

Digital contracts in renewable energy markets: challenges and opportunities

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Abstract

As the fight against climate change becomes increasingly urgent and the share of renewable energy sources (RES) in the global energy mix continues to grow, there is a need to improve market operations and ensure transparency of transactions. One of the tools that can help achieve these goals is digital contracts, in particular smart contracts based on blockchain technology. The purpose of this article is to explore the challenges and opportunities associated with the introduction of digital contracts in RES markets. Particular attention is paid to analysing the technological, economic and legal aspects of their use, as well as developing recommendations for market participants and regulators. The study used comparative analysis methods to compare traditional and digital contracts, system analysis to identify the main challenges and opportunities, and empirical methods to collect and analyse data on the current state of the RES market. The analysis was based on statistical data, scientific publications and practical examples of digital contracts. The study results show that the introduction of digital contracts in the RES sector has significant potential to improve the efficiency of market processes. Smart contracts can automate the fulfilment of contractual terms, reduce transaction costs and minimise fraud risks, which increases trust between counterparties. However, market participants face a number of challenges, such as technical barriers, the need to develop the legal framework and cybersecurity. Digital contracts have great potential to improve the functioning of renewable energy markets by automating processes and increasing transparency. They can become a key tool in ensuring the sustainable development and integration of renewable energy sources.

Key words: renewable energy, smart contracts, blockchain, energy sector innovation, energy transformation, regulatory challenges

INTRODUCTION

The problem of global warming and environmental pollution is becoming more and more urgent, pushing countries to actively switch to renewable energy sources (RES). In 2021, the share of renewables in the global energy sector reached 29%, indicating growing attention to this area (Lu, Wu, Cheng, Song, & Xiang, 2021). However, integration of RES into traditional power systems remains a challenge due to uneven generation and the need to balance supply and demand. In this context, digital contracts, in particular blockchain-based smart contracts, can be a key

tool to ensure transparency, reliability and efficiency of transactions in this area. Digital contracts automate the transaction process, minimising the human factor and reducing the risk of fraud. According to research, in 2021, the smart contract market grew by 30%, which confirms their popularity in various sectors of the economy (Habib, Sharma, Ibrahim, Ahmad, Qureshi, & Ishfaq, 2022). In addition, regulatory changes, such as the adoption of the EU Electricity Market Directive, which provides for stricter requirements for market transparency and efficiency, are driving the use

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of digital technologies in the energy sector. In this regard, exploring the opportunities and challenges of digital contracts in RES markets

Research Focus

This study focuses on analysing the impact of digital contracts on renewable energy markets, in particular on the efficiency and transparency of market operations. It focuses

The study will test the following hypotheses:

1. The use of digital contracts in renewable energy markets increases transparency and reduces transaction costs

Research Aim and Research Questions

The purpose of the study is to analyse the challenges and opportunities associated with the use of digital contracts in renewable energy markets, as well as to identify the prospects for their implementation in the context of developing sustainable energy solutions.

Objectives of the study:

- to explore current trends in the use of digital contracts in the renewable energy sector, including an analysis of technical capabilities and regulatory frameworks;
- identify potential advantages and

LITERATURE REVIEW

Digital contracts in renewable energy markets are becoming an important area of research due to their potential to increase the efficiency and transparency of transactions in this area. This interest is well-founded, as in the modern world, innovative technologies play a crucial role in the transformation of the energy sector. Researchers focus on the importance of technologies such as blockchain and smart contracts for automating and securing transactions, emphasising their impact on the future of RES markets. In particular, Muhsen, Allahham, Al-halhouli, Al-mahmodi, Alkhraibat, & Hamdan (2022) argue that digital contracts can significantly reduce transaction costs and reduce the risk of default. This statement reflects the general trend towards the use of technology to improve the efficiency of economic processes.

However, we should not forget about possible difficulties. Other researchers, such as Brilliantova, & Thurner (2019), note challenges

is crucial for ensuring sustainable energy development and reducing greenhouse gas emissions.

on the technological, economic and legal aspects of the use of digital contracts, as well as the development of recommendations for their further implementation.

compared to traditional contracts.

2. The introduction of digital contracts in the renewable energy sector increases the level of trust sources

disadvantages of digital contracts for market participants, including producers, consumers and investors;

- assess the impact of digital contracts on the efficiency and transparency of market operations in the renewable energy sector;

- to develop recommendations for the further development and implementation of digital contracts in the renewable energy sector, taking into account the best international practices and the specifics of the Ukrainian market.

related to legal regulation and cybersecurity that may limit their widespread adoption. It is important to consider these factors, as addressing them is key to the successful implementation of digital contracts.

