

## Article

# Model Analysis of Eco-Innovation for National Decarbonisation Transition in Integrated European Energy System

Viktor Koval <sup>1,\*</sup>, Oksana Borodina <sup>2</sup>, Iryna Lomachynska <sup>3</sup>, Piotr Olczak <sup>4</sup>, Anzor Mumladze <sup>3</sup> and Dominika Matuszewska <sup>5</sup>

- <sup>1</sup> Institute of Market and Economic-Ecological Researches, National Academy of Sciences of Ukraine, 01030 Kyiv, Ukraine
- <sup>2</sup> Institute of Industrial Economics of the National Academy of Sciences of Ukraine, 03057 Kyiv, Ukraine; borodinaoksana1306@gmail.com
- <sup>3</sup> Faculty of Economics and Law, Odessa I.I. Mechnikov National University, 65000 Odessa, Ukraine; i.lomachynska1@onu.edu.ua (I.L.); anzor.mumladze@gmail.com (A.M.)
- <sup>4</sup> Mineral and Energy Economy Research Institute, Polish Academy of Sciences, 31-261 Cracow, Poland; olczak@min-pan.krakow.pl
- <sup>5</sup> Department of Thermal and Fluid Flow Machines, Faculty of Energy and Fuels, AGH University of Science and Technology, 30-059 Cracow, Poland; dommat@agh.edu.pl
- \* Correspondence: viktor-koval@ukr.net

**Abstract:** Consolidation with European social, economic and environmental programmes in the framework of Ukraine's integration into the European energy space has become extremely important given the growing threats to energy security and should become the basis for greening regional and national innovation systems in the context of decarbonisation, the minimisation of carbon emissions and the transition to alternative energy sources. The comparison of the regions of the country by the level of enterprise innovation and the extrapolation of these results to the share of such enterprises in the total number of industrial entities in the regions helped identify their lack of correlation and emphasised the lack of stable dependence between industrial development and innovation activity. The methodology of the article includes a number of general scientific, special and interdisciplinary methods that allowed the screening of areas for the most favourable economic development, taking into account the synergistic component of regional development and achieving the research goal. The aim of this article is to analyse the innovative component of regional and national economic development for the implementation of decarbonisation and green energy transition in Ukraine, as well as substantiate the world's leading imperatives and national directions for effective integration into relevant European programmes. An analysis of Ukraine's rating status in several international indices of environmental efficiency and innovation activity in the regions showed the lack of correlation between regions of Ukraine, which actualises the search for the most effective drivers of economic development. At the same time, the consolidation of efforts of national stakeholders of innovative development in a country with relevant European institutions, particularly in the direction of greening regional economic systems, will ensure the development of innovative regions and industries, which will in turn be drivers of related territories and industries while ensuring a synergistic effect.

**Keywords:** ecology; innovative development; decarbonisation; energy efficiency; "green" transition; sustainable development



**Citation:** Koval, V.; Borodina, O.; Lomachynska, I.; Olczak, P.; Mumladze, A.; Matuszewska, D. Model Analysis of Eco-Innovation for National Decarbonisation Transition in Integrated European Energy System. *Energies* **2022**, *15*, 3306. <https://doi.org/10.3390/en15093306>

Academic Editor: Peter V. Schaeffer

Received: 12 April 2022

Accepted: 28 April 2022

Published: 1 May 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

The growing impact of the ecological footprint on the environment from activities in the energy sector indicates the need to modernise and increase the level of implementation of environmentally sustainable technologies, which makes the search for ways to

transition to national decarbonisation particularly relevant. The purpose of modernisation is to build such an energy system based on the intensification of clean production and the smart specialisation of regional development, which promotes the development of innovative (environmentally sustainable) technologies that significantly increase the share of renewable energy in the overall production structure. For Ukraine, given the current conditions of European integration, the focus should be on the threats and risks of energy and administrative decentralisation and mechanisms for their appropriate response in the context of the integration of the national energy system with the EU energy system. Despite the reduction in sulphur dioxide emissions in Ukraine in 2018–2020 to 20% annually, mainly due to the replacement of renewable energy production of electricity by heat generation capacity, there is still a need for further national decarbonisation of Ukraine's energy sector through environmental modernisation.

The proclamation of the new Green Deal Strategic Plan by the European Union in December 2019 [1] marked a new stage in its development, which is a significant transformation of public consciousness, and its implementation requires fundamental and ambitious goals to address pressing climate and environmental issues. Decarbonisation, minimisation of carbon emissions and transition to alternative energy sources—the central elements of the Green Deal—will be the basis for a number of fundamental transformational transitions, measures for regulatory adaptation and the introduction of protection mechanisms. As a political framework, this European agenda is a response to the challenges of global climate change, environmental pollution and, in light of its initiatives, the positioning of the European Union as a world leader.

Ukraine was chosen as the focus of the study, because after the accession of the Ukrainian energy system to the European ENTSO-E, the energy space became one, creating conditions for mutual strengthening and collective security throughout the region. In recent years, Europe has radically changed its policies regarding fossil fuels. The EU produces approximately one-third of its electricity using local renewable energy resources. The analysis of the role of energy systems in economic transformation to achieve sustainable development is a subject of research interest for European researchers [2]. Thus, the trend of the increasing share of renewable energy in the Ukrainian energy balance is promising.

The current composition of the national energy balance devotes more than half to nuclear generation; however, it is planned to gradually increase the weight of “green” energy to 25% based on the transformation of the energy balance in favour of low-carbon energy sources and the development of new energy technologies that can be used to achieve carbon neutrality. In the structure of the country's own production, the largest shares were: nuclear energy (35.1%), natural gas (27.8%), coal (22.4%) and renewable energy sources (RES) (10.3%). In the structure of total RES production in 2020, the largest share was occupied by biofuels and waste (75.4%). In the structure of electricity production, hydropower was the largest share of RES, but its share decreased by 16.3 percentage points, and, at the same time, the share of solar energy increased by 11.8 percentage points, wind energy increased by 3.3 percentage points, and biofuels increased by 1.2 percentage points [3].

The electricity market in Ukraine has a surplus, so the benefits to European consumers, namely, receiving cheaper energy than in Europe, as well as reducing dependence on Russian energy, are obvious. The stability of the Ukrainian energy system represents an additional reserve of stability for Europe.

In accordance with the strategic course enshrined in the Constitution of Ukraine to attain full membership in the EU and Ukraine's international obligations, the concept of “green” energy transition by 2050 was formed in Ukraine [4].

At the same time, the large-scale process of global support for Ukraine during the military conflict opens up prospects for its early integration into the European energy system, the transformation of its own energy market by carrying out balanced measures, and general economic integration with the EU, especially since national integration intentions coincide with European resource opportunities.

As one of the largest energy markets in Europe, Ukraine's energy market is primarily in need of integration into the European energy system and decarbonisation to ensure the country's energy security. This study highlights the existing resource and innovation trends in the greening of national and regional ecosystems, particularly in the energy sector of Ukraine's economy.

This study identifies the most relevant prerequisites and factors for greening innovation systems at the national and regional levels in the postwar reconstruction of Ukraine's economy, taking into account the latest integration changes in relations between Ukraine and the EU, as well as between Ukraine and the world. The second section is devoted to the analysis of literature sources, both for the ecological component of regional systems (Section 2.1) and for the environmental regulation of alternative energy sources (Section 2.2). Section 3 illustrates the research methodology, consisting of conceptual principles of integration and European environmental programmes (Section 3.1), the method of screening areas for the most favourable development of Ukraine's postwar economy (Section 3.2) and examples of their application (Section 3.3). The fourth section of the article is aimed at examining innovative components of the sustainable postwar development of Ukraine's economy, such as decarbonisation and "green transition" (Section 4.1), with a review of a number of global innovation indices and the analysis of regional innovation development in the country. This section also contains a study of the impact of state regulation on the process of decarbonisation/adaptation in the region (Section 4.2) and applied models of decarbonisation of energy-intensive sectors (Section 4.3). Finally, the findings include the main results of a study on achieving a carbon-neutral level in Ukraine's economy.

