a model entails maximum integration of achievements of science, technology and innovations (Chernenko, et al., 2020), which society enjoys under conditions of Industry 4.0, into the global production and social living environment of mankind. At the same time, the scientific literature is still not fully researched on the issues of determining the current state of the green economy of Ukraine, analyzing its growth potential in the context of the use of Industry 4.0 technologies. Recognizing the contribution of researchers, the scientific and methodological approach to assessing the development of the „green economy", namely, determining the interrelation of aspects of environmental and economic efficiency, requires further improvement.

Present-day experts of the Organization for Economic Co-operation and Development deem (OECD) that the great deal of the countries in the world and Ukraine among them should prefer new sources of economic growth. To pursue such a policy, one should have favourable conditions for getting on the path of harmonious sustainable development of a green economy compatible with the strategy of the EGD. In the environment of Industry 4.0 there exist 2 scenarios of such development of a green economy worth mentioning, i.e. innovations driven by human capital and an ecology-oriented economy. Put in other words, the global economy may grow towards Society 5.0 (Aquilani, et al., 2020) together with addressing ecological challenges. To attain the aforementioned, it is recommended to start with the implementation of the concept of sustainable (ecology-oriented, harmonious and financially solvent) growth which should be integrated into a comprehensive strategy covering demand and supply issues both on the level of the national economy as a whole and its individual sectors.

The primary objective of this article is to investigate how the green economy in Ukraine can expand by incorporating the provisions of Industry 4.0. This study seeks to provide a comprehensive understanding of the potential for growth in the country's green economy. The article will first provide an overview of the concept of Industry 4.0 and its potential impact on the economy. It will then examine the current state of Ukraine's

green economy. The article will also analyze the potential for growth in the green economy sector in Ukraine, including the role of Industry 4.0 technologies in facilitating this growth. Overall, this study aims to contribute to the development of a more sustainable and resilient economy in Ukraine by promoting the integration of green and Industry 4.0 technologies. By doing so, Ukraine can position itself as a leader in sustainable economic development and attract investment from international partners who prioritize environmental sustainability. The study also aspires to advance the scientific and methodological framework for assessing the progression of the „green economy" by introducing an enhanced indicator that considers environmental and economic efficacy. This novel indicator considers the green (natural) capital, the net income generated from investment in environmental protection measures, and Industry 4.0 conditions. It enables the tracking of the effectiveness of environmental protection measures relative to pollutant emissions. This approach deviates from conventional methods and strives to enhance the evaluation of the green economy's growth potential. Ultimately, the discussion will encompass the policy implications derived from the analysis. Key findings of this research can provide valuable insights for policymakers, businesses, and investors in Ukraine who are interested in promoting sustainable economic development. By incorporating Industry 4.0 provisions into the green economy, Ukraine can create new opportunities for innovation, job creation, and economic growth while reducing its environmental impact.

1. Review of the scientific literature

In was in 1989 when Professor Edward B. Barbier in cooperation with his colleagues, experts on economy and ecology first mentioned the definition of a green economy in a pioneering report for the UK Department of the Environment called *Blueprint for a green economy* (David, Anil, and Barbier, 1989). This research paper was developed for consultations of the UK Department on sustainable development issues. The theory of a green economy was further expounded in the works of the same authors (Barbier, Pearce, and Markandya, 1990) and Plan 3: Measuring Sustainable Development Efficiency (in 1990 and 1994). Later Professor Edward B. Barbier published another work titled *A Global Green New Deal* (February 2009) at the request of UNEP stating that within the next two years investments of 1% global GDP would lead to the creation of a critical mass of green infrastructure sufficient to lay solid groundworks for a green economy on a global scale (Barbier, 2009). It is also worth stating that early XXI century international organizations scrutinized important aspects of investing in sustainable development. Thus, based on the United Nations Environmental Programme Financial Initiative (UNEP FI), the United Nations Global Compact, and other such declarations, the United Nations' Principles for Responsible Investment (UN-PRI) were established in 2006 to encourage financial institutions to integrate ESG (environmental, social, and governance) factors into the decision-making process. In 2011 the European Commission published the Thematic Issues focused on the Global Green Economy (European Commission, 2011). In 2012 Hussein Abaza, a former Chief of the Economics and Trade Branch of the United Nations Environ-

ment Programme (UNEP), structured a number of papers devoted to green economy issues (UNEP, 2012). Thus, for example, Ulrich Brand in his paper *Green Economy – the Next Oxymoron?* focusing on sustainable development expresses the idea that "strategies of a green economy are going to be realized at the expense of other sectors and regions, e.g., the increase of renewable forms of energy at the cost of destructive palm oil production in Indonesia or biofuels in Brazil" (Ulrich, 2012). In their joint report *Moving towards a Common Approach on Green Growth Indicators (*Green growth knowledge platform, 2013) the authors propose a framework that provides a common basis for further developing GG/GE indicators, with a special emphasis on economic-environmental nexus.