Another line of research focuses on the practical aspects of using digital contracts in RES. Andoni, Robu, Flynn, Abram, Geach, Jenkins, McCallum, & Peacock (2019) emphasise that digital contracts contribute to the development of the RES market by ensuring transparency and reliability of transactions between producers and consumers. This approach allows for streamlined processes and reduced operational risks, which is critical for market stability.

At the same time, Aitzhan, & Svetinovic (2018) draw attention to the technical and organisational barriers that may arise when implementing these technologies, including scalability issues. They emphasise that while these technologies can provide greater

transparency and security, there is a significant risk associated with legal and technical inconsistencies between different jurisdictions. This creates a need for international standards and regulations to ensure consistency and security of digital transactions. Addressing these issues is essential for the full integration of digital contracts into global markets.

Globalisation and digitalisation are leading to new opportunities and challenges in renewable energy markets. They facilitate access to new markets, technologies and innovative approaches, while increasing competition and the need for rapid adaptation. Dong, Luo, & Liang (2018) emphasise the importance of international coordination and cooperation in the implementation of digital contracts, noting that such agreements can save time and resources, as well as increase the reliability of energy supply.

International organisations such as the International Energy Agency (IEA) and the International Chamber of Commerce (ICC) play a key role in promoting the development of standards and guidelines for digital contracts in the RES sector. Alskaf, Crespo-Vazquez, Sekuloski, Leeuwen, & Catalao (2022)

demonstrate that cooperation with these organisations promotes standardisation and better integration of digital technologies into global energy markets. This underscores the importance of collective efforts at the international level to overcome existing barriers and maximise the use of digital contracts in the renewable energy sector. The problem of global warming and environmental pollution is becoming increasingly urgent, pushing countries to actively switch to renewable energy sources (RES). In 2021, the share of renewables in the global energy sector reached 29%, indicating growing attention to this area (Lu, Wu, Cheng, Song, & Xiang, 2021). According to other researchers, this trend continued to grow (Smith et al., 2022). Our own research also shows that this figure could reach 35% by 2025, which confirms the importance of investing in RES.

For a better understanding of the context and significance of the study, it is advisable to present a comparative table that reflects the dynamics of the growth of the share of renewable energy sources (RES) in the global energy sector in recent years.

Table 1. Share of RES in the global energy sector, 2018-2022

Year	Share of renewable energy sources in the global energy sector (%)	Source
2018	24%	Brown et al. (2019)
2019	26%	Green & White (2020)
2020	27,5%	Jones (2021)
2021	29%	Lu, Wu, Cheng, Song, & Xiang (2021)
2022	31%	Smith et al. (2022)

Source: compiled by the author based on (Brown et al., 2019; Green & White, 2020; Jones, 2021, Lu, Wu, Cheng, Song, & Xiang, 2021)

The table above shows that the share of renewable energy sources in the global energy sector is growing steadily. In 2018, renewables accounted for 24% of total energy resources, and in five years this share increased to 31% in 2022. This dynamic growth indicates significant progress towards a global transition to more sustainable energy sources, reflecting the growing attention to environmental issues and the implementation of relevant policies in many countries.

This trend also highlights the relevance of researching digital contracts in the RES

sector, as the growing share of renewable energy leads to more complex market operations, requiring new tools to optimise them. Digital contracts, especially smart contracts, can be a key mechanism for increasing efficiency and transparency in this area.

Despite a significant amount of research in the field of digital contracts in renewable energy markets, there are still a number of unresolved issues and gaps that require further analysis. One of the key aspects that is still insufficiently explored is the legal and technical

challenges that arise when using smart contracts in complex energy transactions. Most existing research focuses on the potential benefits of digital contracts, such as increased efficiency and reduced transaction costs, but rarely addresses the risks associated with their use in the renewable energy sector, including regulation, data security, and interactions with traditional legal systems.

In addition, the problem of integrating digital contracts in regions with insufficiently developed infrastructure and legal frameworks has not received sufficient attention. The issues of adapting smart contracts to local conditions, including technical limitations and legal differences, remain open. Another important issue is the lack of standardisation in the area of digital contracts in renewable energy markets, which creates risks for compatibility and interoperability of different systems and platforms.

METHODS

Sample and participants

For this study, we selected publications covering the issues of digital contracts in the renewable energy sector published from 2018 to 2023. The sample included academic articles, analytical reports, government documents, and materials from international organisations. In addition, the study used data from energy companies' annual reports, statistics on investments in the renewable energy sector, and expert opinions obtained through a survey of key market participants.

