UDC 167.7-330.34(519.83+004.056.5)
JEL Classification: K32, Q42, D83
DOI: 10.15587/2706-5448.2021.230370
Article type «Reports on Research Projects»

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# DEVELOPMENT OF METHODOLOGICAL FOUNDATIONS FOR THE DEVELOPMENT OF ENERGY IN INDUSTRY 4.0 IN PART OF GAME THEORY AND BLOCKCHAIN

*The object of research is the implementation of the principles of Industry 4.0, in particular game theory and blockchain, for the development of energy. One of the obstacles to development is the problem of energy supply in modern economic conditions in terms of achieving sustainable development goals. In the course of the research, a systematic approach to the critical analysis of scientific sources of information related to the development of the energy sector, in particular renewable energy, was used. The scientific result of the systemic interaction of distributed generating devices with «smart» consumers using the principles of Industry 4.0 has been obtained. These principles make it possible to increase the level of efficiency of the power system, to reduce the total cost of operating the power system. And also to reduce power losses, improve network performance while reducing $CO_2$ emissions and negative impact on the environment. The possibility of implementing the provisions of Industry 4.0 as a prerequisite for an economical supply of energy is given. The research methodology is proposed based on a critical analysis of the sphere of economics and management in the energy sector in the period 2011–2021. The possibility of using the Vehicle-to-Grid concept based on Industry 4.0 as a component of the energy system is considered. Due to this, a method for managing the sale of electricity is proposed, based on game theory, and taking into account the autonomous response to demand and the interaction of distributed generation in smart power distribution systems using non-cooperative games. The authors have identified the possibilities of energy blockchain technology in terms of efficient energy supply and transformation of commercial relations in the energy market. Focuses on blockchain for energy as part of ensuring energy sustainability, providing opportunities for the development of renewable energy sources. A list of breakthrough energy technologies for the last 5 years has been highlighted with the aim of their implementation to improve the levels of quality and safety of human life. In particular, according to the Massachusetts Institute of Technology, there are 7 technologies out of 50 investigated, directly related to energy, moreover, the overwhelming majority of these technologies are related to renewable energy.*

**Keywords:** *renewable energy, Vehicle-to-Grid concept, game theory, energy blockchain technologies.*

*Received date: 28.12.2020*
*Accepted date: 03.02.2021*
*Published date: 30.04.2021*



***How to cite***
*Voitko, S., Trofymenko, O. (2021). Development of methodological foundations for the development of energy in Industry 4.0 in part of game theory and blockchain. Technology Audit and Production Reserves, 2 (4 (58)), 20–23. doi: http://doi.org/10.15587/2706-5448.2021.230370*

## 1. Introduction

For more than half a century, mankind has been developing the concept of sustainable development. Disruptive technologies in the energy sector play an important role in achieving the global sustainable development goals Goal 7 «Renewable energy»; Goal 13 «Combat climate change» [1]. The Kyoto Protocol [2] was replaced by the Paris Climate Agreement [3]. This agreement will shape the agenda for the preservation of the environment and, in particular, for the energy sector for the third decade of the 21st century. It should also be noted that humanity is currently actively using the achievements of the Fourth Industrial Revolution, which formed the space of the noosphere in the second decade of the 21st century. At the global level, the concept of Industry 4.0 was adopted in 2014 on the sidelines of the World Economic Forum (Geneva, Switzerland), on the results of which the work [4] was published. Note that in the industrial sector, the foundations of Industry 4.0 sounded in 2011 at the opening ceremony of «Hannover Messe-2011» (Hannover Fair), where this term was announced by Professor Wolfgang Walster, who served as CEO of the German Research Center for Artificial Intelligence (German Research Center for Artificial Intelligence). Also, an initiative group led by C. Grifdstaff (Siemens PLN Software) in 2011 defined the foundations for the development of Industry 4.0 as the integration of «cyber-physical systems» into the production process [5]. In 2011, the Industry-Science Research Alliance (Germany) issued a strategic initiative «Future

Project» with the support of the Federal Government in the implementation of the Industrie 4.0 working group, which is reflected in the document [6].