Among the latest research of green economy issues, one should single out the work by Soderholm P. (2020) where the authors analyzed green capitalism and the uncertain business-as-usual scenario and the role of the state and designing appropriate policy mixes. Suggestions for public policies were brought forward by Lucreția Dogaru (2021). The aforementioned postulates were further supported by various researchers in their analyses of such issues. Thus, the work by Meghișan-Toma and others establishes the impact of green productivity on digitalization, green production and environment commitment (Meghișan-Toma, et al., 2022).

Ćetković et al. (2021) in their paper *Economic Analysis of Measures for GHG Emission Reduction* noted in respect to EGD measures as follows: "introducing taxes on carbon or trade systems restraint creates an environment for consumption choice, targeting low-carbon activities, increasing investment in more environment-friendly technologies". The work by Ionescu et al. (2022) establishes a new approach on the foundations of financial allocations for the sustainable growth of the digital economy needed in the current conditions of the global crisis and of the pandemic for the implementation of digital economy growth policies. Muhadinovic, Djurovic, and Bojaj in their paper (2021) investigate and forecast the linkage and causality between greenhouse gas emissions (GHG) and Gross Domestic Product (GDP).

Considering specific aspects of the current development of the world economy in the context of Industry 4.0 economic growth and overcoming of ecological problems should be brought into action by the transition to an ecology-oriented model of a green economy within the framework of the innovative development model of the EGD. The model generates new opportunities and challenges for all member-states of the European Union (EU).

Thus, Brătucu et al. (2022) propose to combine the model of the EGD – to which all 27 member-states have committed themselves by creating new opportunities for innovation, investment and jobs, with the aim of digitally transforming European society – with the problem of avoiding digital disruption in the EU. 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 EGD should be as follows: employment incentives in high-technology sectors of the economy; putting to minimum use of available natural resources (coal, oil and gas) and considerable increase of renewable energy sources in the system for energy supply, generation and introduction of energy-efficient, resource-saving technologies, development of hybrid vehicles. 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. This speaks for the country's intention to attain sustainable development of the national economy without disrupting ecological balance.

Industry 4.0, which represents the integration of advanced digital technologies in manufacturing and other industries, has the potential to support and promote the transition to a green economy in these concepts: circular economy and sustainable production (Bag, 2021; Ottonicar, 2022), green finance (Bhatnagar, 2021), green supply chain management (Umar, 2022), green jobs and green infrastructure (Rutkowska, 2020), green logistics (Seroka-Stolka, 2019), smart buildings, energy model of the building (Agouzoul, 2022), green finance, green climate funds and green bonds (Mohsin, 2023), and others.

In the realm of the European Green Deal, the paper by (Hasse, 2023) advocates for a critical reassessment of the pursuit of infinite economic growth within the constraints of planetary limitations. Emphasizing that the green transition goes beyond a mere quest for economic gains, this research underscores the importance of integrating a vision that prioritizes principles of social and environmental justice.

2. Description of research hypotheses

Robust definition of strategic objectives of the state policy takes the lead in restructuring the national green economy with a green growth. As evidenced by the experience of the countries with high performance in Green Growth Indicators, determination with due regard of outcomes and ecological-socio-economic impacts allows to revise and refuse low-efficient state policies (for example, subsidies given to fuel-production industries) and switch to such effective financial tools as fair pricing, promotion of investments into environment-friendly technologies and increase of responsible companies in society. It is essential that social responsibility should be supported by the state, international organizations and other key economic players. The framework of such support is displayed on Figure 1.

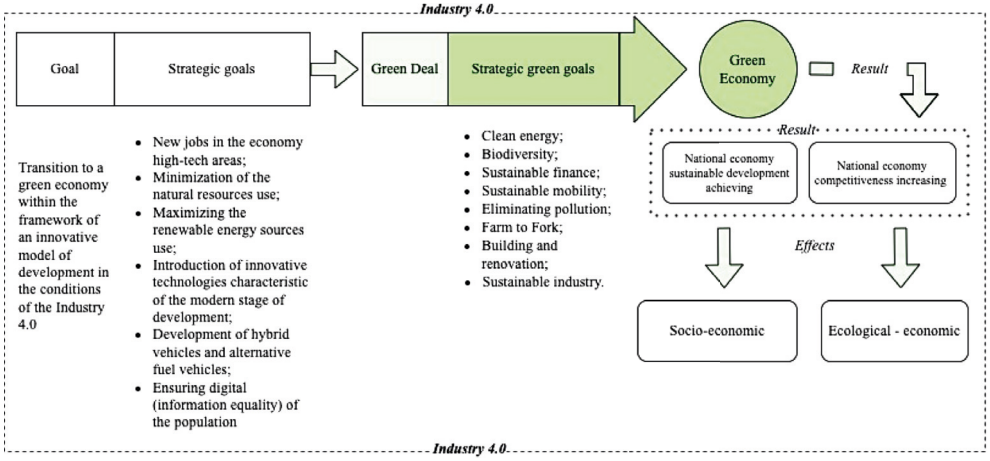

Figure 1. Green economy growth within the framework of innovative model adjusted for Industry 4.0 (as of 2022)

Following (Figure 1), a wide selection of initiatives associated with innovation promotion is also the major driver of creating new environment-friendly technologies, leaner production and expansion of employment by creating new jobs.

