http://dx.doi.org/10.23925/2179-3565.2022v13i4p158-173

RISUS - Journal on Innovation and Sustainability
volume 13, número 4 - 2022
ISSN: 2179-3565
Editor Científico: Arnoldo José de Hoyos Guevara
Editor Assistente: Vitória C. Dib
Avaliação: Melhores práticas editoriais da ANPAD

THE IMPACT OF INDUSTRY 4.0 ON MODELLING ENERGY SCENARIOS OF THE DEVELOPING ECONOMIES

O impacto da indústria 4.0 na modelagem de cenários energéticos das economias em desenvolvimento

Maryna Tymoshenko[1], Kateryna Redko[2], Mykola Serbov[3], Maryna Shashyna[4], Olena Slavkova[5]
[1]University of Customs and Finance, Ukraine; [2]State Institution G. M. Dobrov Institute for Scientific and Technological Potential and Science History Studies NASU, Centre for Innovations and Technological Development, Ukraine; [3]Odessa State Environmental University, Ukraine; [4]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine; [5]Sumy National Agrarian University, Ukraine
Email: marynatymoshenko@yahoo.com, karedko@gmail.com, serbovn@gmail.com, shashynamarina@gmail.com, olenaslavkova@gmail.com

ABSTRACT

At the current stage, developed economies are able to implement measures to improve energy efficiency. At the same time, the developing economies mostly focus on rapid development, which implies a rapid increase in energy demand. The introduction of innovative technologies should meet the energy needs of economies while simultaneously improving energy efficiency. In particular, this applies to increasing renewable energy consumption. The development of this sector can be accelerated through the introduction of Industry 4.0. The aim of the study is to determine the impact of Industry 4.0 on modelling energy scenarios of developing economies. The research involved methods of analysis and synthesis, economic and statistical analysis, graphical methods, and the comparison. The study revealed a high impact of Industry 4.0 on the Ukrainian economy, in particular energy sector. Among other things, an improved energy efficiency is the result of such impact. It was determined that renewable energy consumption in Ukraine increased significantly by 11.5 times during the studied period. The differences in the energy development of Ukraine and China are outlined: China has chosen energy independence. It was concluded that the development and implementation of the latest technologies play a significant role in energy scenarios. The timing of achieving the goals are the main difference in energy scenarios between developed countries and developing countries. The prospect of further research should be the determining means of measuring the impact of uncertainty on the energy modelling.

Keywords: Industry 4.0, Fourth Industrial Revolution, Energy Sector, Renewable Energy Sources, Digitalization, Development, Scenario.

ACEITO EM: 13/11/2022
PUBLICADO: 30/12/2022

RISUS - Journal on Innovation and Sustainability
volume 13, número 4 - 2022
ISSN: 2179-3565
Editor Científico: Arnoldo José de Hoyos Guevara
Editor Assistente: Vitória C. Dib
Avaliação: Melhores práticas editoriais da ANPAD

O IMPACTO DA INDÚSTRIA 4.0 NA MODELAGEM DE CENÁRIOS ENERGÉTICOS DAS ECONOMIAS EM DESENVOLVIMENTO

The impact of industry 4.0 on modelling energy scenarios of the developing economies

Maryna Tymoshenko[1], Kateryna Redko[2], Mykola Serbov[3], Maryna Shashyna[4], Olena Slavkova[5]
[1]University of Customs and Finance, Ukraine; [2]State Institution G. M. Dobrov Institute for Scientific and Technological Potential and Science History Studies NASU, Centre for Innovations and Technological Development, Ukraine; [3]Odessa State Environmental University, Ukraine; [4]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine; [5]Sumy National Agrarian University, Ukraine
Email: marynatymoshenko@yahoo.com, karedko@gmail.com, serbovn@gmail.com, shashynamarina@gmail.com, olenaslavkova@gmail.com

RESUMO

No estágio atual, as economias desenvolvidas são capazes de implementar medidas para melhorar a eficiência energética. Ao mesmo tempo, as economias em desenvolvimento concentram-se principalmente no desenvolvimento rápido, o que implica um rápido aumento na demanda de energia. A introdução de tecnologias inovadoras deverá satisfazer as necessidades energéticas das economias, melhorando simultaneamente a eficiência energética. Em particular, isso se aplica ao aumento do consumo de energia renovável. O desenvolvimento deste setor pode ser acelerado com a introdução da Indústria 4.0. O objetivo do estudo é determinar o impacto da Indústria 4.0 na modelagem de cenários energéticos de economias em desenvolvimento. A pesquisa envolveu métodos de análise e síntese, análise econômica e estatística, métodos gráficos e de comparação. O estudo revelou um alto impacto da Indústria 4.0 na economia ucraniana, em particular no setor de energia. Entre outras coisas, uma maior eficiência energética é o resultado desse impacto. Foi determinado que o consumo de energia renovável na Ucrânia aumentou significativamente em 11,5 vezes durante o período estudado. As diferenças no desenvolvimento energético da Ucrânia e da China são descritas: A China escolheu a independência energética. Concluiu-se que o desenvolvimento e implementação das mais recentes tecnologias desempenham um papel significativo nos cenários energéticos. O momento de atingir as metas é a principal diferença nos cenários energéticos entre países desenvolvidos e países em desenvolvimento. A perspectiva de novas pesquisas deve ser o meio determinante para medir o impacto da incerteza na modelagem energética.
Palavras-chave: Indústria 4.0, Quarta Revolução Industrial, Setor Energético, Fontes Renováveis de Energia, Digitalização, Desenvolvimento, Cenário.

INTRODUCTION

The year of 2020 was notable for a record pace of development of renewable energy sources (RES), in particular wind and solar, even amidst the COVID-19 pandemic. Such changes can be characterized as a new energy economy, the emergence of which is caused by the political trends, technological innovations, and the need to combat climate change. Digital technologies play a prominent role in the integration of individual components of the new energy system. The development of special platforms and data management (Oil & Gas of Ukraine, n.d.) ensure the effective operation and interaction of the sectors of this system. The energy demand is increasing worldwide despite continuous efforts to reduce energy consumption, while degrading the environment. This issue is becoming more relevant in the era of sustainable development goals. Therefore, politicians and stakeholders are increasingly focusing on reducing energy consumption through achieving energy efficiency. Innovation can play an important role in this regard. Achieving innovative energy efficiency requires a proper diffusion of innovations, and various developing economies face challenges in this aspect (Chen et al., 2021).

The Fourth Industrial Revolution, or Industry 4.0, together with digital transformation, open up vast opportunities for energy sustainability. Industry 4.0 refers to full digitization and integration of industrial value chains (Ghobakhloo & Fathi, 2021). In an Industry 4.0 environment, interconnected computers, smart materials, and intelligent machines interact and make decisions with minimal human involvement (Ghobakhloo, 2020). According to Machado et al. (2019), the digitization of the manufacturing industry can provide significant benefits, including:

- increased production efficiency;
- improved safety and quality of data and results;
- improved maintenance;
- improved decision-making process, collection and use of information;
- improved control, stabilization and speed of the production process, etc.

On the contrary, some researchers focus in their studies on identifying the shortcomings of Industry 4.0. In particular, Beier et al. (2020) notes that the production and consumption rates may increase through the labour-saving technologies. This entails increased resource consumption, income inequality, labour market disruptions, and increased cybersecurity risks.