## 2. Literature Review

### 2.1. Research Review on the Environmental Component of Innovative Regional Systems

The last decade has been marked by significant interest in scientific circles worldwide in terms of combating climate change and greening national economic systems. For example, van den Berg, Hof and van Soest studied the implications of different approaches to effort sharing on national carbon budgets and emission trajectories [5]. Extensive coverage of the impact of environmental and energy aspects on economic development in the studies of Olczak et al. [6–8] highlighted the issue of regional financial subsidies of sectoral programmes. The main result of the assessment of the impact of bioenergy on sectoral decarbonisation [9,10] is the fact that almost all scenarios of development and transformation of EU energy by 2050 contain forecasts of strategic long-term development of bioenergy, implementation of the "green transition" and decarbonisation of energy-intensive sectors.

Driven by the scientific interest in the ecological component of innovative regional systems, research [11,12] has revealed that in a decentralised model of government in Ukraine, the formation of effective policies for regional eco-innovation will be one of the important endogenous factors in achieving sustainable development.

Sectoral energy efficiency measures and the investment component for their implementation [13] and industrial "green" transformation on the way to decarbonisation [14] have shown that they are the keys to achieving the energy independence of communities and a competitive economy.

Legal and regulatory aspects of greening and compliance with the regulatory regulations of processes [15–17] allowed the substantiation of recommendations for improving regulations, particularly the movement of energy cooperation in Ukraine, and improving the effectiveness of energy efficiency policies and energy security.

Studies have also analysed the impact of support mechanisms on decarbonisation [18–20]. The findings indicate that instruments such as capacity markets can slow the process of decarbonisation in countries that are highly dependent on fossil fuels [21–23]. However, supporting renewable sources and the hydrogen economy can accelerate this process in these regions [24–26].

At the same time, we should note the lack of research on national and regional greening, decarbonisation and the impact of decentralisation processes on energy efficiency, especially

given the challenges of the postwar organisation of the country's structural policy and significant changes in identifying leading industry drivers of Ukraine's effective development. The system of decarbonisation needs to be systematised and analysed, with the conclusion that a comprehensive, integrated model is needed in modern Ukrainian conditions.

## 2.2. Ecological Regulation of Energy Consumption

In addition to environmental or social problems, which are associated with a significant increase in the world's population and have a negative impact on the environment, another problem that encourages countries to actively use renewable energy sources is the depletion of natural resources.

The ecological preconditions for the problems of the depletion of natural resources and environmental pollution are identical, and the ecological footprint of society exceeds the planet's ability to regenerate [27].

EU member states and other countries using economic methods to achieve environmental security have the opportunity to implement strategic environmental goals of sustainable development, which, according to research, helps to approximate economic methods of environmental management [28]. At the same time, there is currently no unified approach to selecting economic tools in environmental management in the EU; each country independently determines the appropriate instruments and approaches to environmental regulation in the energy sector [29].

The implementation of the European experience in Ukraine, particularly the mechanism of environmental taxation, is a difficult process, given the differences between European and Ukrainian approaches to taxation. In the EU, the vast majority of the objects of taxation are energy resources, vehicles and certain groups of goods, and the main principle is indirect taxation. In Ukraine, the object of taxation is the volume of emissions with harmful effects on the environment, and the established rent for the use of natural resources is a fiscal rather than an eco-incentive tool [30].

However, despite the significant amount of research in the field of environmental regulation of energy consumption, the relationship between research on the environmental component of the economy, the sustainability of the energy sector and the regulation of eco-innovative energy consumption remains controversial and little studied.

Despite a number of scientific works and achievements in the theory and practice of using tools to stimulate the mechanisms of renewable energy in a decentralised environment, some issues need further study. It is necessary to study models of decarbonisation, systematise their advantages and disadvantages and make proposals for a hybrid integrated approach to energy decarbonisation policy in Ukraine, which would combine existing models and have a national orientation, given the force majeure of Ukraine's war-torn economy. Research and proposals on renovation programmes in energy-intensive sectors, primarily in the coal industry in the old industrial regions of Ukraine, are relevant.

## 3. Methodology

### 3.1. Sectoral Study of Greening the Economy in the Energy Industry

Sectoral energy efficiency analysis includes a number of models, such as energy systems analysis (ENPEP, MESSAGE), energy and electricity demand (MAED, ENPEP), environmental impact of energy facilities (SimPacts, WASP-IV, ENPEP) and financial analysis of energy systems (FINPLAN). They are designed to analyse and forecast future energy needs and require time intervals to study the conditions and objectives of the countries where implementation is planned. Key conditions for the development of meaningful scenarios are: the application of systematic procedures to ensure the internal consistency of initial assumptions, especially those on social, economic and environmental factors, and a clear understanding of the dynamic nature of modelling, the interdependence among assumptions, the evaluation of results, plausibility criteria and changes to initial assumptions.

To model the sectoral development of the energy industry, this study used econometric methods of simulative modelling, in particular, the rapid diagnosis of the importance and

share of innovative enterprises in the total number of industrial enterprises in Ukrainian regions. This study contained elements of cluster analysis and panel modelling as a justification for the relevance of the greening policy of national and regional ecosystems, taking into account the international status of Ukraine as a member of many international agreements and projects, including the European Green Deal [1], the transformation of coal regions (fair transition), the Paris Agreement [31] and the Climate Goals of Ukraine until 2030 [32].

The idea that the relationship between the greening of the energy sector of the national economy and the national security of the state (through energy security) is direct has been empirically substantiated. At the same time, the desire to liberalise the national energy sector will reduce the level of state influence as a regulator of ensuring the necessary level of greening of the energy sector, addressing the vast majority of energy security issues. State support for the development of “green energy” motivates companies to participate in eco-transformation.

Simultaneously, the input conditions for the current energy state of Ukraine, given energy integration and military action, are so unique that they require special elements of analysis that can effectively take them into account. This study uses a conceptual and analytical model of comprehensive support for the implementation of renewable energy, which can become an innovative component of the sustainable postwar economic development of Ukraine.

### 3.2. Screening Method

In order to select the direction for the most favourable development of the postwar Ukrainian economy, a comparative analysis was conducted to compare the impacts of several project initiatives on sustainable regional development. We selected region-leaders of innovation-active enterprises, which can become a model for the proactive development of Ukraine, taking into account the initial crisis conditions. The screening method highlights the areas of effective postwar development: this is the direction of fair transformation of old industrial coal regions, provoked by the closure of coal mines and related infrastructure. In addition, the focus is on the movement of energy cooperation, which, in the context of decentralisation and the acquisition of a number of financial powers by urban communities, can become a driver of local development.

### 3.3. Mathematical Modelling

The method of applied concretisation of the research results was illustrated by considering the energy cooperative movement in Ukraine and its relationship with the large-scale decentralisation process and the acquisition of a number of powers and rights by local communities to manage their own budgets. It has been proven that the convenience of cooperative organisational and legal forms is due to their flexibility and variability. Simultaneously, the basic resource base for the use of biofuels in agricultural regions of the country is indisputable. The development of energy cooperation is complex, as it has an impact on the revival of processing processes in agriculture and the organisation of the process of organic waste disposal, which is environmentally friendly and economically rational.

The authors’ conceptual-analytical model of the complex support of mechanisms for the introduction of renewable energy is formalised by methods of mathematical logic. Thus, in order to achieve the goal of developing mechanisms for the implementation of renewable energy at the regional and local levels, a system of organisational and economic, fiscal, institutional and regulatory measures was applied.

This study also covered the issues of legal, social and infrastructural organisation of the process of transformation of coal enterprises in a city of constituent entities in old industrial regions.

Analysis of the legal, social and infrastructural organisation of the process of the transformation of coal enterprises was performed using cities as subjects in industrial regions. Thus, the fair transformation of coal regions should create a framework for public-

private partnerships between central government, local communities and investors. As part of the renovation programmes of mono-regions, not only should support be provided to miners from liberated coal enterprises, but opportunities for education and retraining and new jobs for young people and the unemployed should also be created. Thus, the structural transformation of the economy of old industrial coal regions involves direct investment in new infrastructure in these regions, the development of new industries and the mitigation of unemployment.

#### 4. Results

##### 4.1. Decarbonisation and the “Green Transition” as an Innovative Component of Sustainable Economic Development of Ukraine

A significant step towards Ukraine’s European integration was the full connection of the Ukrainian energy system to the ENTSO-E continental European energy system in March 2022, which will secure the Ukrainian energy system in the face of technological, economic and foreign policy risks. The synchronisation of power systems has been carried out since 2017 and demonstrated to be comprehensive and systematic in nature in testing, static and dynamic stability and other technological measures.