Consequently, the relevance of the study lies in the feasibility of carrying out scientific research in terms of ensuring the development of the socio-economic sphere in the conditions of the Sixth technological order, the post-industrial era, the knowledge economy, the Fourth Industrial Revolution (Industry 4.0). And also, if necessary, to comply with the provisions of sustainable development, resource conservation, economical energy supply, preservation of the environment for future generations.

Energy permeates all spheres of public life, industry and services, is an integral part of industrial revolutions, technological orders, sustainable development and the like. The development of energy is also relevant in the context of the Fourth Industrial Revolution (Industry 4.0), as evidenced by the work [7]. Among scientists, technological innovations in energy supply systems based on the principles of sustainable development deserve attention [8]. By the way, researchers have identified the role of Industry 4.0 in ensuring sustainability [9]. It is appropriate to pay attention to the work, it concerns the strategies of energy development, in particular for Ukraine [10]. The effects of the incorporation of modern technologies in such a classical sphere as energy provides a number of advantages in the development of both the energy sector itself and the latest technologies. The problems of using smart technologies and smart management in energy systems are considered in [11].

Such a list of scientific works and their content shows the interest of scientists in the problem of efficient use of energy in modern economic conditions. However, a number of issues still remain unresolved related to the integration of energy sources with consumers in terms of the return transfer of energy from the consumer back to the network in order to balance the energy system. This is due to the fact that now there is a rapid growth in the number of electric vehicles, which means that the volume of storage batteries in total is growing. Part of this volume can be used during peak loads on the power system in order to increase its reliability and balance. Controlling such energy flows for distributed systems is a rather difficult task, because each electric vehicle can be a source of low-power energy, and the whole set of such sources is distributed over a large area of the system. Consumers are also divided into the same area. Accordingly, let's get better balancing when the energy source and consumer are located at a close distance from each other. There are other problems, both scientific and practical.

Thus, *the object of research* is the implementation of the principles of Industry 4.0, in particular the theory of games and blockchain, for the development of energy.

*The aim of research* is to develop methodological foundations for the development of energy based on the results of the analysis of theoretical and practical approaches of world researchers.

## 2. Methods of research

The study is based on the analysis of scientific sources of information related to the development of the energy sector, in particular renewable energy. A small period of time, about ten years, was chosen as the limits of the study, which is due to the period of development of industry 4.0 (2011–2021). The basis of scientific research is a critical analysis of the groundwork in the field of economics and management in the energy sector. For the information base, scientific works of recent years have been selected, which largely correspond to the set aim of research.

Based on a systematic approach, the following research objectives have been set:

1) identify the main sections affected by the energy sector at the beginning of the third decade of the 21st century;

2) explore the main milestones in the dissemination of Industry 4.0 provisions, in particular in the energy sector;

3) determine the main tasks for the further development of renewable energy and methods for their solution;

4) identify the positive aspects of using the Vehicle-to-Grid concept as a component of energy transaction management based on game theory;

5) to identify the possibilities of energy blockchain technology in terms of efficient energy supply and established relations in the energy market;

6) categorize a selection of socially important energy technologies from the Massachusetts Institute of Technology;

7) propose the structure of the methodology for the use of the energy system in modern conditions.

## 3. Research results and discussion

The branch of energy accompanies humanity throughout its existence. With the change in social systems, the development of technological structures and the onset of industrial revolutions, the energy component of human life is also being transformed. The use of energy from fossil sources is harmful to the environment, the noosphere, and the planet Earth as a whole. Of course, mankind will not give up energy in any case, but there is an opportunity to implement global measures for the rational use of all energy sources and the gradual abandonment of fossil fuels. Energy savings can be made by a number of means, in particular, based on calculations performed by various tools for mathematical modeling of energy systems. Classical optimization methods have shown their advantages over a long period of time. However, new challenges pose more complex problems that can no longer be solved by classical methods.