Regardless of whether the implications of Industry 4.0 are mostly positive or not, this process is irreversible and has no alternative. Therefore, an urgent issue is the ways of optimizing economic development scenarios and adapting them to the impact of Industry 4.0 under the current conditions. In particular, this applies to the energy sector, which is in the focus of researchers because of its close connection with environmental problems, as well as social and economic development. In this context, modelling energy scenarios of the developing economies deserves special attention because of greater restrictions on efficient energy development compared to developed countries.

Therefore, the aim of this study is to determine how the digital economy tools and innovative technologies affect the energy scenarios of developing economies. The aim involved the fulfilment of the following research objectives:

- conduct a theoretical review of Industry 4.0 in the context of the energy sector development;
- carry out a comparative analysis of the energy scenarios of the developed and developing economies;
- review and analyse global energy scenarios;
- determine the differences in achieving the objectives of the scenarios for countries with different levels of development;
- describe the impact of Industry 4.0 and prospects for Ukraine.

1 LITERATURE REVIEW

Current political, social and environmental problems largely depend on the energy efficiency of countries. This is why research on the development and implementation of innovations in this area is becoming highly relevant. Most researchers believe that it is possible to achieve a higher energy efficiency through the Fourth

Industrial Revolution. Chen et al. (2021) note the problems that the modern world community faces because of the increasing energy demand. Researchers study the role of innovation in energy transformation processes, and also note inequal opportunities between developed and developing countries.

Pustovhar (2022) recognizes that the share of renewable energy sources will increase with the introduction of new technologies. The researcher provides data indicating a reduction of carbon dioxide emissions by up to 40% through the use of innovations. She distinguishes the digital double technology as an example of innovative technology that will contribute to increasing energy efficiency. Jones et al. (2020) study this technology.

Omelianenko V. and Omelianenko O. (2022) note the latest models — the service model and the circular supply model, which belong to the key concepts of the digital economy. One of the tasks of the models are the optimization of the production process and the replacement of limited resources with renewable ones.

Researchers pay special attention to the energy sector in developing countries. Due to their rapid development, these countries will play a key role in increasing energy demand in the future. However, their development is associated with increasing carbon dioxide emissions into the atmosphere, and therefore with the environmental degradation. Therefore, it is extremely important for developing countries to improve energy efficiency through the introduction of the latest technologies, including the renewable energy development (Oil & Gas of Ukraine, n.d.).

Researchers provide a successful example of China, which is a developing country and a world leader in the development of renewable energy sources. Honcharenko et al. (2019) explore the reasons for this success, including legislative changes, statistics on innovation in China, etc. Nurton (2020) found that China has the fifth largest number of patents in the field of renewable energy. China is also among the top five in other country energy ranking studies. In particular, these are the country wind energy rankings and the ranking of countries that invest the most in renewable energy sources. (Energy Transition, 2019; CERN, 2018).

Oliinyk (2018) compares the energy development of China and Ukraine as two developing countries. The researcher points out the commonalities in the energy sector of these two countries, and describes the reasons for the differences. The work notes the reasons for China's success and the circumstances that caused Ukraine to take a different path of energy development.

Many researches and works of world organizations are aimed at developing energy scenarios. Table 1 provides a list of scenarios proposed by leading global organizations with references to primary sources.

Table 1 – Scenarios presented in leading energy studies

Scenarios	References
Business-as-usual (BAU) scenario	
McKinsey's New Global Energy Perspectives 2019	(McKinsey & Company, 2019)
"Forecast" scenario	
DNV-GL's Energy Transition Outlook 2019	(DNV-GL, 2019)
Decarbonisation scenarios that claim compatibility with Paris Agreement targets	
IEA's 2019 "SDS" scenario	(IEA, 2019)
Shell's 2018 "Sky" scenario	(Shell Global, 2018)
Greenpeace's 2015 "Advanced" scenario	(Greenpeace, 2015)
Equinor's 2019 "Renewal" scenario	(Equinor, 2019)
The scenarios in the "Achieving the Paris Climate Agreement Goals" report from the Institute for Sustainable Futures at the University of Technology Sydney	(UTS-ISF, 2019)
The "Below 1.5°C" and "1.5°C High" scenarios from the Intergovernmental Panel on Climate Change	(IPCC, 2018)

Source: IRENA (2020).

A large number of different scenarios necessitates recommendations for making them more accurate, which is the subject of the work of Child et al. (2018). The views of researchers differ, first, in determining the nature of the impact of Industry 4.0 on the energy development of countries. Some consider this impact as positive, others indicate a number of negative consequences. Second, the goals and results of energy scenarios being developed differ significantly. That is why determining the impact of Industry 4.0 on energy scenarios requires further study and clarification of aspects.

2 METHODOLOGY

The research was divided into several stages in view of its complex nature:

1. The first stage involved a theoretical review of Industry 4.0 in the context of the energy sector development. At this stage, the impact of Industry 4.0 on all spheres of life and activity of Ukraine, in particular on the energy sector, was confirmed. It was established that the introduction of Industry 4.0 should ensure an increased energy efficiency, in particular, the development of renewable energy sources. The energy consumption trend based on renewable energy sources in Ukraine is presented and analysed. The integration of Ukraine with the European association ENTSO-E was noted, which has potential positive consequences for Ukraine, in particular, in terms of improving energy efficiency.

2. The second stage provided for a comparative analysis of the energy scenarios of developed and developing economies. The countries of the European Union and the United States were chosen among the developed countries as a bases of comparison, as well as Ukraine and China – among the developing countries. The analysis revealed discrepancies in the total amount of energy consumption and in the amount of renewable energy consumption. The reasons and main directions of the obtained trends were revealed.

3. The third stage of the study involves an overview and analysis of global energy scenarios. The main content of energy scenarios proposed in the most influential world studies is revealed. It was established that developed and developing countries may have common scenarios. The difference is the timing for the developed and developing countries to achieve the defined goals. The scenarios proposed in the Energy Security Strategy approved by the Decree of the *Cabinet of Ministers of Ukraine* No. 907-p of 4 August 2021 are described. The optimistic scenario of Ukraine's energy development was focused on. It was noted that the digital economy and the development of renewable energy sources play an important role in this scenario.

The research involved the following methods:

– analysis and synthesis to study the theoretical background and analytical reports on the issue under research;
– economic and statistical analysis of the dynamics and structure of the studied indicators;
– graphic methods for the representation of theoretical, analytical, statistical and legislative human-readable information;
– comparative analysis to compare the impact of Industry 4.0 on the developing and developed economies.

The sample included the countries of the European Union and the United States among the developed ones, as well as Ukraine and China among the developing countries as the objects of the study. This choice is explained by the high levels of development of the EU and the USA, as well as their and close political, economic, and cultural relations with Ukraine. China is chosen for comparison as the country with the fastest rate of development of renewable energy sources in recent decades. Moreover, China, like Ukraine, is a developing country.

Statistics that provide a general description of the state of development of energy consumption in Ukraine and other studied countries were taken from the official websites of the State Statistics Service of Ukraine and The World Bank. The charts were built in MS Excel.