The European course for the transition to a low-carbon economy is a list of actions agreed upon by all stakeholders of the process, which should lead to the separation of the socio-economic development of the country from emissions of harmful greenhouse gases (GG). Moreover, anthropogenic factors of harmful emissions of greenhouse gases from vehicles can be represented as a function:

$$TC = P \cdot G \cdot (E \cdot C_{EN} + C_{NE}) \quad (1)$$

where TC—anthropogenic greenhouse gas emissions, tons of CO<sub>2</sub>-eq.; P—population, people; G—consumption of goods per capita, units/person; E—energy intensity of production and consumption of goods, GJ/unit; C<sub>EN</sub>—specific greenhouse gas emissions per unit of energy used in the production and consumption of goods, including emissions from the production of energy, as well as in the production, processing and transportation of fuel for energy production, tons of CO<sub>2</sub>-equivalent/GJ; and C<sub>NE</sub>—specific non-energy GG emissions per unit of good consumed, tons of CO<sub>2</sub>-eq./unit.

Calculated according to this principle, the anthropogenic factor of harmful carbon emissions of CO<sub>2</sub> allows us to state that the problem of greenhouse gas emissions such as carbon dioxide and methane is a priority for the central and southern regions (Figure 1, Table 1).

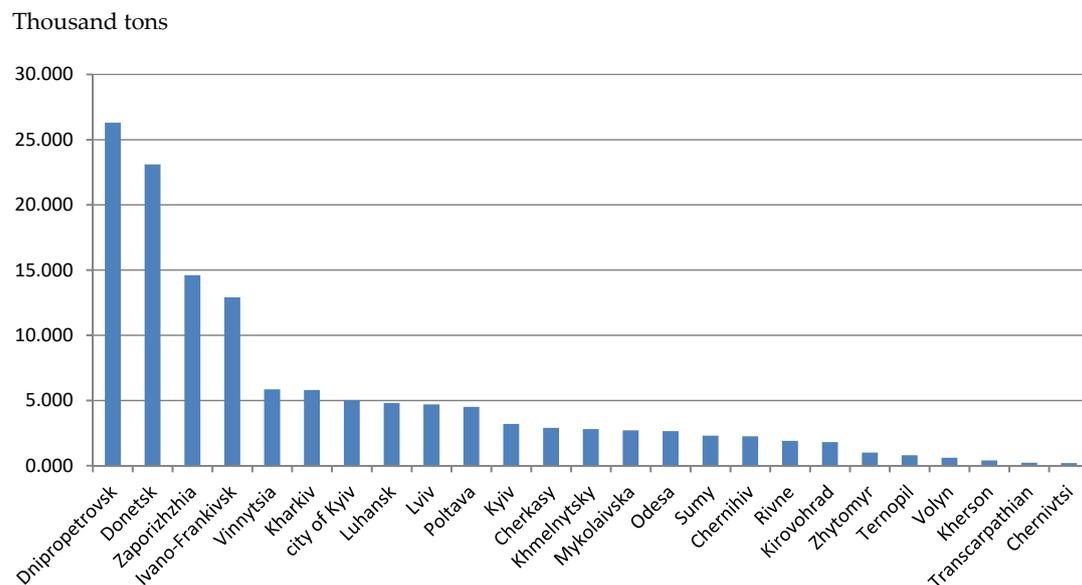


Figure 1. The impact of anthropogenic factor CO<sub>2</sub> emissions in the regions of Ukraine in 2021 [33].

The priority of solving problems to minimise such anthropogenic pressure on the regions is illustrated in Table 1.

**Table 1.** Priority of solving problems of anthropogenic factor of CO<sub>2</sub> emissions into the atmosphere by region of Ukraine.

The Order in the Queue to Resolve the Issue	1	2	3	4	5
Emissions of carbon dioxide into the atmosphere	Centre	South	East	West	North

For Ukraine, especially in the conditions of postwar economic recovery, measures of the synergetic effect of solving problems in key areas are extremely important. Against the background of the unconditional priority of military and civil protection measures, it is necessary to note the real progress in foreign policy and economic processes between Ukraine and the EU and between Ukraine and the world, which has developed over several years and considered only potential scenarios.

At the end of February 2022, the Ukrainian power system was disconnected from the power systems of Belarus and Russia in a test format and underwent technical measures to integrate it into the ENTSO-E continental European energy network as soon as possible and harmonise regulations [32].

It should be emphasised that the process of preparation for the integration of Ukraine's energy system into the EU energy system was carried out for six years and received financial confirmation in the form of 700 million euros of investment [34]. Ukraine has been provided opportunities for crisis assistance from Europe, which is extremely important during wartime. The long-awaited event will attract investors, as Ukraine can count on financial assistance from European partners to rebuild its war-torn infrastructure, and foreign partners have already stated their readiness to provide assistance, with at least 100 billion euros from the EU [35] and 32.5 billion from the USA [36]. Such investment funds, in addition to rebuilding destroyed infrastructure and critical social facilities, should be directed to the most profitable and environmentally friendly production, which can be drivers of postwar economic recovery.

It should be noted that in recent years, Ukraine has implemented several programmes and strategies aimed at reducing the harmful effects of human economic activity on the environment. For example, these areas are reflected in relevant legislative and regulatory acts, such as the Ukrainian law "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030" and the Strategy for Environmental Safety and Adaptation to Climate Change for the period up to 2030.

A separate component is the greening of Ukraine's energy sector in the context of the Green Deal in the EU. Ukraine's implementation of the Green Deal principles in its own legal and economic environment, especially given European opportunities and the desire to integrate Ukraine in most areas as a result of Russia's military actions, will be an indisputable catalyst for economic modernisation. Measures will be especially urgent and appropriate in the context of the reconstruction of enterprises and infrastructure after the end of hostilities.

Among the policy documents of environmental orientation in Ukraine, we must highlight the Strategy of State Environmental Policy of Ukraine until 2030, the Strategy for Environmental Security and Adaptation to Climate Change until 2030, and regional environmental programmes.

These documents are intended to outline the transition of the Ukrainian economy to an ecologically oriented decarbonised (low-carbon, "green") path of development, which involves the rational use of natural resources. However, despite a significant number of efforts by the state in this direction, at present, the quality and speed of economic transformation on the way to greening cannot be called satisfactory, as demonstrated by relevant indicators. Thus, according to the International Environmental Performance

Index (EPI-2020) [37], on the basis of ranking by 32 criteria, Ukraine took 60th place out of 180 countries in 2020 (Table 1).

The analysis of the leaders of the EPI rating shows a steady trend in its dynamics. The top rankings are traditionally occupied by European countries with a high standard of living (high-income group economies) and significant investments in environmental projects (Figure 2). For example, in 2020, the top five were Denmark, Luxembourg, Switzerland, the United Kingdom and France, where sustainable development programmes are successful and stable.

The Global Innovation Index (GII) 2021, generated for 131 countries, is based on 80 indicators of resource importance in the context of this study. According to the index, Switzerland took 1st place in 2021, Britain was in 4th place, Denmark was in 6th place, France was in 11th place, and Luxembourg was in 18th place. Ukraine was in the 49th position in this rating. That is, the correlation between innovation and the environmental efficiency of the state is indisputable.

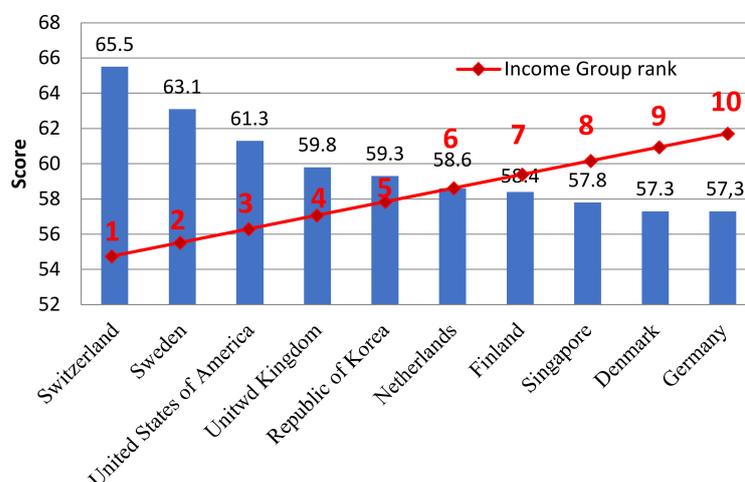


Figure 2. Top ten countries according to the GII-2021 Global Innovation Index. Reproduced with permission from [38]. Copyright 2021, World Intellectual Property Organization.