In [12], an energy management method based on game theory is presented, which takes into account the autonomous response to demand and the interaction of distributed generation in smart power distribution systems. The basis of the proposed approach is a game-theoretic method of functioning of an intelligent («smart») power distribution network, which operates according to programs of generation and response to demand. The method is based on the use of non-cooperative games, in which the idea is the «cooperation» of distributed generating devices with «smart» consumers. That is, for a real system, the distribution of electricity is carried out taking into account the existing demands from «smart» devices under real operational constraints. This use of the principles of Industry 4.0 makes it possible to increase the level of efficiency of the power system, reduce the total cost of the power system, reduce power losses, and in general, improve the performance of the network while reducing $CO_2$ emissions and negative impact on the environment.

In the development of an approach to the cooperation of distributed generating devices with «smart» consumers, specialists in [13] proposed a scientific solution to the problem of using the V2G (Vehicle-to-Grid) concept. This

ISSN 2664-9969

concept is about the «two-way» energy use of electric vehicles and hybrid cars. That is, on the one hand, these cars are connected to the general power grid to recharge the electric vehicle. And, on the other hand, it provides a technical opportunity to use the already accumulated energy in car batteries in the power grid in order to participate in the management of demand and supply for electricity. This paper proposes a game theory and convention-based energy transaction management method for Internet of Electric Vehicles (IoEV). With the proliferation of intelligent grid systems, the interaction of the energy system and the electric vehicle population is shaping the newest type of energy interaction based on the Internet IoEV. Using the charging/discharging option for electric vehicles using artificial intelligence algorithms makes it possible to reduce the imbalance between supply and demand in the energy system. However, it is worth noting that the implementation of interoperability between existing V2G technology and IoEVs has to weigh on «energy» transactions. To leverage V2G technology effectively, scalable, high-performance cloud services and game-theory-based energy transaction management strategies should be used. The optimal pricing strategy and the strategy for discharging electric vehicles (as energy sources) are obtained based on the use of noncooperative Stackelberg games and equilibrium of price and energy. Here such a phenomenon arises as social responsibility in the behavior of the owner of an electric vehicle. The realization that a car that is not yet in use can be a source of «green» energy and help reduce $CO_2$ emissions. It should be borne in mind that the negative of using this technology is the reduction in the duration of the operation phase of the electric vehicle battery.

Another modern technology from Industry 4.0 is blockchain technology. The integration of this technology into the energy sector opens up fundamentally new opportunities for the development of the industry, increasing reliability, ensuring energy conservation, and the like. The work [14] reveals the possibilities of blockchain technology for energy, in particular for renewable energy sources, in order to ensure energy sustainability. In the case of blockchain-based energy, the principle of distributed (decentralized) energy is used, as well as for distributed data storage in information and communication systems. The energy blockchain solves the bottleneck problem in the development of energy systems, in particular in the problem of replacing fossil energy with renewable energy. Thus, blockchain contributes to the development of renewable energy and ensuring energy sustainability.

The financial component of the energy blockchain was developed in [15]. Electricity pricing for consumers is possible through the use of a game theory based model within the energy blockchain. The peculiarity of this interaction is that the methodology considers not only the commercial relationship between the seller and the buyer, but also the interaction between the sellers. Ultimately, this approach provides an opportunity to provide benefits to consumers and contributes to the development of the electricity market. The potential of the energy blockchain has not been exhausted and requires further scientific research.

The use of game theory and blockchain in the energy industry predetermines the consideration of a number of other technological innovations that have arisen or may arise in the energy field. The Massachusetts Institute of Technology, which has been publishing a selection of technologies important to society for 20 years in a row, is making significant progress in this. Over the past five years (2017–2021) in the section with the general title «10 Breakthrough Technologies» in the reports «MIT Technology Review» [16], the following breakthrough technologies in the energy sector are presented:

– 2017 – Hot Solar Cells;
– 2018 – Zero-Carbon Natural Gas;
– 2019 – New-Wave Nuclear Power and Carbon Dioxide Catcher;
– 2020 – Climate Change Attribution;
– 2021 – Lithium-Metal Batteries and Green Hydrogen.

So, there are 7 technologies out of 50 studied, directly related to energy, moreover, the overwhelming majority of these technologies are related to renewable energy. This shows the prospects for the development of renewable energy and its derivatives, as well as environmentally oriented initiatives.