3 RESULTS

3.1 Theoretical review of industry 4.0 in the context of the energy sector development

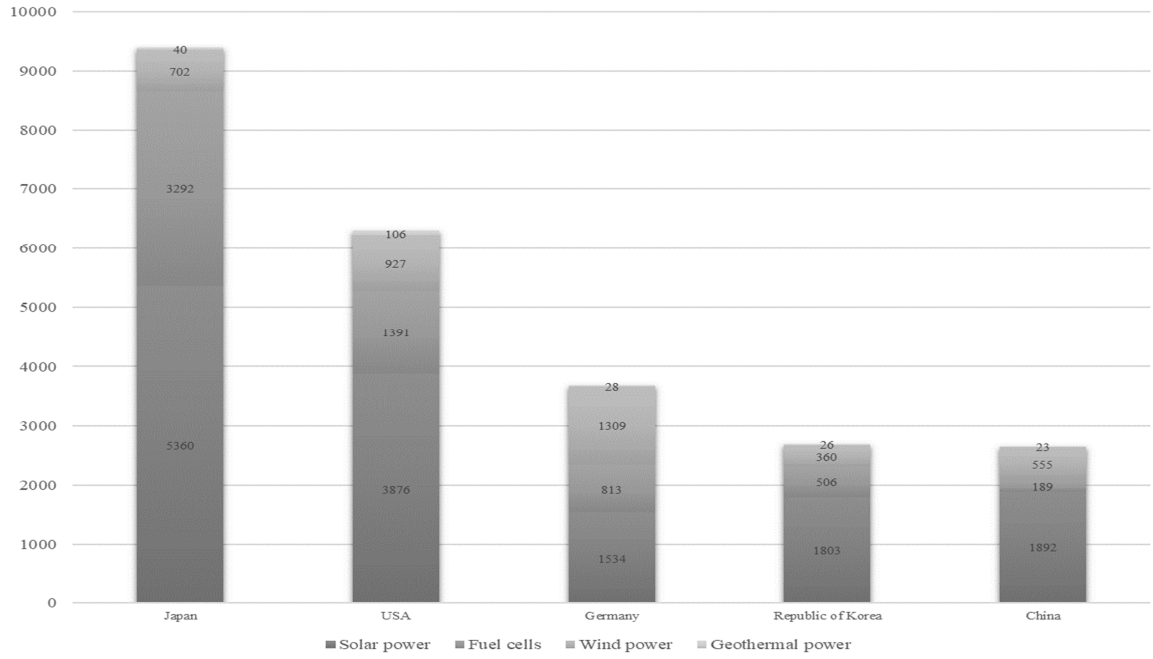
The Fourth Industrial Revolution is a continuous and irreversible process in which all countries of the world are involved to a certain degree. Ukraine has also chosen the path of Industry 4.0 despite political and economic difficulties. The Resolution of the Cabinet of Ministers of Ukraine No. 750 of 12 July 2021 approved the Regulation on the Implementation of the Industry 4.0 Technological Approach. This Regulation provides that Industry 4.0 implies complex digitalization and automation of production processes and management of the real sector of the economy (Resolution of the Cabinet of Ministers of Ukraine No. 750 of 12 July 2021). The

implementation of Industry 4.0 comprises production, technology, education, science, the government, and individual citizens.

So, it can be recognized that the Fourth Industrial Revolution has being implemented in Ukraine and spreading its impact actively. Like other sectors, energy sector is subject to this impact, although it can have both positive and undesirable consequences. The Industry 4.0 measures must be carefully balanced in order to prevent an increased production and consumption rates caused by the introduction of labour-saving technologies. First of all, they should focus on improving the environmental friendliness of energy production, in particular the use of renewable energy sources. It is appropriate to note positive changes in energy consumption in Ukraine. In particular, the share of renewable sources in the total supply of primary energy increased from 1.7% in 2007 to 6.6% in 2020. Figure 1 shows the distribution of RES-based energy consumption by RES types.

Figure 1 shows a noticeable increase in RES-based energy consumption. Most of the growth came from biofuels and waste-to-energy, as well as wind and solar power. The energy consumption decreased only in relation to hydropower.

Figure 1 – RES-based energy consumption in Ukraine

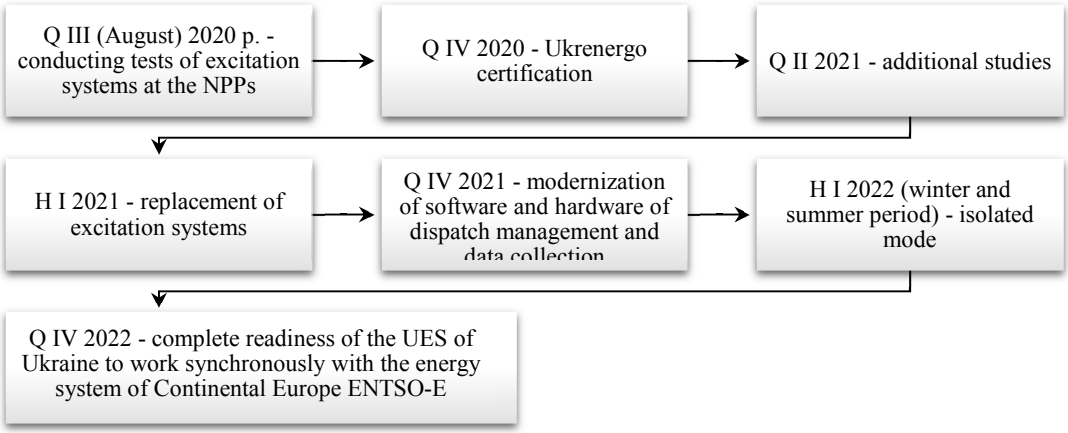


Source: created by the author based on the data of the State Statistics Service of Ukraine (n.d.).

The energy sector is a key object of research, and the significant event that took place in the energy sector of Ukraine in the current year is worth mentioning. On March 16, 2022, Ukraine acquired the status of a full member of the European Transmission System Operators (ENTSO-E). This association includes forty-two system operators belonging to thirty-five European countries. The future synchronization agreement was signed back in 2017. The agreement provided for the planned start of operation of the Ukrainian energy system synchronously with the European one in 2023. However, the events changed this deadline, having made it a year closer. Integration measures are estimated at UAH 11 billion, but the annual economic effect of synchronization can reach UAH 40 billion. It should be noted that even before the invasion, 96% of Ukraine's energy system was technologically connected to the aggressor countries and Moldova. Only 4% were synchronized with the association of European countries (National Energy Company "Ukrenergo", 2020).

Figure 2 summarizes the process of Ukraine's integration into ENTSO-E.

Figure 2 – The process of integration into ENTSO-E



Source: National Energy Company "Ukrenergo" (2020).

The advantages of combining the Ukrainian energy system with the European one include a reduced energy production cost through savings in the use of generating capacities. Besides, opportunities for exporting Ukrainian electric power, as well as for importing foreign electric power, are improving. Opportunities for attracting foreign investors are increasing. The development of renewable energy sources through special European programmes deserves special attention as a positive consequence of integration.

Further development of cooperation with the EU in the energy sector is closely related to the successful implementation of Industry 4.0. This is explained by the need for the domestic energy system to meet European standards, in particular with regard to data exchange, information protection, cyber security, etc.

3.2 Comparative analysis of energy scenarios of developed and developing economies

Increased attention to energy development in developing countries is explained, first, by their population: about two-thirds of the Earth's population lives in developing countries. Second, access to energy resources in most of these countries is so limited that part of the population cannot use household electrical appliances. For example, the 45.8% of the population of East and Southern Africa had access to electricity in 2020. This indicator in the countries of West and Central Africa reaches 52.1% (The World Bank, n.d.). Third, developing countries usually have fewer opportunities to implement and use renewable energy sources. Therefore, countries focus on how to provide themselves with energy in the future with affordable means, which results in increased harmful emissions.