To have the possibility to create innovations, green latest technologies one should use various ways, methods and techniques covering not only pricing tools and incentives for companies' engagement in ecology-oriented activities, but also public procurements and financing of fundamental research (Chernenko et al., 2021). Against this background, the authors suggest a flow chart of green economy growth for Ukraine in settings of Industry 4.0 presented on (Figure 2).

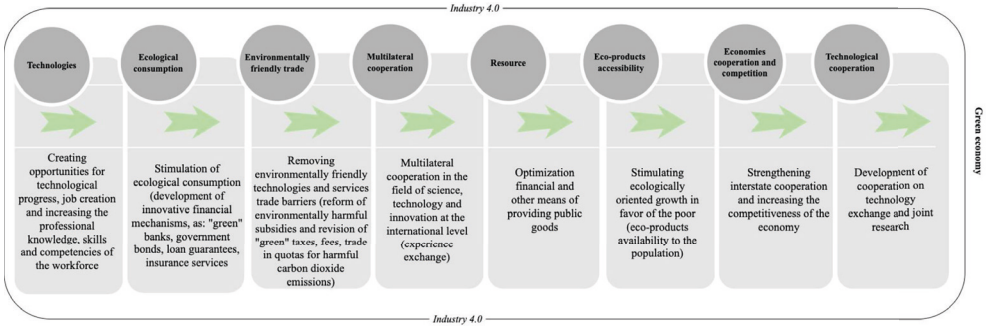

Figure 2. Flow chart of green economy growth for Ukraine in settings of Industry 4.0. (as of 2022)

Figure 2 shows visually the transition to green technologies, i.e. Ukrainian economy's pursuing to sustainable green development. It is influenced by certain circumstances such Industry 4.0. It is worth mentioning that the transfer and further sustainable development of Ukraine's green economy are aligned with UN recommendations on the implementation of green state policies and development of environment-friendly vehicles, usage of alternative energy sources, green building and industry. Implementation of the state green economy growth in Ukraine under conditions of Industry 4.0 is expected to give rise to the following:

- creation of new and renewable energy sources; innovative resource-saving technologies and refinement of electric power plants;
- machine building as the basis for high-technology renovation of all industry sectors resulting in the growth of high-quality metallurgy;
- nanotechnologies as one of prerequisites, specifically: microelectronics, information technologies and telecommunications;
- development of biotechnologies (becoming of prime importance in XXI-century global pandemic), improvement of chemical technologies, introduction of new materials, raw materials and byproducts;
- high-technology development of agriculture and processing industry;
- state-of-the-art transportation systems: building and reconstruction;

- environment protection and enhancement, recovering of people; development of the innovative public culture;
- production of vehicles, development and introduction of innovative technologies for their manufacturing.

For the Ukrainian economy to achieve high level of innovation and competitiveness the above directions of science and technology development should become top-priority and advanced from the perspective of their importance and efficiency while manufacturing.

3. Methods and methodology

To achieve the goal and address the main tasks of the article, the authors have applied various methods of scientific research, such as: dialectical, historical-logical, method of scientific abstraction. Methods of comparison, statistical grouping are used for the analysis of the number of air pollutant emissions and greenhouse gases, spending of business entities on nature-protection measures, economic-statistical methods are used to determine the dynamics coefficient of ecological spending efficiency and quantity of air emissions of enterprise. Tabular and graphical description methods are used to systematize the data and also, to visualize organized data related to a specific research question.

The primary purpose of this research is to suggest to the global community an improved methodology to assess ecological-economic efficiency of advanced green technologies (fostering such growth) in the context of increased interest of the global community to the notion of a green economy. Such methodology rests on the introduction of a new economic definition of efficiency of green (natural) capital in settings of Industry 4.0. It should be emphasized that a suggested improved methodology complies with basic postulates of the EU concept of the EGD.

Let us consider a standard production function with three factors (L,K,t) (Sharapov, Derbentsev and Semonov, 2004) and add an additional compulsory factor Z - efficiency of green (natural) capital:

$$Q = f(L, K, t, Z), \tag{1}$$

where as Q – potential production volume of advanced technologies at a certain period of time (from a macroeconomics perspective, this could be a Gross Domestic Product);

L – labour (human capital) engaged into production of advanced technologies;

K – capital (venture);

t – time during which advanced technologies are released with involvement of green component, innovative technologies;

Z – green (natural) capital to provide society with ecological sustainability, high level of innovation and competitiveness, i.e. enhance ability of the natural environment to supply the society with resources and ecological assets at a given time and in the future (over a period of time) for sustainable development of a green economy following the selected path.