According to the GII, Ukraine improved only three indicators in 2021: creativity, scientific knowledge, and human capital and research (Figure 3).

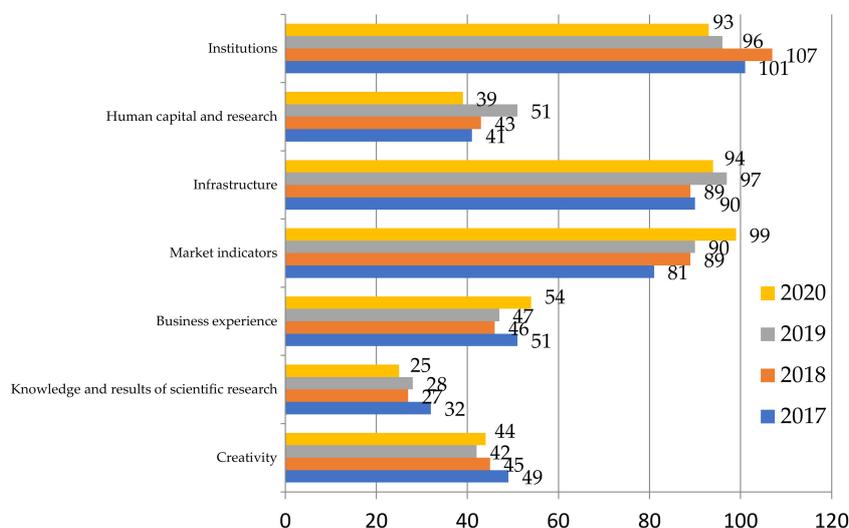
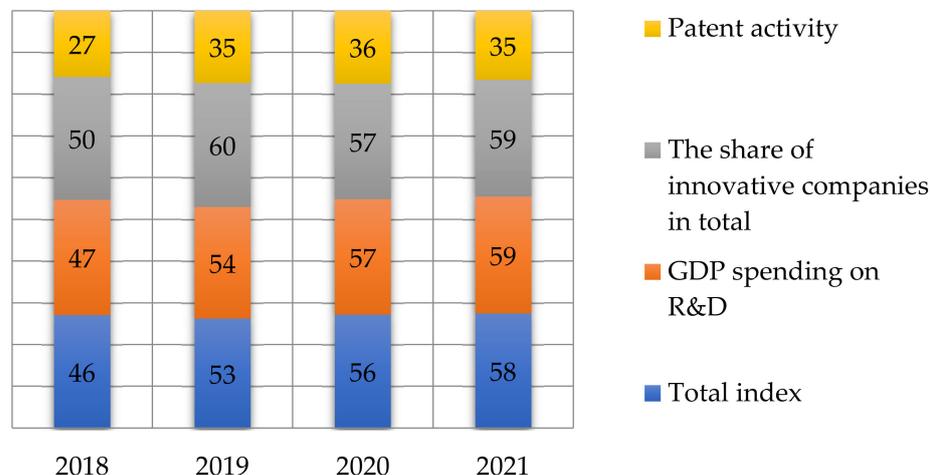


Figure 3. Dynamics of GII indices for Ukraine in 2017–2021. Reproduced with permission from [38]. Copyright 2021, World Intellectual Property Organization.

At the same time, Ukraine's ranking has worsened in the category of lower-middle-income countries, declining in comparison with 2020. In addition, Ukraine's place in the annual Bloomberg Innovation Index [39] in 2018–2021 only deteriorated and is determined by the following indicators (Figure 4).



**Figure 4.** Ukraine's place in the Bloomberg Innovation Index in 2018–2021. Adapted with permission from [39]. Copyright 2021, European Commission.

Thus, innovative transformation of the economy is a necessary strategy for Ukraine to rebuild the infrastructure destroyed by hostilities, and clustering in this sense is an auxiliary and powerful mechanism for development at regional and local levels.

According to studies [40–42], the innovative development of the region is determined by a number of interrelated factors that promote each other during innovation, including the following factors:

- Continuous and sustainable growth of the socio-economic level of the region, based on innovative entrepreneurial activity, smart specialisation of the region, a significant level of competitiveness, adaptation to market changes, and flexible response to infrastructure challenges and political conditions;
- Constant self-development based on the constant growth of social needs of the region, which must be ensured by constant commercialisation of innovations, and as a consequence, the formation of new social needs of higher quality and the cyclical nature of further innovative development;
- Causal relationships, which are reflected in the interaction and motivation of regional development stakeholders.

Simultaneously, according to the data on industrial activity in the regions of Ukraine, it is possible to confirm a significant differentiation among regions by the criterion of the number of such enterprises and the existing features of regional innovation development [43,44].

For the period 2018–2020, the statistics for the regions of Ukraine regarding the number of innovatively active industrial enterprises are shown in Table 2, where regions are highlighted in green if they showed growth over the past three years.

Thus, the stable growth of innovative enterprises over the past three years has been demonstrated by the Ukrainian regions Vinnytsia, Poltava, Cherkasy and Ternopil, which are mostly agricultural, which is another argument for focusing investments in the energy cooperative sector based on biofuels.

**Table 2.** Regions of Ukraine by number of innovation-active enterprises [33].

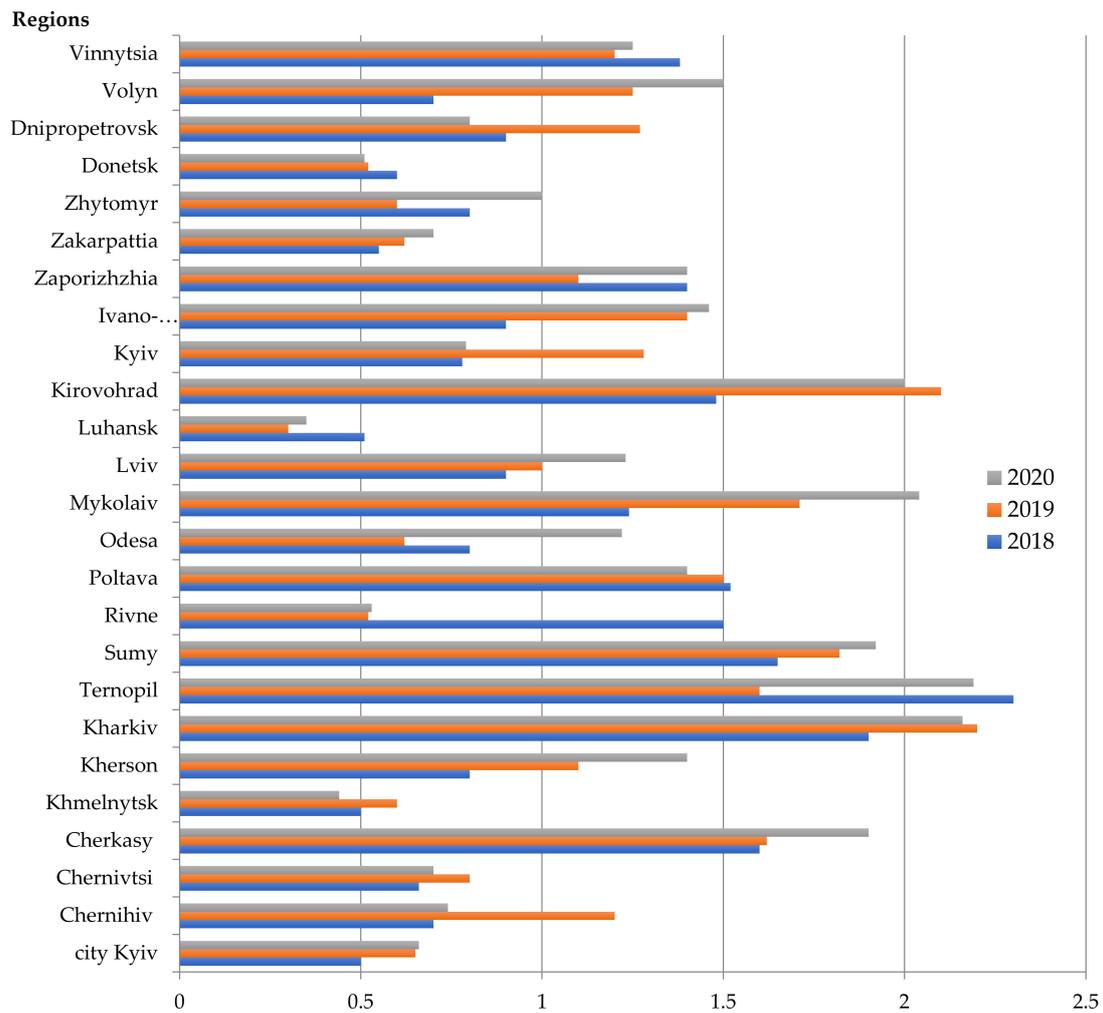
Regions	2018	2019	2020	+/- 2020 before 2019	+/- 2019 before 2018
...	...	...	...	...	...
Vinnytsia	25	28	31	3	3
Volyn	14	11	12	1	-3
Dnipropetrovsk	71	64	75	11	-7
Donetsk	23	27	24	-3	4
Zhytomyr	19	24	15	-9	5
Zakarpattia	12	9	10	1	-3
Zaporizhzhia	36	47	41	-6	11
Ivano-Frankivsk	28	22	28	6	-6
Kyiv	54	41	56	15	-13
Kirovohrad	26	20	20	0	-6
Luhansk	5	11	10	-1	6
Lviv	44	44	60	16	0
Mykolaiv	14	22	14	-8	8
Odesa	25	33	30	-3	8
Poltava	30	32	35	3	2
Rivne	8	20	19	-1	12
Sumy	25	23	23	0	-2
Ternopil	20	29	35	6	9
Kharkiv	119	116	96	-20	-3
Kherson	14	13	14	1	-1
Khmelnitskyi	11	10	15	5	-1
Cherkasy	29	30	31	1	1
Chernivtsi	9	7	13	6	-2
Chernihiv	15	11	22	11	-4
City				0	0
Kyiv	101	88	79	-9	-13
...	...	...	...	...	...