Thus, the energy scenarios of developing countries should ensure a balance between meeting the energy needs of the population and the economy on the one hand, while the introduction and use of the most efficient (in terms of productivity and environmental friendliness) energy sources on the other.

The next step in the research is to examine and compare energy consumption in developed and developing countries. The countries of the EU and the USA were chosen among the developed economies as the bases of comparison, while Ukraine and China — among the developing ones. The EU countries and the USA have extremely high levels of development, as well as close political, economic, and cultural relations with Ukraine. China is chosen for comparison as the country with the fastest development rate of renewable energy sources in recent decades. Moreover, China, like Ukraine, belongs to developing countries.

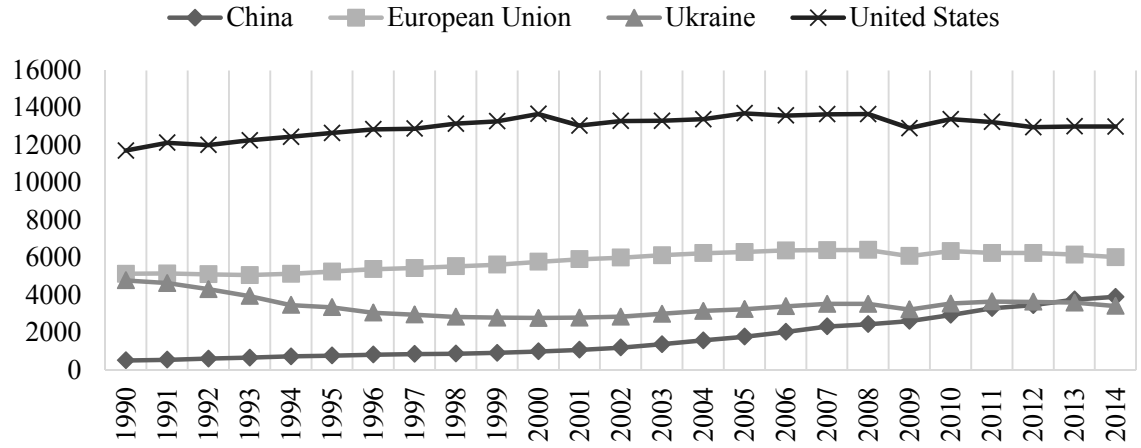
First of all, it should be noted that in order to reach the current level of development, developed countries had an extremely high energy consumption rates. Figure 3 represents the electricity consumption of the selected countries. The period of the study is limited to 2014 because of the lack of data on the relevant online resource, but it is informative enough as a retrospective.

As Figure 3 shows, the USA has the highest electricity consumption rates, followed by the EU. This is explained by energy-intensiveness of the rapid development of the economy and the development of the relevant infrastructure of countries. However, this provided developed countries with enough resources, innovative and

technical potential for further implementation of energy-saving technologies. During the same period, Ukraine's energy consumption decreased significantly, while China actively increased its energy consumption.

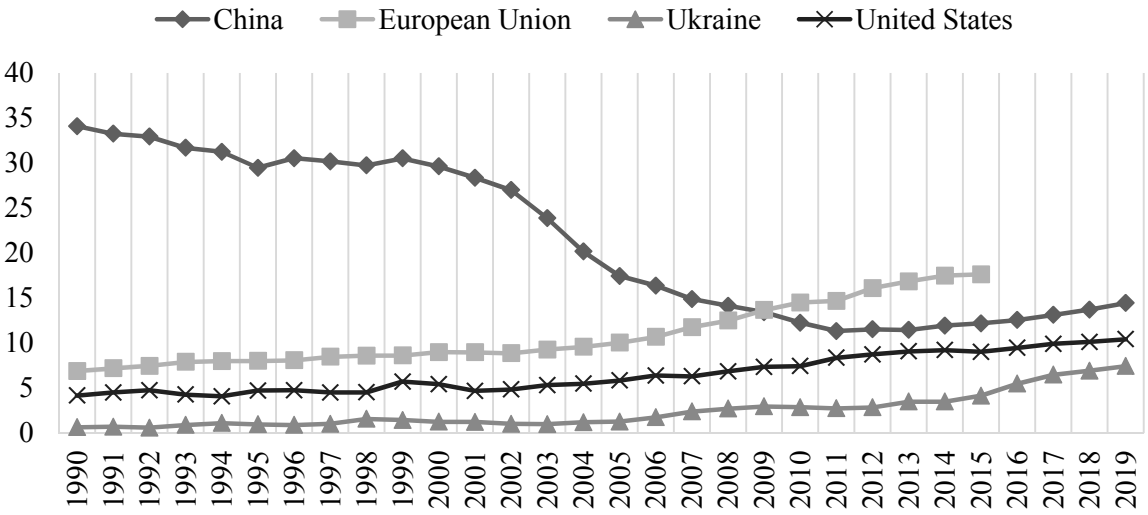
In view of the foregoing, it is of particular interest to determine the share of renewable energy sources in their total volume for the studied countries. Figure 4 shows the dynamics of this indicator over the last three decades.

Figure 3 – Electricity consumption by China, the EU, Ukraine and the USA (kWh per capita)



Source: created by the author based on The World Bank (n.d.).

Figure 4 – Renewable energy consumption (% of total final energy consumption)



Source: created by the author based on The World Bank (n.d.).

As Figure 4 shows, the European Union has the highest share of renewable energy in total consumption. China ranks second, although this indicator has significantly decreased over the studied period — from about 35% to almost 15%. However, this is explained by the fact that the indicator is relative, and therefore its trend depends on the change in total energy consumption. The share of renewable energy consumption by China decreased because of the rapid growth of the country's total electricity consumption. The USA ranks third after China, and Ukraine ranks fourth. At the same time, the indicator of the USA increased by almost 2.5 times, Ukraine – by almost 11.5 times during the studied period.

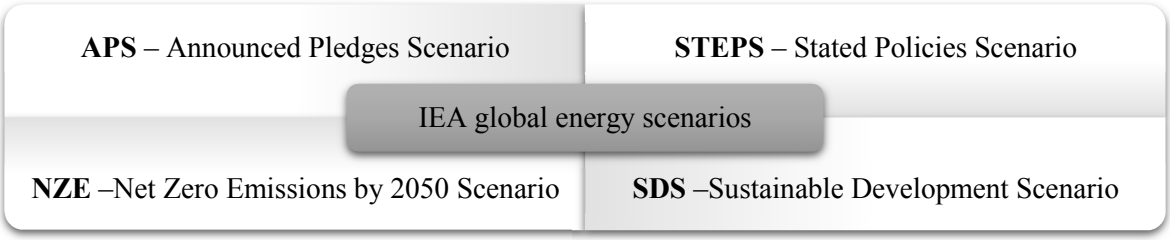
3.3 Overview of global energy scenarios

Environmental problems, in particular, climate change, environmental pollution, harmful emissions, etc., cause concern of the entire world community. Therefore, leading environmental organizations are putting a lot of

effort into developing energy scenarios for individual countries and the world. The possibility of developing such scenarios can be recognized as an achievement of Industry 4.0. This is explained by the opportunity that the latest technologies provide to build models and make predictions with high accuracy. Besides, achieving the desired development indicators, for example, increasing the share of renewable energy sources in the total consumption volume, is also impossible without digitalization. Innovations enable increasing the productivity and efficiency of renewable energy sources, identifying opportunities for expanding their use, reduce harmful emissions, etc.