With the help of a factor analysis it is possible to establish the impact of each factor on a function resulting indicator (1) describing sustainable development of the national green economy. After that such factors are considered while determining, as the authors suggest, an efficiency coefficient of green (natural) capital, advanced green technologies (labour, capital, natural resources, environment condition and quality). The authors believe that these factors move the green economy growth towards Industry 4.0 emphasizing high-priority trends of progress in science and technology.

An improved methodological approach to the assessment of ecological-economic efficiency of advanced green technologies is based on defining ecoefficiency, i.e. efficiency of green (natural) capital. To this end, new indicators should be introduced representing:

$\frac{Q}{Z} = GI$ – return of green (natural) resources over a period of time under conditions of Industry 4.0;

$\frac{Z}{Q} = GR$ – green capacity (natural resource intensity).

It is worth pointing out that the need to establish a coefficient of green (natural) capital efficiency (hereinafter referred to as "GNC") arose due to keeping the track of ecological and green (natural resource) factors in the decision-making process by enterprises being compatible with new rules of the EGD. A suggested indicator (GNC) reflects the theory of getting more products and services with less deployed resources including natural and ecological ones and should be determined as follows:

$$GNC = \frac{Green\ Result\ (GR)}{Green\ Impact\ on\ Environment\ (GI)}, \quad (2)$$

where as, GR – assessment of derived economic result or effect (added value of gross output, additional profit);

GI – environmental impact assessment (volume of consumed natural resources, economic losses from ecological destruction). For example, in 2018 V. Frechko, an inventor from Ukraine won the gold medal at Genius Olympiad in New York for his project Recycle of Fallen Leaves. An invention on manufacturing paper from recycled fallen leaves during a year allows to cut down deforestation by 18% in the world (processing just 600 kg leaves a day) (Frechka, 2018).

The given method proves useful when choosing among several alternative options for environmental impact decline or selecting the most appropriate and competitive advanced technologies. Such alternatives may be implemented subject to careful analysis of many details (design of product specifications, condition of financial and production capabilities of a company, repayment period of state-of-the-art advanced technologies, analysis of environmental impact types, environmental assessment of product life cycle, analysis of risk factors). Selectable indicators and parameters should comply with objectives and production environment of advanced technologies.

Schematically a formula numerator GNC (2) may be presented in the form of green results (GR):

$$GR = E - CS - AC - CC + OI - OE - CTax, \quad (3)$$

where as, E – earnings, money units;
CS – cost of sales, money units;
AC and CC – administrative and commercial costs, money units;
OI and OE – other income and expenses, money units;
CTax – corporate tax, money units.

Then formula (2) will look as follows:

$$GNC = \frac{GR}{GI} = \frac{E - CS - AC - CC + OI - OE - CTax}{GI} \quad (4)$$

(Formula 4) is an approach to assessing the growth of the „green economy", unlike existing ones, is based on the proposed indicator (coefficient) of environmental and economic efficiency, which takes into account the use of green (natural) capital, the level of net income received from each monetary unit invested in environmental protection measures, and the factors (features) of Industry 4.0. Formula (4) based on the research by (Galushkina, T., 2011) "Vector Of Green Economic Development Of Ukraine" which considering trends and ways of creating «green» economy. (Galushkina, T., 2011) identified that investigated stages of development of «green» economy and transformation processes taking place in Ukraine towards the reorientation of «brown» economy to «green».

It is noteworthy to acknowledge the manner in which this study advances upon prior research and the extanted literature. „Green Capital: A New Perspective on Growth" by

Christian de Perthuis and Pierre-André Jouvet (Perthuis, C. D., & Jouvet, P. A., 2015) – this book explores the concept of green capital and how it can be used to promote sustainable economic growth. „The Net Benefits of Pollution Prevention: A Case Study of the Paint Manufacturing Industry" by David Pennington and Charles H. Kriebel (Pennington, D., & Kriebel, C. H., 1992) - this article presents a case study on the net income generated from pollution prevention measures in the paint manufacturing industry. „Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries" by Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015) and „The Fourth Industrial Revolution" by Klaus Schwab (Schwab, K., 2016) – this book discusses the potential of Industry 4.0 technologies, such as automation and artificial intelligence, to transform manufacturing industries and promote economic growth. „Green Growth: Economic Theory and Political Discourse" by Richard Perkins and Eric Neumayer (Perkins, R., & Neumayer, E., 2012) - this article provides a critical analysis of the concept of green growth and its potential to promote sustainable development. „ Sustainability Assessment Tools" by Marco Taisch and others (Taisch, M., Sadr, V., May, G., Stahl, B.,

2013) – this article reviews existing information on the intersection of Industry 4.0 and sustainable production, highlighting the potential benefits and challenges of integrating these two concepts. However, based on the description provided, the approach mentioned (formula 4) seems to be a novel one that combines elements of green capital utilization, net income generated from environmental protection measures, and Industry 4.0 features to assess the growth potential of the green economy. This approach may differ from existing methods and could potentially provide more comprehensive insights into the economic benefits of sustainable development.