Simultaneously, the absolute number of industrial innovation-active economic entities in the region does not illustrate the level of regional innovation development, which can be represented by the relative share of innovation-active industrial enterprises in the region at the end of the reporting year.

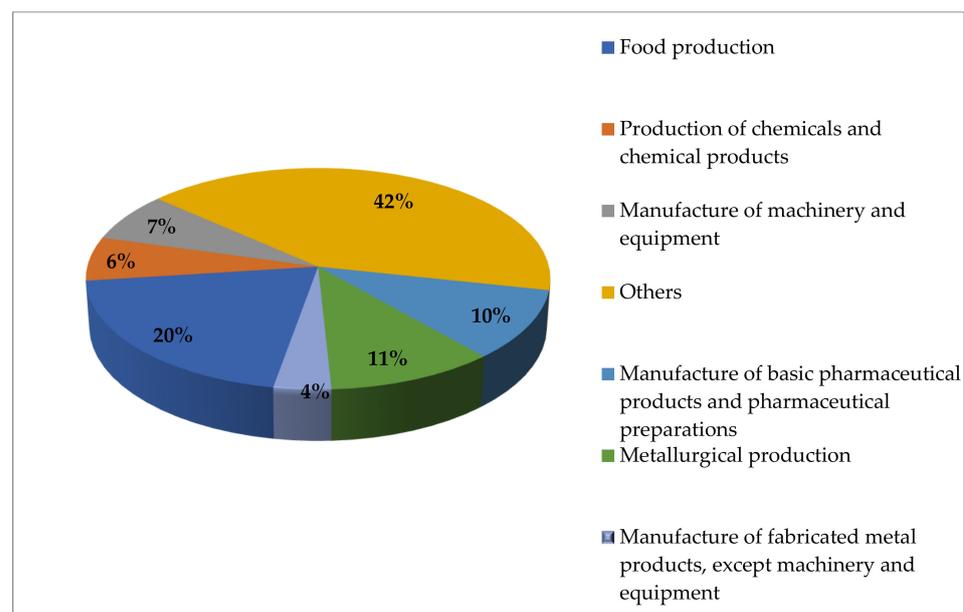
In general, in Ukraine, as shown in Figure 5, the share of innovative enterprises in the total number of medium and large-business industrial enterprises (codes B, C and D according to the Classifier of Economic Activities) does not exceed 2.5%. This indicates an extremely low technological level of industry in Ukraine.

In addition, the leading regions in the number of innovation-active enterprises do not coincide with the leading regions of the index. The leaders here are the Ternopil, Kharkiv, Sumy, Cherkasy and Kirovohrad regions. The Dnipropetrovsk region is in ninth place, and the Donetsk region is at the bottom of the list. Thus, in Ukrainian regions, there is no stable dependence on the level of industrial development and the level of innovation activity, which, moreover, undergoes significant fluctuations in statistics, even from year to year.

In the sectoral structure of total expenditure by area of innovation, the leaders are the sectors that represent the processing industry of all technological segments, for example, the food industry in the low-tech sector, metallurgical production in the medium-low-tech sector and the production of pharmaceuticals in the high-tech sector (Figure 6).



**Figure 5.** The share of innovation-active enterprises in the total number of industrial enterprises by region at the beginning of 2021, % [33].



**Figure 6.** Structure of total costs by area of innovation, % [44].

An effective indicator of the environmental friendliness of regional economic systems is an integrated indicator of the effectiveness of environmental management, which is calculated using a linear function according to the formula:

$$I = \sum_{i=0}^3 \binom{n}{k} C_i I_i \quad (2)$$

where  $I_i$ —integrated ecological characteristic;  $C_i$ —weight coefficient of integrated indicators.

The integrated indicator of the effectiveness of environmental management provides a comprehensive assessment from the standpoint of compliance with objectives based on integrated environmental characteristics calculated by groups of indicators.

Therefore, solutions to problematic environmental issues, particularly climate issues, can be achieved through the intensive implementation of technological innovations and the effective management of the latter. An example of such implementation is “green” technologies, which, together with similar models, should be applied primarily to production processes in the real sector of the economy in order to minimise harmful effects on the environment. Innovation itself can form a breakthrough in consciousness and cause the rethinking of the usual processes and technologies, which, in turn, is a necessary factor for the greening of economic activity, even in the absence of public support.

Undoubtedly, the most significant level of innovation in regional development is reflected in the indicators of the sales of innovative products because they form the gross regional product and reflect the end result of innovation.

Simultaneously, the situation in Kyiv is consistently ahead in these indicators in terms of regions. In addition, the analysis in the current study allows us to state that innovative products by region did not determine the regional sales volume and, as a consequence, were not a crucial component of gross regional product.

#### 4.2. Influence of State Regulation on the Process of Decarbonisation/Adaptation in the Region

The state’s influence on the management of innovation development in the region is currently significant. At the same time, the state plays the role of facilitator in the initial stages of regional development and later transfers these functions to the relevant institutions of innovative development. It should be noted that the state and executive authorities are among the stakeholders in the processes of decarbonisation and adaptation, and assessing the feasibility and possible consequences of their regulation requires the creation of hybrid model complexes that combine climate modelling, energy modelling, economic modelling and investment in the development of certain technologies and directions. Currently, we can discuss two groups of models for different stakeholders because they all need to consider climatic factors in their activities. The first group assesses the scale of climate change and how humanity can adapt to it (adaptation scenarios), and the second group examines how to resist climate change itself (decarbonisation scenarios). At the same time, each group of stakeholders is concerned with specific questions (Table 3).

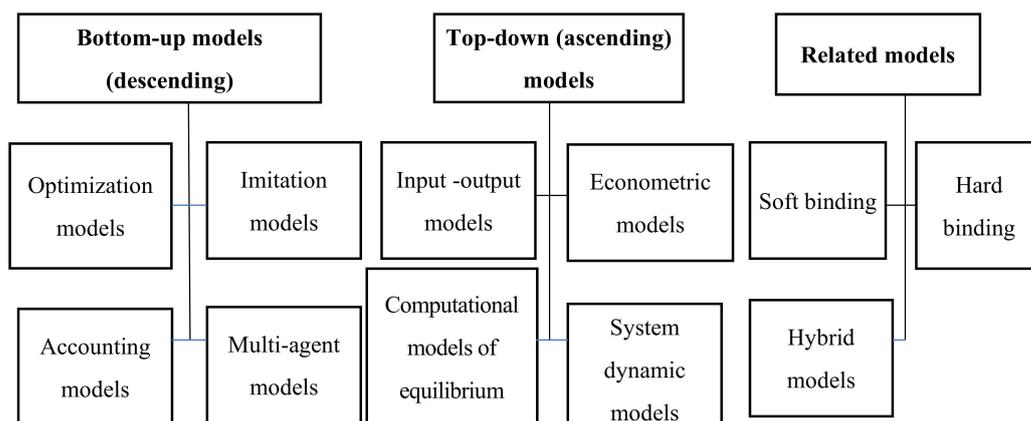
Approaches to modelling different sectors of the economy are universal, but owing to the focus of research on energy issues, we consider modelling tools focused on the energy sector. Such models can be divided into two major categories: top-down and bottom-up (Figure 7, Table 4), as well as integrated related models.