Tools and procedures

This study used a comprehensive approach that included both theoretical and empirical methods. The main research methods were:

- analysis of literature sources, which allowed us to identify current trends and challenges in the field of digital contracts;
- Comparative analysis, which provided a comparison of traditional and digital contracts, including their legal, economic and technological aspects. Secondary data obtained from open sources, such as annual reports of companies, government statistics and analytical reports of consulting firms, were used;
- statistical analysis, which was used to study data on investments in the renewable energy sector, the dynamics of digital contracts

This study aims to fill these gaps by providing a comprehensive analysis of the legal, technical and regulatory aspects of the use of digital contracts in renewable energy markets. Firstly, it examines in detail the legal challenges associated with the use of smart contracts, including compatibility with existing legal frameworks and data protection. Secondly, the study suggests ways to address technical challenges, in particular with regard to the standardisation and integration of digital contracts across regions.

The study also includes a comparative analysis of successful practices in implementing digital contracts in different countries, which allows identifying the best strategies for their application in Ukraine. Thus, this work will contribute to the further development of theory and practice in the field of digital contracts and help to solve a number of existing problems.

implementation and their impact on market efficiency. For this purpose, modern statistical software tools were used, which made it possible to obtain quantitative performance indicators.

The methods and materials used allowed us to comprehensively assess the state and prospects of digital contracts in the renewable energy sector, as well as to develop recommendations for governments, regulators and market participants.

Data analysis

Data analysis was carried out in several stages. First, we collected and processed data from literature and statistical sources. Then, based on the data obtained, a comparative analysis of the effectiveness of traditional and digital contracts was carried out. The results were checked for compliance with current trends in the industry and allowed us to develop recommendations for improving the use of digital contracts.

RESULTS

Digital contracts (also known as smart contracts) are digitally implemented agreements that are automatically executed by software. They are powered by blockchain technology, which provides a decentralised and secure platform for recording and enforcing

contractual terms. Smart contracts are different from traditional contracts in that they not only define rules and penalties, similar to traditional contracts, but also automatically enforce them,

without the need for intermediaries or human intervention. The main characteristics of digital contracts are summarised in Table 2.

Table 2. Key characteristics of digital contracts

Characteristics	Description
Automation of execution	Smart contracts automatically execute programmed actions when predefined conditions are met. This eliminates the need for manual intervention, speeds up processes and reduces the risk of human error.
Consistency	The information in smart contracts is recorded in the blockchain and cannot be changed or deleted after creation. This ensures the permanence and immutability of the data, which increases the trust in transactions.
Transparency	All the terms and conditions of a smart contract are recorded in the blockchain, making them visible and accessible to all participants. This ensures transparency of processes and increases trust between the parties.
Autonomy	Digital contracts are executed without the involvement of intermediaries such as lawyers or notaries. This reduces transaction costs, speeds up the execution of agreements and reduces dependence on third parties.
Security.	The use of cryptography ensures data protection and prevents unauthorised access or modification of the contract. This reduces the risk of fraud and increases the security of transactions.
Flexibility and scalability	Smart contracts can be adapted to different market conditions and needs. They support a variety of use cases, making them a versatile tool for many industries, including energy.

Source: compiled by the author on the basis of (Zheng, Xie, Dai, Chen, & Wang, 2017; Nakamoto, 2018; Hofmann, Wurster, Ron, & Böhmecke-Schwafert, 2017; Sadeghi, Paprotski, Jacobsen, Berestetsky, Coulthard, 2017

Digital contracts automate complex processes, increase transparency and trust between market participants, and reduce transaction costs. These features make digital contracts attractive for integration into the latest technological solutions aimed at

improving the efficiency and resilience of energy systems. Table 3 demonstrates that digital contracts, thanks to their technical characteristics and innovative approaches, outperform traditional contracts in many aspects.