4. Data and analyses

The study is conducted to provide insights into how Industry 4.0 provisions can be incorporated into the green economy in Ukraine to promote sustainable economic development. The research will use a mixed-methods approach, including a literature review and case studies. The findings will be analyzed using statistical methods and presented as a comprehensive report with some recommendations for policymakers, businesses, and investors on promoting the growth of the green economy in Ukraine.

Before applying an improved methodological approach to calculations of certain enterprises it is recommended to assess the number of air pollutant emissions (Figure 3) and the general spending behavior of business entities on environmental protection (Figure 4).

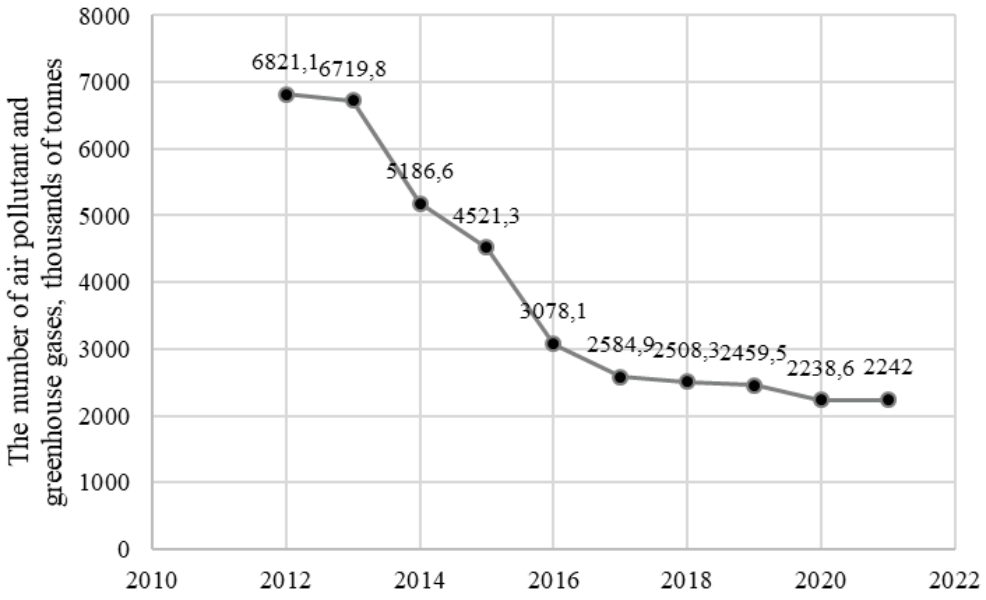

Figure 3. The number of air pollutant emissions and greenhouse gases in Ukraine (for the period 2010-2022)

Research findings (Figure 3) in Ukraine, the number of air pollutant emissions have been steadily declining since 2013, according to data analysis. The creation and implementation of environmental protection program by businesses is one of the major causes of this decline. Within the framework of its European integration, Ukraine should fulfill a number of commitments before EU on enhanced environmental protection and gradual reduction of polluting emissions (Figure 4).

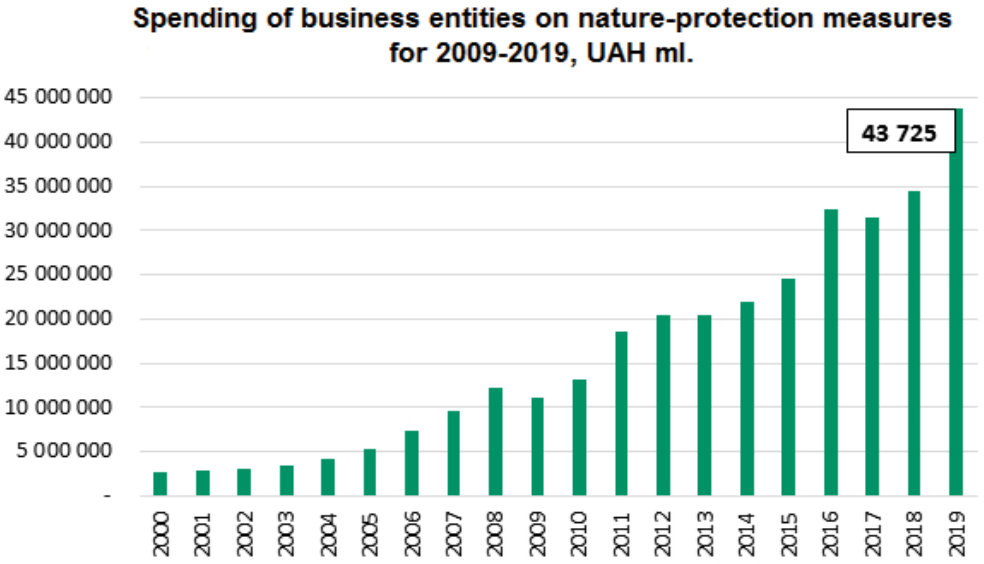

Figure 4. Spending of business entities on nature-protection measures for 2009-2019 in Ukraine

Research findings (Figure 4) presented at ECO BUSINESS Group demonstrate a steady trend of increased spending of Ukrainian business entities on nature-protection measures. Whereas in 2012 and 2013 such spending just crossed the limit of UAH 20 ml then in 2019 it increased almost twofold as compared to the aforementioned years and made UAH 43.7 ml. (Kuznetsova, M., 2020).