The methodological gap in approaches to the implementation of decarbonisation has stimulated the emergence of hybrid-related approaches that combine the technological clarity of upward models with microeconomic realism and the macroeconomic feedback of downward models. The linking of models was achieved through iterations with feedback between models.

It should be emphasised that the list of integrated models of decarbonisation currently used in the EU in the energy sector includes several examples, such as: PRIMES, GAINS, GLOBIOM-G4M, PROMETHEUS, CAPRI and POLES. These integrated models have a variety of targets in methodology, time horizons, sectoral coverage and input–output data.

**Table 3.** The main stakeholders of the decarbonisation process. Adapted with permission from [31]. Copyright 2018, United Nation.

Stakeholder	The Question Answered by the Related Model Complex
National regulators and central executive bodies	How and with what speed can the economy be decarbonised as efficiently as possible for the country?
Regulators at the international level	How and when will most countries in the world be able to achieve the goals of the Paris Agreement?
Financial sector	What are the possible consequences of the complete cessation of funding for carbon-intensive projects?
Business community	How can a company be decarbonised as effectively as possible? How can a company’s real assets be adapted to climate change?
National climate organisations and climate activists	What are the possible consequences for the world in the event of non-acceptance of mitigation of climate change?
Population	How will decarbonisation/adaptation methods affect incomes, health and living standards?



**Figure 7.** The classification of decarbonisation models focusses on the energy sector. Reprinted with permission from [42]. Copyright 2009, Boehringer, C.; Rutherford, T.

An analysis of the possible application of models of the decarbonisation of Ukraine’s economy in the projected postwar period of development makes it possible to state the need for an integrated approach and the use of hybrid models.

After all, models of rigid bonding are ill-suited for modelling in crisis and force majeure conditions, which are the conditions for the recovery of an economy destroyed by hostilities. Soft binding often provokes interference, namely, differences between the results of energy flow models, prices and technologies within a particular region. Noise control is difficult because most useful sets of common measurement points are non-exclusive.

*4.3. Applied Models of Decarbonisation of Energy-Intensive Sectors*

In recent years, Ukraine has begun to implement a model of regional development for fair transformation.

According to the Concept of the State Target Program for Fair Transformation of Coal Regions of Ukraine for the period up to 2030, approved by the Resolution of the Cabinet of Ministers of Ukraine dated 22.09.2021 № 1024, the concept of “fair transformation” is interpreted as “a model of regional development to all residents, including workers who will be affected by the process of abandoning fossil fuels (liquidation of production facilities, closure of coal mining enterprises, etc.)” [32].

**Table 4.** Advantages and disadvantages of decarbonisation models.

Type of Decarbonisation Model	Functional and Structural Features	Disadvantages and Shortcomings
Descending models	Economists and governments commonly use descending models. These models focus on aggregating macroeconomic sectors. They are usually characterised by a simplified presentation of components and therefore do not fit the definition of sectoral policy. Their scope is to assess the impact of energy and climate policies on socio-economic sectors, such as social growth and social welfare, employment, etc. A top-down approach may also consider interdependence between sectors or countries.	Descending models lack technological details and are limited to modelling financial policy instruments. This study has methodological limitations. The parameters of elasticity and autonomous efficiency in descending models were estimated based on empirical data.
Rising models	The ascending approach is to develop engineering models with a detailed description of the technological aspects of the energy system and how they may develop in the future, which allows the determination of sectoral policies. Energy demand is usually set exogenously, and models analyse how this energy demand should be met at minimal cost. However, the bottom-up approach does not consider the link between the energy system and macroeconomic sectors, thus ignoring the impact on these sectors.	Traditional ascending models describe technologies, but they realistically reflect the economic decisions made by enterprises and consumers when choosing technologies and do not reflect the potential feedback of macroeconomic equilibrium.

In this context, the formation of a national Green Deal is a critical priority for Ukraine. A national feature of this area is environmentally harmful coal. Ukraine has historically formed certain socio-economic clusters around the coal regions—Donetsk, Luhansk, Dnipropetrovsk, Lviv-Volyn and Transcarpathian basins. However, the reduction in the share of coal energy should be gradual based on the formation of an appropriate alternative to this type of economic activity, using the experience of China, the Czech Republic, Germany and Poland in terms of diversification in the industry. Global examples of the harmonious transformation of coal regions demonstrate the strategic course of events and significant impact on the economy. Therefore, for Ukraine, which is fairly new to the process of coal industry transformation, these processes should be reflected and adjusted in the national Green Deal.

Difficulties with the transition to a decentralised electricity market in Ukraine are both objective (regulatory) and locally subjective.

The Ukrainian situation requires urgent action at the highest level of government. Thus, the Government of Ukraine announced the creation of four revival funds for the restoration of property and infrastructure, economic transformation, debt service and repayment, and support for affected businesses [45]. The proposed funds combine two trends: national, to obtain funds for development through the relevant state institution, and European, to obtain funding through the relevant fund.

In addition, Ukraine has negative or neutral trends in the development of alternative energy and energy cooperation, provoked by the instability of the regulatory environment, the passivity of the business environment and public awareness of the existing benefits of the green energy market. The fragmentation and imperfections of the current legal framework worsen the situation.

Simultaneously, developed agriculture in Ukraine can and should become the basis for the development of bioenergy. The energy cooperative movement is currently in its infancy in Ukraine [46].

The flexibility and variability of cooperative organisational and legal forms determine the convenience of their use. Thus, an energy cooperative can unite energy producers or

consumers or act in both roles simultaneously to produce and consume energy (that is, the cooperative prosumer) or to accumulate (aggregate) energy from other producers [47].

Renewable energy, as a new technology, needs to implement appropriate support mechanisms: political, legislative and economic [48,49]. The models represented in this study, using the apparatus of mathematical logic, can be interpreted as follows: to achieve the goal of developing mechanisms for the implementation of renewable energy at the regional and local levels (development of mechanisms for the implementation of renewable energy at regional and local levels), a set of ten organisational, economic, fiscal, institutional and regulatory measures was applied (Table 5).

These measures belong to many methods for the effective stimulation of investment inflow to renewable green energy (methods of effective stimulation of investment inflow to renewable green energy).

**Table 5.** Correspondence of mechanisms to support renewable energy and their formalised presentations.

The Name of the Event	The Essence of the Event	Formalised Term in Equation (3)
Adoption of laws regulating the conditions for access to energy systems for installations of renewable energy sources (RES)	Adoption of laws regulating access to energy systems	$Law^{en}$
Establishment of special guaranteed tariffs for the purchase of electricity produced from RES and obligations for energy networks to purchase electricity	Transition to renewable energy sources (RES)	$E_S^{tar}$
Establishment of a mandatory share of electricity produced from RES in the balance of electricity sold by power grids	Establishment of special guaranteed tariffs for the purchase of electricity produced from RES as well as obligations for energy networks to buy this energy	$E_S^{mand}$
Financing research activities leading to a reduction in renewable energy cost	Establishment of a mandatory share of electricity generated from RES in the balance of electricity sales of power grids	$Fin^{res}$
Establishment of state and other institutions to promote renewable energy, implement special programmes and demonstrate projects	Funding for research activities that reduce RES costs	$E_S^{state}$
Preferential loans for purchasing renewable energy equipment and partial returns on investment for consumers	Establishment of state institutions for the promotion of RES and implementation of special projects	$Loans^{pref}$
Accelerated depreciation of RES equipment	Preferential loans for purchasing RES equipment and partial returns on investment for consumers	$Dep^{ac}$
Organisation of public support and the introduction of voluntary forms of support, such as the purchase of green energy by consumers as well as the transparency of information on the share of clean electricity in the balance of energy networks	Accelerated depreciation of RES equipment	$Pub^{sup}$
Subsidising investment in renewable energy	Organisation of public support and introduction of voluntary forms of support, such as consumer purchases of "Green Energy" as well as transparency of information on the share of clean electricity in the balance of energy networks	$Inv^{sub}$
Tax exemptions and tax rate reductions	Subsidising RES investments	$Tax^{ex}$

In this case, the formalisation of the conceptual and analytical model of integrated support mechanisms for the implementation of renewable energy has the following form (Formula (3)), and definitions of terms in the formula are given in Table 5.

$$Dev^{re} \approx \left\{ Law^{en} \cup Es^{tar} \cup Es^{mand} \cup Fin^{res} \cup Es^{state} \cup Loans^{pref} \cup Dep^{ac} \cup Pub^{sup} \cup Inv^{sub} \cup Tax^{ex} \right\} \in METHOD^{ge} \quad (3)$$

where  $Dev^{re}$ —achieving the goals of developing mechanisms for the implementation of renewable energy at the regional and local levels;  $METHOD^{ge}$ —methods for the effective stimulation of investment inflow to renewable green energy.