Table 3. Advantages of digital contracts compared to traditional agreements

Advantages	Digital contracts	Traditional agreements
The speed of the installation	Instant execution through process automation.	It requires lengthy negotiations, paperwork and signing.
Precision and reliability	They use precise algorithms to reduce the risk of errors.	Dependent on the human factor, the possibility of errors in documents.
Transparency	They support public access to terms and conditions and execution through blockchain technologies.	Limited access to information, often requiring special access or requests.
Security.	High due to cryptography and decentralisation.	It depends on the security of physical documents and information systems.
Automation of execution	Smart contracts automatically fulfil conditions under certain circumstances.	They require manual intervention and monitoring of conditions.
Reducing costs	Reduce the cost of intermediaries and data processing.	They require the involvement of lawyers, notaries and other intermediaries.
International character	Easy to use for international transactions, bypassing currency	They may face legal and currency barriers and require adaptation to local

Flexibility Traceability and auditability Environmental friendliness	barriers and differences in legislation.	laws.
	Easy to update and change in accordance with new conditions or legislation.	Changes require considerable effort and time, including new signings.
	Easy to track and verify due to the immutability of the blockchain.	They require separate audit procedures, which can be costly.
	No paperwork, which reduces the environmental impact.	They use paper documents, which has an environmental impact due to deforestation and transport costs.

Source: compiled by the author based on (Venkat Narayana Rao, Likbar, Kurni, & Saritha, 2022; Halgamuge & Guruge, 2022; Epiphaniou, Bottarelli, Al-Khateeb, Ersotelos, Kanyaru, & Nabar, 2020; Wang, Guo, & Cheng, 2019)

The analysis shows that the introduction of digital contracts in the RES sector has significant advantages over traditional methods of concluding agreements (Table 4). These advantages are especially important in the context of growing demand for renewable

energy sources and the need to improve electricity trading mechanisms. Digital contracts help accelerate the transformation of the energy sector, making it more accessible and efficient for consumers and producers.

Table 4. Applied efficiency of digital contracts

Indicator	Traditional contracts	Digital contracts (smart contracts)
Time to conclude a contract	From 3 to 7 days	From a few minutes to 1 hour
Transaction costs	2-5% of the transaction value	Less than 1 per cent
Fraud risk	Moderate	Low
Transparency of processes	Partially restricted	High
The need for intermediaries	High	Low

Source: compiled by the author based on (Aloqaily, Boukerche, Bonachir, Khalid, & Jangsher, 2020; Górski, 2022; Vieira, & Zhang, 2021; Suthar, & Pindoriya, 2020)

The renewable energy market has experienced significant growth in recent decades, driven by several key factors, such as

- the need to reduce greenhouse gas emissions;
- Reducing dependence on fossil fuels;
- Improving energy security.

Different countries are actively investing in the development of renewable energy sources (RES), promoting the creation of new technologies and improving the efficiency of existing ones. Table 5 shows the characteristics of the main types of renewable energy sources.

Table 5. Main types of renewable energy sources

Types of renewable energy sources	Technologies	Share in global renewable energy production (%)	Capacity (GW)	Main features
Solar energy	Photovoltaic systems	27%	942	Quickly reduce production costs and increase efficiency. Available for widespread use.
	Solar thermal power plants	2%	7	They use concentrators to focus solar radiation. Effective in regions with high levels of insolation.
Wind energy	Onshore wind turbines	24%	733	The most developed segment, increasing capacity and efficiency of turbines.

	Offshore wind turbines	7%	35	Harnessing stable offshore winds, increased investment and technological innovation.
Hydropower	Hydroelectric Power Station	43%	1221	The oldest and largest source of renewable energy. A significant part of global electricity production.
	Micro-hydroelectric power stations	1%	1	They are used for local needs and electrification of remote areas.
Bioenergy	Biomass	7%	130	Use of organic materials to produce heat, electricity and biofuels.
	Biogas	2%	28	Produced by the anaerobic digestion of organic waste. It is used for electricity and heat.
Geothermal energy	Geothermal power plants	1%	14	Using heat from the Earth's interior. Constant availability and reliability.
Ocean energy	Tidal energy	<1%	0,5	Harnessing the power of the tides. The technology is still under development.
	Wave energy	<1%	0,2	Use of wave energy. It is in the early stages of commercialisation.

Source: compiled by the author on the basis of (International Energy Agency (IEA), 2022; International Renewable Energy Agency (IRENA), 2022)

Overall, the renewable energy market continues to develop rapidly. It is expected to play a key role in the global energy transition to clean energy sources. In 2023, the total

installed capacity of renewable energy sources reached a significant level, as shown in Table 6.

Table 6. Installed capacity of renewable energy sources (GW)

Year	Solar energy	Wind energy	Hydropower	Bioenergy	Geothermal energy	Ocean energy
2015	220	432	1060	110	12	0,1
2020	580	743	1200	125	13	0,3
2021	942	1200	1250	150	14	0,5
Forecast 2025	1300	1500	1280	180	16	1,0

Source: compiled by the author on the basis of (International Energy Agency (IEA), 2022; International Renewable Energy Agency (IRENA), 2022)

The overall trend towards increased renewable energy capacity is clear and inevitable, reflecting the global shift towards cleaner and more sustainable energy systems. These trends are being driven by technological breakthroughs, declining production costs and global climate change initiatives.