Let us consider the dynamic pattern and efficiency of spending on environmental activities by Ukrainian companies emitting the most pollutants and taking a proactive approach in introducing green technologies into manufacturing for a research period (Table 1).

Domestic enterprise environmental programs are typically designed for multi-year periods, making it difficult to evaluate their economic effects in relation to a specific year.

To address this issue, we propose an environmental and economic efficiency indicator that can be tracked over time to capture the cumulative effects of gradual financing in environmental protection measures.

Table 1. Comparative analysis of efficiency of green (natural) capital in 2018-2020 at enterprises of Ukraine

Enterprises	Year	Spending on nature protection measures, UAH ml.	Net profit, UAH ml.	Net operating income, UAH ml.	GNC (efficiency „Green (natural) capital")	Quantity of air emissions, thousand tons	Coefficient of ecological spending efficiency
PJSC "AZOVSTAL IRON & STEEL WORKS"	2018	331,2	3570,9	81960,9	10,8	88,8	247,5
	2019	834,8	-5670,9	57293,1	*-*	81,4	68,6
	2020	844,7	420,8	50563,3	0,5	84,3	59,9
PJSC "ILYICH IRON AND STEEL WORKS"	2018	1925,0	3372,3	79091,1	1,8	3743,9 (carbon dioxide)	41,1
	2019	2600,0	-5405,2	80921,2	*-*	3536,8 (carbon dioxide)	31,1
	2020	3046,0	186,5	77153,9	0,1	3921,6 (carbon dioxide)	25,3
National Nuclear Energy Generating Company «Energoatom»	2015	275,0	1115,4	32903,9	4,1	227,4	119,7
	2016	316,1	232,8	36067,9	0,7	234,1	114,1
	2017	489,9	3822,4	38487,7	7,8	230,0	78,6
	2018	763,7	4631,8	83402,4	6,1	236,4/4516,8 (carbon dioxide)	109,2
	2019	515,0	3773,6	90352,3	7,3	146,2/1386,8 (carbon dioxide)	175,4
	2020	3240 (3502)	-4845,2	75291,6	*-*	145,7/1555,8 (carbon dioxide)	23,2
DTEK	2007	91,4	1193	8969	13,1	391,9	98,1
	2008	211,6	119	12969	0,6	526,6	61,3
	2009	191,1	856	15009	4,5	464,5	78,5
	2010	194,7	2857	24294	14,7	493,2	124,8
	2011	320,3	3522	39594	11,0	588,9	123,6
	2012	916,4	5922	78340	6,5	1126,7	85,5
	2013	976,0	3332	92817	3,4	1090,9	95,1
	2014	777,2	-19660	93254	*-*	989,7	120,0
	2015	822,5	-41890	95375	*-*	771,7	115,9
	2016	858,3	-1215	131815	*-*	*-*	153,6
	2017	1116,5	4628	145070	4,1	863,8	129,9
	2018	1314,1	12373	157619	9,4	771,8	119,9
	2019	1350,1	12592	137742	9,3	723,1	102,0
	2020	728,1	-13895	116046	*-*	607,8	159,4
PJSC «Ukrhydro-energo»	2018	5,22	3668	7960	702,7	6,0	1524,9
	2019	59,35	3222	8262	54,3	4,5	139,2
	2020	44,36	4136	13153	93,2	4,0	296,5
JSP «Ukrzaliz-nytsia »	2018	522,7	203,9	83402,4	0,4	196,6	159,6
	2019	540,3	2988,2	90352,3	5,5	171,9	167,2
	2020	488,2	11899,7	75291,6	24,4	151,2	154,2

Source: compiled by the authors. (PJSC "Azovstal Iron & Steel Works" 2020 page 3; 2019 page 3; PJSC "Ilyich Iron and Steel Works" 2020 page 4; 2019 page 4).

- Due to the enterprise's apparent loss, it is not possible to calculate the coefficient.

We discovered that PJSC Ilyich Iron and Steel Works (PJSC IISW, 2019, 2020) and the National Nuclear Energy Generating Company Energoatom (SE „NNEGC „Energoatom“, 2019, 2020) had the highest pollutant emissions and the most extensive environmental programs by analyzing this indicator for a sample of enterprises (as shown in Table 1). In addition, the National Nuclear Energy Generating Company Energoatom demonstrated a significant reduction in pollutant emissions - by 69.3% - in the first year of the program‘s launch (2018-2019).

However, as these businesses implemented environmental protection measures, their Environmental Spending Efficiency Coefficient decreased. This pattern emphasizes the potential for these programs to provide both environmental benefits and cost savings over time.