The International Energy Agency (IEA) is an independent organization headquartered in Paris. One of the objectives of the organization is the development of recommendations and the analysis of the global energy sector. The organization's has recently focused on reducing carbon dioxide emissions and achieving global climate goals, in particular those defined by the Paris Agreement (Iacobuţă et al., 2022; IEA, 2021). In its World Energy Outlook-2021 report, the organization examines three main energy scenarios and also provides forecasts for the Sustainable Development Scenario. The report noted differences in the achievement of the main objectives of the scenarios by developed and developing countries. Figure 5 represents the above-mentioned energy scenarios.

Figure 5 – Global energy scenarios



Source: according to the IEA (2021).

The NZE scenario considers a narrow but possible path to achieving net zero carbon dioxide emissions by 2050. It is noted that developed countries will reach this indicator earlier than others.

The APS takes into account all the climate commitments of the world's governments, including nationally determined contributions and long-term net zero targets. It is expected that all these commitments and goals will be realized in full and on time.

STEPS does not take into account that all the goals announced by world governments will actually be achieved. It explores the future path of the energy system without implementing additional policy measures. This scenario is not intended to achieve a specific result, nor is APS. It is rather intended to provide a detailed review of existing policies and those under development. A residual difference in global emissions is determined between the APS and STEPS scenarios. It reflects the "implementation gap" that must be covered in order to achieve the countries' declared decarbonization goals.

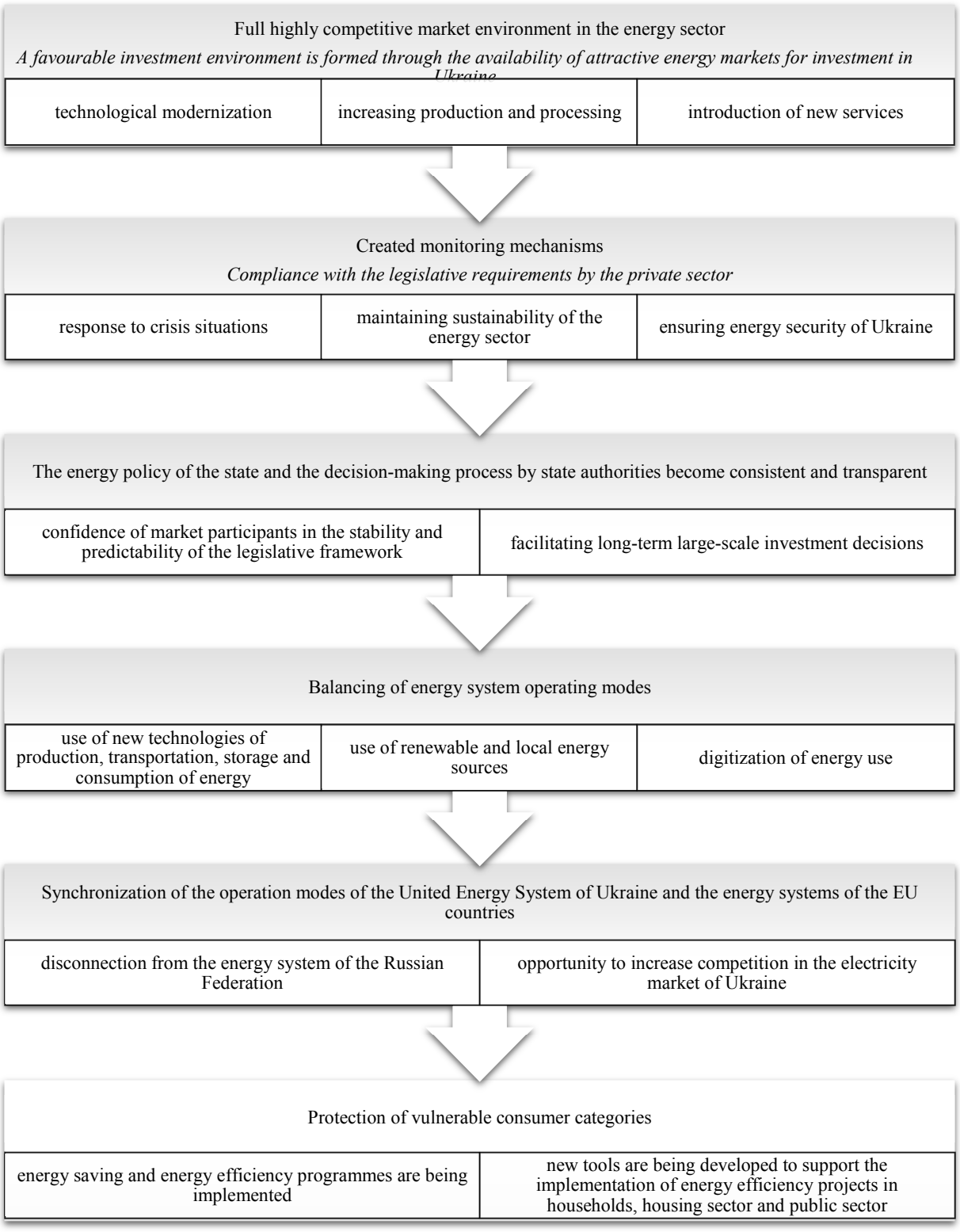
The SDS defines the path to achieving the results defined by the Paris Agreement and expects that all the goals and commitments of governments are achieved. According to its results, developed countries will achieve zero emissions by 2050, China — by 2060, and other countries — by 2070 (IEA, 2021).

The Ukrainian government offers its own vision of energy scenarios. The Decree of the Cabinet of Ministers of Ukraine No. 907-p of 4 August 2021 approved the Energy Security Strategy (hereinafter referred to as the Strategy). The Strategy defines three forecast scenarios of changes in the energy sector:

– the "no change" scenario provides for the maintenance of existing trends;
– the "unfriendly influence" scenario involves no significant changes in energy policy with an aggravating aggression on the part of the Russian Federation;
– the "positive transformation" scenario is the most desirable as it provides for the achievement of the Strategy goals (Decree of the Cabinet of Ministers of Ukraine No. 907-p of 4 August 2021).

The latter scenario, as desirable and optimistic, is the worthiest, so its main aspects are summarized and shown in Figure 6.

Figure 6 – The "positive transformation" scenario



Source: Decree of the Cabinet of Ministers of Ukraine No. 907-p (2021).

As Figure 6 shows, the use of the latest technologies of production, transportation, storage and consumption of energy occupies a special place in this Scenario. The use of renewable and local energy sources, as well as the digitalization of energy use are the next priorities. So, the basic concepts of Industry 4.0 are fundamental in the development of effective energy scenarios and ensure the achievement of defined goals.

4 DISCUSSION

The impact of Industry 4.0 on the development of energy scenarios can be considered from two perspectives. On the one hand, the scenarios can be developed using Industry 4.0 technologies, where the latter is a development tool. On the other hand, Industry 4.0 can define the requirements for setting the goals for scenario development.