It should be noted that some of the measures to stimulate the mechanisms of renewable energy have already begun to be implemented under current conditions in Ukraine. For example, the announced onset of tax reform will certainly contribute to the effective implementation of the proposed conceptual and analytical model. In addition, the revolutionary step of connecting the Ukrainian energy system to the European ENTSO-E system will ensure the stable operation of the Ukrainian energy system in wartime and in the postwar period, as well as the development of energy generation and investment.

## 5. Conclusions

Summarising the results of the study, we note that the European experience of socio-economic development demonstrates a systematic and integrated approach, including state-of-the-art measures to achieve a climate-neutral Europe. Recent events: Considering Ukraine's application for EU accession under the accelerated procedure, the development of Ukraine after the military conflict requires non-standard solutions to improve the regulation of energy security and nature management.

Unfortunately, in the Ukrainian region, at the beginning of 2022, innovative products have not yet been a significant component of indicators such as gross regional product (GDP) and gross sales. Simultaneously, the state's involvement in the management of innovation processes in the region and their facilitation has a significant impact on the level of innovative regional development.

The environmental goals of achieving a carbon-neutral level of the economy and the decarbonisation of energy-intensive industries involve the introduction of balanced and effective approaches to coordinating financial investments in relevant segments, the formation of a legal and regulatory framework, the use of available resource potential and integration prospects, and the state's environmental facilitation. For example, the decarbonisation of green energy to alternative energy sources can have significant financial implications for households. Simultaneously, the negative consequences of effective state measures of regional greening, as well as decentralisation, can be a positive vector for the development of communities and territories.

The comparative analysis of decarbonisation models conducted in this study allowed the systematisation of its advantages and disadvantages, on the basis of which, in turn, the methodological gap in approaches is evident. These factors are the basis for the development of a hybrid integrated approach to energy decarbonisation policy in Ukraine, which would combine existing models and have a national orientation, taking into account the force majeure circumstances of the recovery of Ukraine's economy. This course of events is actualised by the peculiarities of Ukraine's integration into the European energy system and the prospects of accession to the EU both on a general basis and under the accelerated procedure.

The results of the current study should be considered within certain limitations, which can be addressed in future studies. Thus, the uncertainty of the economic situation caused by hostilities produced methodological imperfections in the study, namely, the limited ability to conduct a thorough analysis using mathematical modelling. In addition, objectively limited access to statistics on the regions of Ukraine requires the adjustment of the survey results, provided that these data are available.

The most effective way to develop the Ukrainian economy will be the development of innovation-active regions and industries, which, in turn, will be drivers of the development of related territories and industries while ensuring synergies. The transition to an environmentally friendly, green economy is a multi-layered process that is not quick and painless. Thus, given the global trends in the framework of green energy transition, it is important to consider planning the development of innovation-active industries and regions of the state.

At the same time, it is necessary to take into account the legal and infrastructural preconditions typical for Ukraine, namely: the social and economic weight of the coal industry; the comparatively low cost and significant share of nuclear energy; obstacles and shortcomings in the decentralisation of the electricity market; negative trends in the development of renewable energy; asymmetry in the distribution of energy resources at the regional level; and the initial position in the development of the energy cooperation movement, but also a strong agricultural sector as a basis for the development of bioenergy, making it possible to state the available resource potential for creating a synergetic impact in various sectors of Ukraine's economy.

**Author Contributions:** Conceptualisation, V.K. and O.B.; methodology, V.K.; software, I.L.; validation, I.L. and A.M.; formal analysis, O.B.; investigation, I.L.; resources, P.O.; data curation, O.B.; writing—original draft preparation, V.K.; writing—review and editing, D.M.; visualisation, A.M.; supervision, D.M.; project administration, V.K. and D.M.; funding acquisition, P.O. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. European Commission. A European Green Deal. 2019. Available online: [https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal\\_en](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en) (accessed on 29 March 2022).
2. Klanięcki, K.; Duse, I.A.; Lutz, L.M.; Leventon, J.; Abson, D.J. Applying the energy cultures framework to understand energy systems in the context of rural sustainability transformation. *Energy Policy* **2020**, *137*, 111092. [CrossRef]
3. State Statistics Service of Ukraine. Available online: <http://www.ukrstat.gov.ua> (accessed on 10 April 2022).
4. Ministry of Environmental Protection and Natural Resources. The concept of “green” energy transition of Ukraine until 2050. 2020. Available online: <https://mepr.gov.ua/news/34424.html> (accessed on 29 March 2022).
5. Van den Berg, N.J.; van Soest, H.L.; Hof, A.F.; den Elzen, M.G.J.; van Vuuren, D.P.; Chen, W.; Drouet, L.; Emmerling, J.; Fujimori, S.; Höhne, N.; et al. Implications of various effort-sharing approaches for national carbon budgets and emission pathways. *Clim. Chang.* **2020**, *162*, 1805–1822. [CrossRef]
6. Cader, J.; Olczak, P.; Koneczna, R. Regional dependencies of interest in the “My Electricity” photovoltaic subsidy program in Poland. *Energy Policy J.* **2021**, *24*, 97–116. [CrossRef]
7. Long, X.; Chen, Y.; Du, J.; Oh, K.; Han, I. Environmental Innovation and Its Impact on Economic and Environmental Performance: Evidence from Korean-Owned Firms in China. *Energy Policy* **2017**, *107*, 131–137. [CrossRef]
8. Sribna, Y.; Koval, V.; Olczak, P.; Bizonych, D.; Matuszewska, D.; Shtyrov, O. Forecasting solar generation in energy systems to accelerate the implementation of sustainable economic development. *Energy Policy J.* **2021**, *24*, 5–28. [CrossRef]
9. Tang, M.; Walsh, G.; Lerner, D.; Fitza, M.A.; Li, Q. Green Innovation, Managerial Concern and Firm Performance: An Empirical Study. *Bus. Strategy Environ.* **2017**, *27*, 39–51. [CrossRef]
10. Brunel, C. Green Innovation and Green Imports: Links Between Environmental Policies, Innovation, and Production. *J. Environ. Manag.* **2019**, *248*, 109–290. [CrossRef]
11. Abbas, J.; Sağsan, M. Impact of Knowledge Management Practices on Green Innovation and Corporate Sustainable Development: A Structural Analysis. *J. Clean. Prod.* **2019**, *229*, 611–620. [CrossRef]
12. Zhang, F.; Zhu, L. Enhancing corporate sustainable development: Stakeholder pressures, organizational learning, and green innovation. *Bus. Strategy Environ.* **2019**, *28*, 1012–1026. [CrossRef]
13. Hetman, O.; Iermakova, O.; Laiko, O.; Nikishyna, O. Eco-innovations under conditions of globalization of economic and sustainable development of the regional economy. *Ekon. I Sr.* **2019**, *4*, 69–82.