The conducted calculations indicate that the proposed coefficient allows for a comprehensive assessment of the effectiveness of aligning financial goals with environmental responsibility for the enterprise. As evidenced by data on pollutant emissions, a portion of the surveyed enterprises successfully utilizes financial resources to protect the environment while simultaneously demonstrating profitable activities (JSP «Ukrzaliznytsia», PJSC «AZOVSTAL IRON & STEEL WORKS», PJSC «Ukrhydroenergo»). Simultaneously, at certain enterprises (DTEK), significant expenditures on green policy measures have resulted in a reduction of pollutant emissions into the air. The practical results obtained highlight the existence of certain challenges and affirm the relevance of applying the proposed model for assessing the effectiveness of implementing green economy measures in enterprises.

5. Results and discussion

The primary objective of comparing these research findings with the existing literature is to contextualize the results, validate the research, and make a meaningful contribution to the broader body of knowledge in the field of green economy. Through this comparative analysis, the authors aim to identify potential gaps in the current literature, which may open avenues for further exploration and research in the realm of transitioning towards a green economy in the context of Industry 4.0.

Industry 4.0 as well as the enhanced international division of labour in the area of science and commercial exploitation of scientific results, necessitate intensification of international scientific and technical cooperation of Ukraine and a review of its forms. Within the EGD, Ukraine recognizes the urgency to carry out technical and process modernization of all manufacturing up to the best global practices. To that end, one should take advantage of available innovative potential, broader international cooperation in the domain of science, education and production adjusted for their environmental impacts.

With due regard to Industry 4.0, as well as techno-globalism growth, Ukraine in pursuing its international scientific-technical cooperation should focus on the deployment of the latest achievements in science and technologies to attain sustainable development of its economy (i.e. settlement of differences in the field of ecology, energy, transportation,

IT), as well as address national security issues (socio-economic wellbeing, stability, counter-terrorism, cyberwars, pandemics with all clear threats to the society). It is worth mentioning that the legislation of Ukraine provides for the following priority areas of international cooperation embedded into national concepts of economy growth in various sectors, specifically scientific and innovative activities: resource-saving technologies, alternative energy sources, nano and biotechnologies; aerospace technologies; information technologies, creation of new competitive materials and products, computer and automated technology, robotic technology and other types of innovative products.

One of the top-priority areas of international cooperation should imply the development of up-to-date technologies in the context of national ecological security. This is exemplified remarkably by the consequences of the Chornobyl catastrophe (XX century) and the global pandemic (XXI century) suffered by the whole world.

Relevance of the given research involves drafting recommendations to the Government and country's leadership on cooperation with other countries to recover from global ecological crises and in the context of Industry 4.0 to promote Ukraine's transformation to an ecologically safe and responsible country of the world by means of the introduction of innovative ecotechnologies being the only a modern green existence (Figure 5).

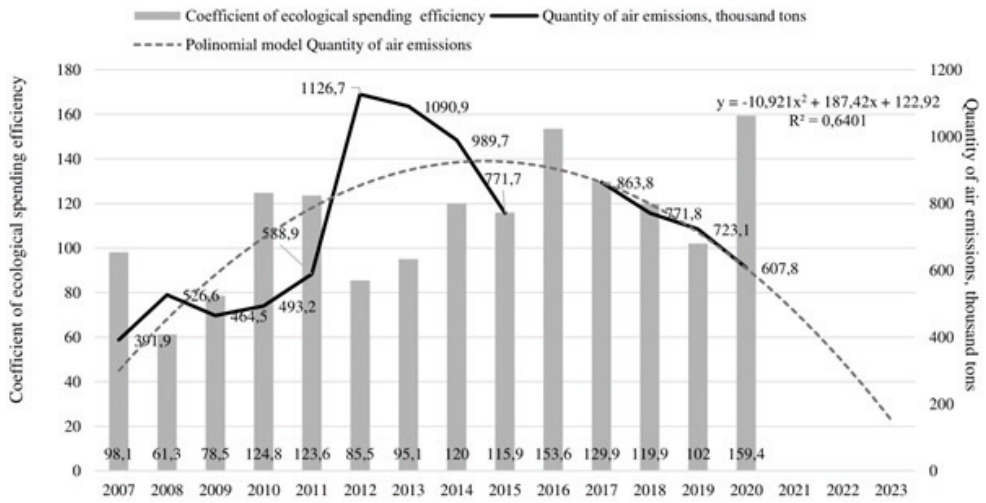

Figure 5. Dynamics coefficient of ecological spending efficiency and quantity of air emissions DTEK for 2007-2023

Source: compiled by the authors. (Activities in the sphere of sustainable development report for 2010-2011, (2012). *DTEK. PJSC "Azovstal Iron & Steel Works" 2020 page 3; 2019 page 3; PJSC "Ilyich Iron and Steel Works" 2020 page 4; 2019 page 4*).