Taking into account the above, methodological foundations for the development of energy based on Industry 4.0 have been developed in terms of game theory and blockchain, Fig. 1.

The implementation of these methodological foundations will contribute to the development of the energy sector to a greater extent on the basis of renewable energy sources using modern technologies, which are largely spread in other areas.

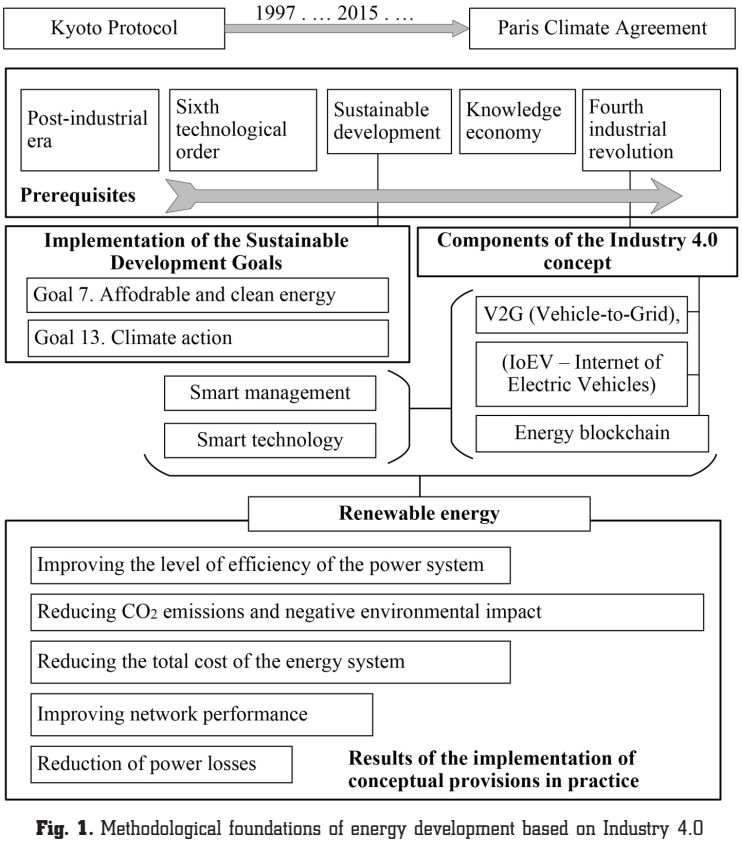


**Fig. 1.** Methodological foundations of energy development based on Industry 4.0 in terms of game theory and blockchain

## 4. Conclusions

Based on a critical analysis of scientific sources, the possibility of implementing the provisions of Industry 4.0 as a prerequisite for economical energy supply based on the use of the Vehicle-to-Grid concept is proven. It is determined expedient to use the method of effective management of electricity sales, which is based on game theory, that is, on the game-theoretic method of functioning of an intelligent («smart») distribution network, which operates according to programs of generation and response to demand when using non-cooperative Stackelberg games. To implement the above, it is advisable to use the method of energy transaction management based on game theory and agreements for Internet of Electric Vehicles (IoEV – Internet of Electric Vehicles), which forms the newest type of energy interaction between electric vehicles and the power grid based on the IoEV Internet. This takes into account the autonomous response to consumer demand and the interaction of distributed power generation in smart power distribution systems. Let's emphasize that now such a concept as «smart» energy consumers is spreading, which can «order» certain amounts of energy in advance, which requires further scientific research. The same, at the moment there is an opportunity to use energy blockchain technologies in the field of efficient energy supply and transformation of commercial relations between generating companies and consumers. This is a novelty in terms of obtaining an economic effect from the use of the Vehicle-to-Grid concept with Internet of Electric Vehicles technologies and blockchain in order to ensure energy sustainability, develop renewable energy sources, reduce $CO_2$ emissions and negatively impact the environment. It is also worth considering the interest in renewable energy technologies, which have been identified by experts from the Massachusetts Institute of Technology.

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