The majority of authors of energy-related researches agree that the implementation of Industry 4.0 should primarily involve the energy consumption improvement. Chen et al. (2021) note that Industry 4.0 entails structural economic transformations. The role of innovation is reinterpreted as a factor of digital transformation and automation. In such a scenario, innovation is designed, among other things, to enable nations to achieve energy efficiency. This should be realized by improving existing production processes or promoting solutions in the field of renewable energy. (Chen et al., 2021).

Pustovhar (2022) also believes that the share of renewable energy sources can increase in Industry 4.0 through the use of new technologies. The aim of their implementation is to improve the production process, increase energy efficiency, and reduce carbon dioxide emissions by up to forty percent. For example, the Digital Twin technology is one of such innovative technologies. It is a virtual model of a physical product with information about this product, which comes from the product life cycle management (Jones et al., 2020).

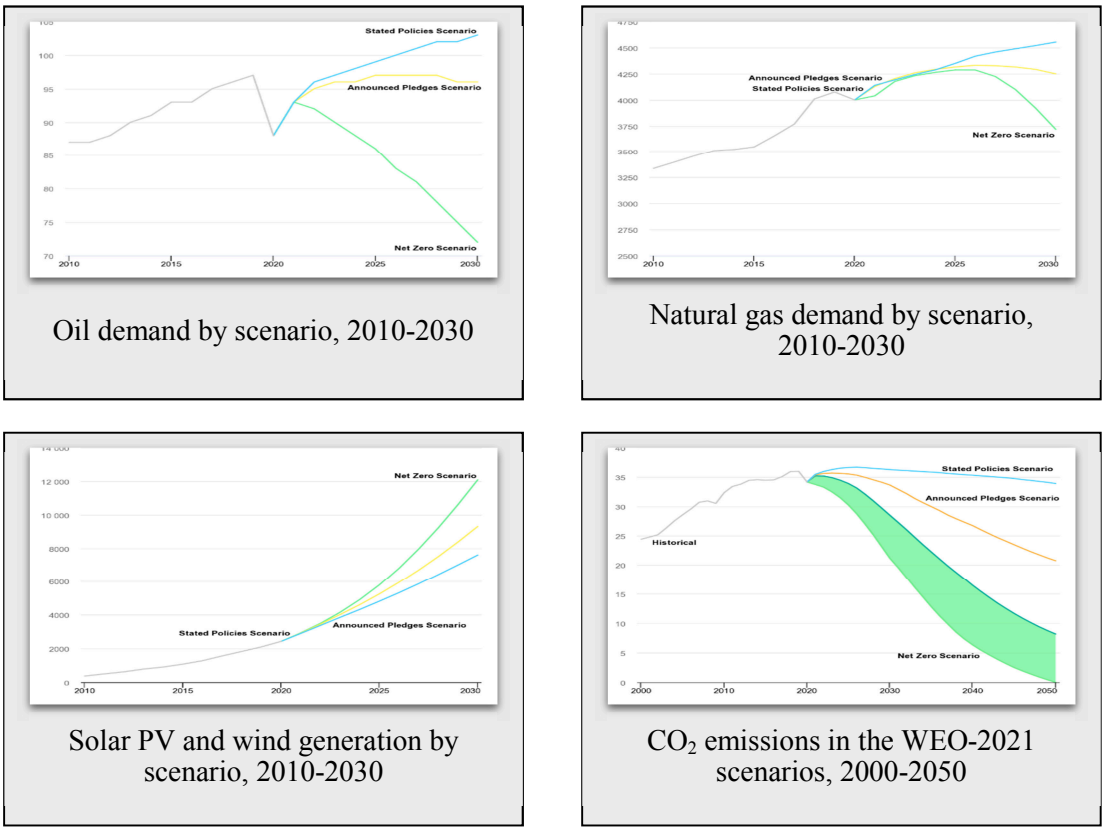
The central concept of the digital economy is the Product as a Service model. It involves reducing the amount of resources for the production of goods and services, restoring and extending their service life, and, ultimately, recycling. The Circular Suppliers model, which aims to replace limited resources with renewable ones, is worth noting. The use of renewable energy sources solves many social and economic problems: improving the environment, making the region more attractive for investors, etc. (Omelianenko V. & Omelianenko O., 2022).

A considerable number of studies deal with the prospects for the development of the energy sector in developing countries. Such countries have more limited resources and capabilities compared to developed countries, and their energy development will be slower.

However, the developing economies that have a significant impact on the global energy trends. According to the STEPS mentioned above, these economies will experience a significant increase in demand for energy resources in 2030 compared to 2020. In particular, oil demand will increase by about 30%, for gas — by 25%, and for coal — by 4%. Under the APS, fossil fuel demand in developed countries will decline, but demand trends in developing countries will not get worse. At the same time, more and more developing countries are following the example of China in actively developing the infrastructure of renewable energy sources. They include India, Brazil, countries of the Middle East and Africa. According to STEPS, in 2030 renewable sources will account for about two-thirds of production in developing countries. This indicator is currently 50% of production (China is not taken into account in the calculations).

Figure 7 shows the forecast trends of certain main indicators according to the defined scenarios by 2030-2050.

Figure 7 – Forecast trends for the IEA scenarios



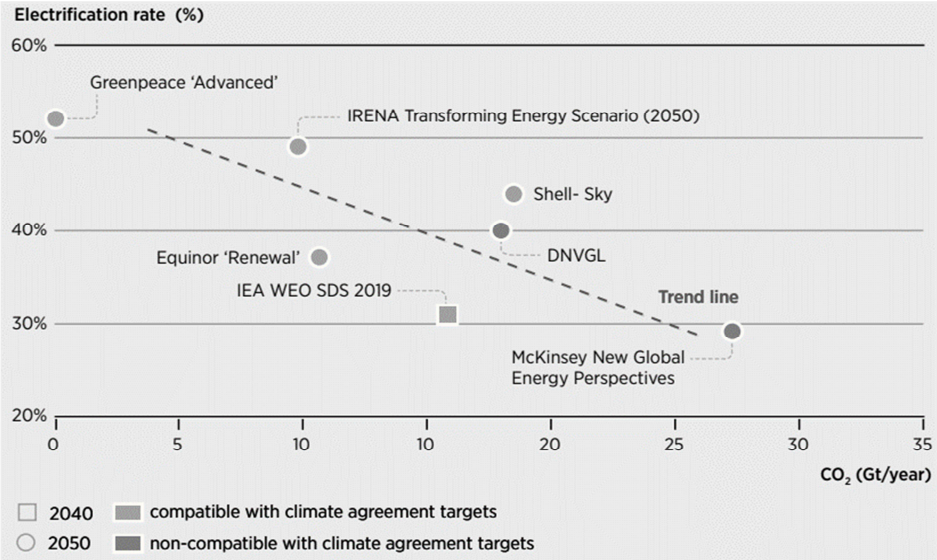
Source: IEA (2021).

As Figure 7 shows, there are significant gaps between the scenarios. The NZS scenario is the most optimistic, but the STEPS scenario has dramatic differences in predicted values. The oil and natural gas consumption will only increase until 2030 under STEPS, while it will decrease significantly under NZS. However, both scenarios anticipate increasing solar and wind power generation, as well as decreasing carbon dioxide emissions. STEPS also predicts increased electricity demand in developing countries, but this will happen more quickly because of the use of industrial capacity. Electrification of transport currently faces certain barriers, such as insufficient number of charging stations, reluctance to use electric vehicles, etc. In general, electrification cannot meet all the needs of rapidly developing economies, which is why carbon dioxide emissions by these countries will increase. Thus, developing countries need to make maximum efforts to improve the situation. The exception is China, which has been actively engaged in solving these problems a long time ago (Oil & Gas of Ukraine, n.d.).