14. Savina, N.; Sribna, Y.; Pitel, N.; Parkhomenko, L.; Osipova, A.; Koval, V. Energy Management Decarbonization Policy and Its Implications for National Economies. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *915*, 012007. [CrossRef]
15. Anderlini, L.; Felli, L.; Immordino, G.; Riboni, A. Legal institutions, innovation, and growth. *Int. Econ. Rev.* **2013**, *54*, 937–956. [CrossRef]
16. Iermakova, O.A. Economic efficiency of clusters functioning: Estimation and analysis of their impact on region's competitiveness. *Actual Probl. Econ.* **2012**, *137*, 174–180.
17. Capra, F.; Mattei, U. *The Ecology of Law: Toward a Legal System in Tune with Nature and Community*; Berrett-Koehler Publishers: Oakland, CA, USA, 2015.
18. Komorowska, A. Can Decarbonisation and Capacity Market Go Together? The Case Study of Poland. *Energies* **2021**, *14*, 5151. [CrossRef]
19. Komorowska, A.; Benalcazar, P.; Kaszyński, P.; Kamiński, J. Economic consequences of a capacity market implementation: The case of Poland. *Energy Policy* **2020**, *144*, 111683. [CrossRef]
20. Matuszewska, D.; Kuta, M.; Olczak, P. Techno-Economic Assessment of Mobilized Thermal Energy Storage System Using Geothermal Source in Polish Conditions. *Energies* **2020**, *13*, 3404. [CrossRef]
21. Benalcazar, P.; Komorowska, A. Prospects of green hydrogen in Poland: A techno-economic analysis using a Monte Carlo approach. *Int. J. Hydrogen Energy* **2021**, *47*, 5779–5796. [CrossRef]
22. Wróblewski, P.; Niekurzak, M. Assessment of the Possibility of Using Various Types of Renewable Energy Sources Installations in Single-Family Buildings as Part of Saving Final Energy Consumption in Polish Conditions. *Energies* **2022**, *15*, 1329. [CrossRef]
23. Dyczko, A.; Kamiński, P.; Stecuła, K.; Prostański, D.; Kopacz, M.; Kowol, D. Thermal and mechanical energy storage as a chance for energy transformation in Poland. *Energy Policy J.* **2021**, *24*, 43–60. [CrossRef]
24. Kulpa, J.; Kamiński, P.; Stecuła, K.; Prostański, D.; Matusiak, P.; Kowol, D.; Kopacz, M.; Olczak, P. Technical and Economic Aspects of Electric Energy Storage in a Mine Shaft—Budryk Case Study. *Energies* **2021**, *14*, 7337. [CrossRef]
25. Rutitis, D.; Smoca, A.; Uvarova, I.; Brizga, J.; Atstaja, D.; Mavlutova, I. Sustainable Value Chain of Industrial Biocomposite Consumption: Influence of COVID-19 and Consumer Behavior. *Energies* **2022**, *15*, 466. [CrossRef]
26. Trushkina, N.; Pahlevanzade, A.; Pahlevanzade, A.; Maslennikov, Y. Conceptual Provisions of the Transformation of the National Energy System of Ukraine in the Context of the European Green Deal. *Energy Policy J.* **2021**, *24*, 121–138. [CrossRef]
27. Van de Graaf, T. Fragmentation in global energy governance: Explaining the creation of IRENA. *Glob. Environ. Politics* **2013**, *13*, 14–33. [CrossRef]
28. Toohey, M.; Krüger, K.; Sigl, M.; Stordal, F.; Svensen, H. Climatic and societal impacts of a volcanic double event at the dawn of the Middle Ages. *Clim. Chang.* **2016**, *136*, 401–412. [CrossRef]
29. Koval, V.; Olczak, P.; Vdovenko, N.; Boiko, O.; Matuszewska, D.; Mikhno, I. Ecosystem of Environmentally Sustainable Municipal Infrastructure in Ukraine. *Sustainability* **2021**, *13*, 10223. [CrossRef]
30. Nitsenko, V.; Mardani, A.; Streimikis, J.; Shkrabak, I.; Klopov, I.; Novomlynets, O.; Podolska, O. Criteria for Evaluation of Efficiency of Energy Transformation Based on Renewable Energy Sources. *Montenegrin J. Econ.* **2018**, *14*, 237–247. [CrossRef]
31. United Nation Climate Change. The Paris Agreement—Publication. Available online: <https://unfccc.int/documents/184656> (accessed on 29 March 2022).
32. The Verkhovna Rada of Ukraine. State Target Program for Fair Transformation of Coal Regions of Ukraine until 2030. Available online: <https://zakon.rada.gov.ua/laws/show/1024-2021-%D0%BF#Text> (accessed on 29 March 2022).
33. State Statistics Service of Ukraine. Available online: [http://ukrstat.gov.ua/druk/publicat/Arhiv\\_u/Arch\\_reg.htm](http://ukrstat.gov.ua/druk/publicat/Arhiv_u/Arch_reg.htm) (accessed on 29 March 2022).
34. Interfaks—Ukraina. Available online: <https://ua.interfax.com.ua/news/general/804185.html> (accessed on 29 March 2022).
35. Polish Press Agency. A reconstruction plan for Ukraine is needed—EUR 100 billion from the EU. Available online: <https://www.pap.pl/aktualnosci/news,1099121,premier-zaapelowalem-zeby-ue-nalozyla-embargo-na-rosyjski-wegiel-potrzebny> (accessed on 29 March 2022).
36. The Washington Post. Biden administration requests \$32.5 billion in Ukraine aid and coronavirus funds. Available online: <https://www.washingtonpost.com/world/2022/03/03/russia-ukraine-war-putin-news/#link-HRAPLUUIN5BHNIOMUNDOXZQEL4> (accessed on 29 March 2022).
37. Environmental Performance Index. 2020 EPI Index. 2020. Available online: <https://epi.yale.edu/epi-results/2020/component/epi> (accessed on 29 March 2022).
38. Dutta, S.; Lanvin, B.; Leon, L.R.; Wunsch-Vincent, S. Global Innovation Index 2021. Available online: [https://www.wipo.int/edocs/pubdocs/en/wipo\\_pub\\_gii\\_2021.pdf](https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021.pdf) (accessed on 29 March 2022).
39. European Commission. Bloomberg Innovation Index—2021. Available online: <https://ec.europa.eu/newsroom/rtd/items/713430/en> (accessed on 29 March 2022).
40. Snisarenko, O. Estimation of Innovative Potential in Regions of Ukraine. Ph.D. Thesis, Kharkiv National Academy of Municipal Economy, Kharkiv, Ukraine, 2008; pp. 20–44.
41. Serbanica, C.; Constantin, D.L. Sustainable cities in central and eastern European countries. Moving towards smart specialization. *Habitat Int.* **2017**, *68*, 55–63. [CrossRef]
42. Boehringer, C.; Rutherford, T. Integrated assessment of energy policies: Decomposing top-down and bottom-up. *J. Econ. Dyn. Control* **2009**, *33*, 1648–1661. [CrossRef]

43. Sotnyk, I.; Kurbatova, T.; Kubatko, O.; Prokopenko, O.; Prause, G.; Kovalenko, Y.; Trypolska, G.; Pysmenna, U. Energy Security Assessment of Emerging Economies under Global and Local Challenges. *Energies* **2021**, *14*, 5860. [CrossRef]
44. Ministry of Education and Science of Ukraine. Available online: <https://mon.gov.ua/storage/app/media/innovatsii-transfer-tehnologiy/2020/08/za-2019-1-1.pdf> (accessed on 29 March 2022).
45. UNIAN. Available online: <https://www.unian.ua/economics/finance/uryad-stvoryuye-chotiri-fondi-vidnovlennya-ukrajini-shmigal-novini-ukrajina-11727847.html> (accessed on 29 March 2022).
46. Diachuk, O.; Podolets, R.; Balyk, O.; Yukhymets, R.; Pekkoiev, V.; Bosack Simonsen, M. Long-term Energy Modelling and Forecasting in Ukraine: Scenarios for the Action Plan of Energy Strategy of Ukraine until 2035. 2019. Available online: <https://orbit.dtu.dk/en/publications/long-term-energy-modelling-and-forecasting-in-ukraine-scenarios-f> (accessed on 29 March 2022).
47. Yang, L. Idiosyncratic information spillover and connectedness network between the electricity and carbon markets in Europe. *J. Commod. Mark.* **2022**, *25*, 100185. [CrossRef]
48. Cucchiella, F.; D'Adamo, I.; Gastaldi, M.; Stornelli, V. Solar Photovoltaic Panels Combined with Energy Storage in a Residential Building: An Economic Analysis. *Sustainability* **2018**, *10*, 3117. [CrossRef]
49. Wang, J.B.; Huang, L. A Game-Theoretic Analytical Approach for Fostering Energy-Saving Innovation in the Electric Vehicle Supply Chain. *SAGE Open* **2021**, *11*, 21582440211021581. [CrossRef]