The dependency presented (Figure 5) which was made on Annual reports in 2008-2011, Integrated reports in 2013-2020 by DTEK, shows that in years with the lowest efficiency coefficient values, DTEK enterprises had the highest volumes of pollutant emissions

(in 2008, the coefficient was 61.3, and emissions amounted to 526.6 thousand tons; in 2012 - 85.5 and 1126.7 thousand tons, respectively; in 2013 - 95.1 and 1090.9 thousand tons). With the increase in the effectiveness of environmental protection measures, DTEK demonstrated a decrease in emissions into the atmosphere. For example, in 2010, the coefficient was 124.8, and emissions were 493.2 thousand tons; in 2020 - 159.4 and 607.8 thousand tons, respectively. It is also worth noting that a relatively high level of efficiency coefficient, starting from 2014, leads to a sustainable reduction of pollutant emissions into the atmosphere over time (in 2017 - 863.8 thousand tons, in 2020 - 607.8 thousand tons).

The results of the analysis demonstrate that the proposed methodology is effective in evaluating the expansion of the green economy in Ukraine. The mentioned improved indicator of environmental and economic efficiency provides a comprehensive assessment of the impact of green investments on the economy, society and the environment. The findings indicate that the green economy has significant potential for growth in Ukraine and the green capital and Industry 4.0 technologies can enhance the efficiency and effectiveness of environmental protection measures. However, it is important to note that this study has limitations and further research is needed to fully understand the challenges and opportunities of transitioning to a green economy in Ukraine.

This research aimed to explore the peculiarities of green economy development in Ukraine amidst the fourth industrial revolution. The authors, by comparing the results of global studies, considered international advancements and identified how they differ from prior scientific works in the field of green economy. Current trends in green economy and Industry 4.0 initiatives have gained recognition globally, showcasing positive outcomes and innovative approaches. Consequently, Ukraine is recommended to consider global experience, particularly the European Green Deal (an initiative by the European Union with the goal of making Europe the first climate-neutral continent by 2050) and the Digital Strategy 2025 (aiming to integrate concepts of Industry 4.0 and environmental sustainability). This will enable the incorporation of digital technologies to optimize production and reduce environmental impact.

Conclusions

The results of the research performed are to improve the scientific and methodological approach to the assessment of ecological-economic efficiency of advanced green technologies which unlike existing methodology suggests a coefficient of efficiency of green (natural) capital (GNC). A suggested coefficient is driven by the need to keep the track of ecological and green (natural resources) factors which will enhance the integrity of management decisions taken by enterprises.

The concept of sustainable development gained further support and the authors regulated and structured the chronological order of the world green economy growth. Guided by methodological provisions of Green Growth Indicators the authors described Ukraine's green economy growth in the context of Industry 4.0. The research also presents a further categorial analysis of sustainable development theory, specifically a suggested definition

of efficiency of green (natural) capital aligned with basic provisions of the European Commission concept of the EGD.

Following the findings obtained, the authors consider that formulation and introduction worldwide of the model of green sustainable economic development should be further analyzed as the only option for overcoming global ecological-economic problems. Such a model should provide for maximum integration of scientific-technological and innovative achievements, the society would enjoy the world production and social living environment of mankind.

There are some limitations in this research work. The study is limited to the context of Ukraine and the findings may not be generalizable to other countries or regions. The study relies on secondary data sources, which may not always be accurate or up-to-date. The study does not provide a detailed analysis of the challenges that Ukraine may face in transitioning to a green economy. Also it is necessary to give some recommendations for farther future researches: a studies should consider the socio-economic and political factors that may impact the growth of green economy in Ukraine; it also should compare the experiences of Ukraine with other countries that have successfully transitioned to a green economy; the next future studies should explore the potential role of Industry 4.0 technologies in promoting the growth of green economy in Ukraine.

The findings align with certain aspects of the research conducted by other authors on the same topic. The study has identified several commonalities and differences between global trends and Ukraine's approach to integrating Industry 4.0 concepts into green economy growth. The alignment is evident in the recognition of global initiatives like the European Green Deal, Germany's Digital Strategy 2025. These initiatives share common goals of enhancing productivity, reducing environmental impact, and promoting innovation.

However, unlike existing approaches, the research combines a situational and comprehensive methodology, allowing for a synergistic effect by considering the unique challenges and opportunities of Ukraine (territorial pollution due to armed conflicts, destruction and damage to hydro, thermal, and nuclear power stations) alongside global trends in the application of the Industry 4.0 concept.

It would be beneficial to delve deeper into the specific mechanisms and policies that can enhance the integration of Industry 4.0 in Ukraine's green economy. Exploring case studies, success stories, and potential barriers in more detail could provide practical insights for policymakers and industry stakeholders. Additionally, examining the social and economic impacts of these initiatives on local communities and businesses would contribute to a comprehensive understanding.

Taking into account the current realities happening in Ukraine the destruction and damage to the infrastructure of hydro, thermal, and nuclear power stations, soil and water pollution, as well as air pollution resulting from armed conflicts on the country's territory, have necessitated the assessment of the effectiveness of the environmental component in the development and implementation of restoration projects in Ukraine. The acquired experience can be applied by other countries worldwide whose energy infrastructure has suffered from environmental and climatic catastrophes.

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