The international agency for renewable energy sources (International Renewable Energy Agency - IRENA) is also engaged in the study of key global energy development scenarios. The organization reviewed and compared energy scenarios developed by leading global organizations. Figure 8 schematically shows the results of the review conducted by IRENA.

Figure 8 shows the vision of the future for the energy sector in different energy-related studies (see Table 1). It is evident that the scenarios differ significantly both in terms of projected volumes of carbon dioxide emissions and the electrification rates. Besides, some of the scenarios are compatible with the climate agreement goals, while others are not. This is explained by the different researchers' views of the scenario development. In some works, attention can be paid to the development of optimistic scenarios, in particular, the fulfilment of all obligations by governments, etc. Other researchers try to assess the prospects as realistically as possible. Besides, uncertainty has a significant impact on scenario development.

Figure 8 – Scenarios presented in large energy-related studies



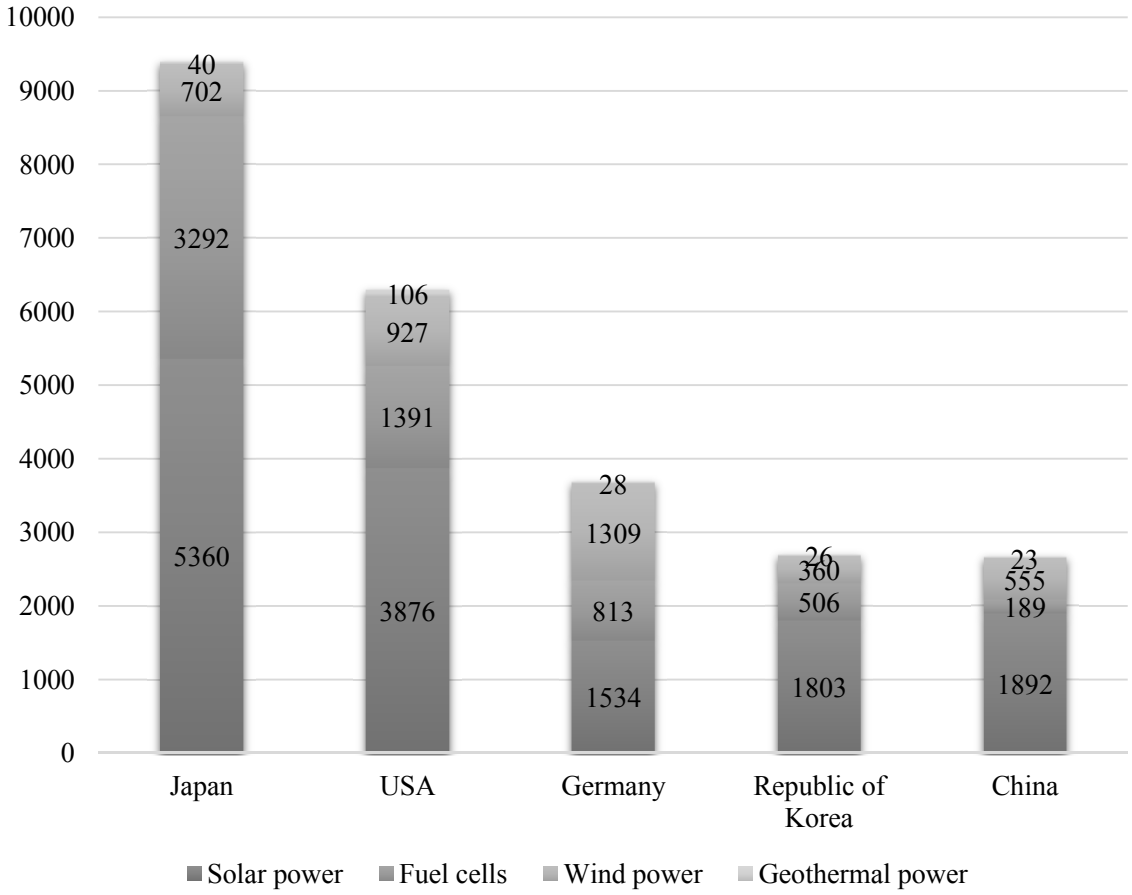
Source: IRENA (2020).

It should be noted that the special researchers' interest concentrated around the development of China's energy industry is not accidental. Although China is a developing country, it occupies a leading position in terms of energy development. The development was promoted by the adoption of the Law "On Renewable Energy in the People's Republic of China" in 2005 and the creation of the Renewable Energy Development Fund. China's renewable energy sector is currently attractive to private investors due to balanced policies and early-stage public investment. China overtook the United States in 2015, and Europe — in 2018 in terms of solar power generation. Over a decade and a half, the country has transformed from a consumer of innovations to an innovation leader. In 2050, China plans to increase the share of renewable energy to 73%. Figure 9 shows a comparison of the number of patents for inventions in the field of renewable energy in five leading countries for 2010-2019 (Honcharenko et al., 2019).

Besides, China ranks first in other country rankings for renewable energy. It has the world's largest wind farm located in Gansu. The farm has a capacity of 7,965 MW (Energy Transition, 2019). Over the four-year period 2016 to 2020, China's investment in the development of renewable energy amounted to EUR 343. In 2017, the country's government rejected more than 100 projects related to energy production through the use of fossil fuels (CERN, 2018).

Ukraine and China have similar energy development problems. The states have considerable coal reserves, but the number of explored deposits is insufficient. The oil and gas production in the countries is not enough to satisfy all their own needs. China's key difference is its focus on the development of the coal industry, which has protected the country from dependence on other countries. China began to increase the imported oil and gas volumes only after two decades of reforms. The country has the opportunity to influence the price and production of imported resources. On the contrary, Ukraine became dependent on the Russian Federation because the latter had the monopoly to supply gas to Ukraine. Gas is the main fuel for Ukraine, and it should diversify the sources of gas supply and actively develop renewable energy sources (Oliinyk, 2018).

Figure 9 – Patents for inventions in the field of renewable energy of selected countries for 2010-2019



Source: created by the author based on Nurton (2020).

As the conducted research found, energy scenarios, in particular scenarios for Ukraine, have large differences in terms of goals and results. Child et al. (2018) developed their own recommendations to increase the transparency and credibility of the scenarios. Therefore, increasing the transparency and credibility of scenarios is possible by:

- better disclosure and clear reference to the sources of information;
- specifying the method of data processing;
- providing a full set of cost assumptions;
- examining how changes in cost assumptions affect research results;
- setting goals in accordance with sustainable development goals and measuring results;
- discussing the impact of scenario outcomes on the planet;
- implementing an adequate methodology for the analytical description of the main characteristics of the flexibility of energy systems with a high share of renewable sources;
- disclosure of information.

CONCLUSION

The following key conclusions can be drawn based on the conducted research:

- Industry 4.0 is an irreversible and non-alternative process that covers and affects all spheres of life of any country;
- the energy sector development is largely affected by Industry 4.0;
- on the one hand, Industry 4.0 acts as a tool for energy sector development, while it actually sets certain requirements for such development on the other hand;

– the energy scenarios are modelled by means and under the influence of Industry 4.0;
– developed and developing economies may have common energy scenarios. The key difference is the timing of achieving goals.

This study of the impact of Industry 4.0 on the countries' energy scenarios found that innovation plays a key role in the energy sector development. A comparison of the energy development paths of Ukraine and China led to the conclusion that effective political decisions play a decisive role in the success of the sector. First of all, it applies to the stimulation of innovative activity, the commitment to meet the sustainable development goals.

The obtained results should be taken into account by the government of Ukraine when elaborating further programmes for the Industry 4.0 implementation and the energy sector development. The prospect for further research is determining the means of measuring the impact of uncertainty on the modelling of energy scenarios.

REFERENCES

Beier, G., Ullrich, A., Niehoff, S., Reißig, M., & Habich, M. (2020). Industry 4.0: How it is defined from a sociotechnical perspective and how much sustainability it includes – A literature review. Journal of cleaner production, 259, 120856. https://doi.org/10.1016/j.jclepro.2020.120856

CERN. (2018). Top 5 countries that invest in RES more than anyone else. Retrieved from https://cern.com.ua/2018/09/29/top-5-krayin-yaki-vkladayut-u-vde-bilshe-vsih/#:~:text=Лідерство%20по%20вкладеннях%20в%20створення,і%20виробленні%20сонячної%20теплової%20енергії

Chen, M., Sinha, A., Hu, K., & Shah, M. I. (2021). Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. Technological Forecasting and Social Change, 164, 120521. https://doi.org/10.1016/j.techfore.2020.120521

Child, M., Koskinen, O., Linnanen, L., & Breyer, C. (2018). Sustainability guardrails for energy scenarios of the global energy transition. Renewable and Sustainable Energy Reviews, 91, 321–334. https://doi.org/10.1016/j.rser.2018.03.079

DNV-GL. (2019). Energy transition outlook 2019. A global and regional forecast to 2050. Retrieved from https://eto. dnvgl.com/2019

Energy Transition. (2019). Top 5 countries - leaders in wind energy. Retrieved from https://energytransition.in.ua/top-5-krain-lideriv-u-vitroenerhetytsi/

Equinor. (2019). Energy perspectives 2018: Long-term macro and market outlook. Retrieved from https://www.readkong.com/page/energy-perspectives-2018-long-term-macro-and-market-outlook-2176428

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. Journal of Cleaner Production, 252, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Ghobakhloo, M., & Fathi, M. (2021). Industry 4.0 and opportunities for energy sustainability. Journal of Cleaner Production, 295, 126427. https://doi.org/10.1016/j.jclepro.2021.126427

Greenpeace. (2015). Energy [r]Evolution. A sustainable world energy outlook 2015. Brussels: Greenpeace, Solar Power Europe and Global Wind Energy Council.

Honcharenko, V., Babenko, V., Panteleimonenko, A., & Pozhar, A. (2019). China innovative development of renewable energy. Economic Scope, 152, 5-16. Retrieved from http://dspace.puet.edu.ua/handle/123456789/8320

Iacobuţă, G. I., Brandi, C., Dzebo, A., & Duron, S. D. E. (2022). Aligning climate and sustainable development finance through an SDG lens. The role of development assistance in implementing the Paris Agreement. Global Environmental Change, 74, 102509. https://doi.org/10.1016/j.gloenvcha.2022.102509

IEA. (2019). World Energy Outlook 2019 – Analysis. Paris: International Energy Agency.

IEA. (2021). World Energy Outlook 2021. Retrieved from https://www.iea.org/reports/world-energy-outlook-2021

IPCC. (2018). Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. Geneva: Intergovernmental Panel on Climate Change.

IRENA. (2020). Global Renewables Outlook: Energy transformation 2050 (Edition: 2020). Abu Dhabi: International Renewable Energy Agency. Retrieved from https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020

Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology, 29, 36-52. https://doi.org/10.1016/j.cirpj.2020.02.002

Machado, C. G., Winroth, M., Carlsson, D., Almström, P., Centerholt, V., & Hallin, M. (2019). Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalization. Procedia Cirp, 81, 1113-1118. https://doi.org/10.1016/j.procir.2019.03.262

McKinsey & Company. (2019). New global energy perspective 2019: Reference case. Retrieved from www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2019

National Energy Company "Ukrenergo". (2020). Integration plan of UES of Ukraine in ENTSO-E. Retrieved from https://getmarket.com.ua/storage/event-speakers-presentations/November2020/OtLUfdF0DBcr4nZzrPna.pdf

Nurton, J. (2020). Patenting trends in renewable energy. Retrieved from https://www.wipo.int/wipo_magazine/en/2020/01/article_0008.html

Oil & Gas of Ukraine. (n.d.). The emergence of a new energy economy. Retrieved from https://oil-gas.com.ua/novyny/%D0%9F%D0%BE%D1%8F%D0%B2%D0%B0-%D0%BD%D0%BE%D0%B2%D0%BE%D1%97-%D0%B5%D0%BD%D0%B5%D1%80%D0%B3%D0%B5%D1%82%D0%B8%D1%87%D0%BD%D0%BE%D1%97-%D0%B5%D0%BA%D0%BE%D0%BD%D0%BE%D0%BC%D1%96%D0%BA%D0%B8

Oliinyk, O. M. (2018). State and prospects of the development of China's energy industry: prospects of cooperation for Ukraine. Ukraine–China – 25 Years of Cooperation: Results and Prospects: "One Belt, One Way", 271-281. Retrieved from https://elibrary.ivinas.gov.ua/935/1/Стан%20та%20перспективи%20розвитку%20енергетичної.pdf

Omelianenko, V., & Omelianenko, O. (2022). Servicing in the economy of Industry 4.0: regional context. Materials of the 4th International Scientific Conference "Competitive Strategies of Economic Development in the Conditions of Global Challenges", 108-109. Retrieved from http://iuf.edu.ua/wp-content/uploads/2022/05/IUF_Conference-2022.pdf#page=108

On the approval of the Energy Security Strategy. Decree of the Cabinet of Ministers of Ukraine No. 907-p of 4 August 2021. Retrieved from https://zakon.rada.gov.ua/laws/show/907-2021-%D1%80#Text

Pustovhar, S. (2022). Trends in the development of entrepreneurship in Ukraine under the conditions of Industry 4.0. Economy and Society, 39. https://doi.org/10.32782/2524-0072/2022-39-15

Regarding the promotion of the implementation of the technological approach "Industry 4.0" in Ukraine. Resolution of the Cabinet of Ministers of Ukraine No. 750 of 12 July 2021. Retrieved from https://zakon.rada.gov.ua/laws/show/750-2021-%D0%BF#Text

Shell Global. (2018). Shell Scenarios Sky. Meeting the goals of the Paris Agreement. Retrieved from https://www.shell.com/energy-and-innovation/the-energyfuture/scenarios/shell-scenario-sky.html

State Statistics Service of Ukraine. (n.d.). Retrieved from https://ukrstat.gov.ua/

The World Bank. (n.d.). Retrieved from https://data.worldbank.org/

UTS-ISF. (2019). Achieving the Paris Climate Agreement goals, global and regional 100% renewable energy scenarios with non-energy GHG pathways for +1.5°C and +2°C. Sydney: University of Technology Sydney – Institute for Sustainable Futures. Retrieved from www.springer.com/gp/ book/9783030058425.