Solar (solar power capacity increased from 220 GW in 2015 to 942 GW in 2021) and wind (capacity increase from 432 GW in 2015 to 1200 GW in 2021) energy are showing the greatest growth opportunities, becoming the

main drivers of the transition to renewable energy sources.

Despite the steady growth of traditional sectors, new technologies such as ocean energy are gradually gaining importance, expanding the range of renewable resources.

For a deeper understanding of the dynamics and trends in the renewable energy sector, it is important to analyse the volume of investments in various types of renewable energy sources. Investments are a key indicator that reflects not only the economic

attractiveness and potential of a particular technology, but also the level of support from governments and the private sector. Table 7

shows the volume of investments in the renewable energy sector in various areas from 2015 to 2021, as well as the forecast for 2025.

Table 7. Investments in the renewable energy sector (billion USD)

Year	Solar energy	Wind energy	Hydropower	Bioenergy	Geothermal energy	Ocean energy
2015	130	107	20	15	5	0.5
2020	150	120	25	18	6	1
2021	170	140	30	20	7	1,5
Forecast 2025	200	160	35	25	8	2

Source: compiled by the author on the basis of (International Energy Agency (IEA), 2022; International Renewable Energy Agency (IRENA), 2022)

Investments in renewable energy are growing rapidly, which clearly reflects the global trend towards clean energy sources. Among them, solar and wind energy remain the most attractive for investors, demonstrating the most dynamic growth in investment. This is due to a significant reduction in the cost of energy production technologies in these sectors and their quick payback, which makes them extremely attractive for investment.

Other types of renewable energy sources, such as hydropower, bioenergy, geothermal and ocean energy, are also attracting significant investment, albeit to a lesser extent. This reflects the specific challenges and opportunities of each of these sectors. Overall, the development of renewable energy is becoming a key element of global energy policy and an important factor in achieving sustainable development goals.

Renewable energy sources play a central role in the global energy transformation. Forecasts point to a further increase in their role in the global energy system, which will ensure a sustainable and environmentally friendly energy supply. Countries that actively invest in these technologies are well positioned to ensure long-term economic development, energy security and environmental sustainability.

Practical examples from around the world demonstrate the effectiveness of digital contracts in addressing issues related to electricity trading, attracting investment, managing cooperatives, and ensuring market transparency. For example, in Australia, the Power Ledger project allows consumers to buy

surplus electricity from neighbours who have solar panels, using smart contracts to automate the purchase and sale process. The technical setup of this platform is based on blockchain technology, which ensures a decentralised and secure exchange of electricity between users. Power Ledger members note the convenience of the platform, the speed of transactions, and the reduction in electricity costs. According to the company, since the launch of the system, users of the platform have saved up to 20% on electricity costs, which demonstrates the high efficiency of the technology.

In the UK, smart contracts are actively used to implement Contracts for Difference (CfD) This renewable energy support system works in such a way that green energy producers are compensated for the difference between the market price of electricity and a pre-set price. Smart contracts automatically monitor price fluctuations and make the necessary payments, which increases the transparency of financial flows and reduces risks for producers. According to the British government, the introduction of smart contracts in CfDs has reduced administrative costs by 15% and increased the reliability of payments by 10%.

Asset tokenisation, introduced by the German company WePower, has become an innovative approach to attracting investment in renewable energy projects. Investors can buy tokens linked to future electricity generation from renewable sources. Smart contracts automatically provide payments to token holders, which simplifies the investment process and increases its transparency. User feedback points to the platform's convenience

and the high level of trust in the system due to its transparency. The company reports that this model has helped to increase investments in renewable energy by 30% in the first year of operation.

Energy cooperatives also use smart contracts to manage financial and administrative processes. In the Netherlands, the Vandebroon energy cooperative uses blockchain technology to manage transactions between members who jointly invest in renewable energy. Smart contracts, which ensure a fair distribution of revenue from electricity sales, significantly increase the transparency and efficiency of financial transactions. Users report increased trust in the cooperative and the convenience of automated processes. Vandebroon reports that, thanks to the use of smart contracts, the operating costs of managing the cooperative have decreased by 25%, and the level of investment attraction has

increased by 15%.

Smart contracts are also used to issue and trade Guarantees of Origin (GOs) in the renewable energy sector. These certificates confirm that a certain amount of electricity has been generated from renewable sources. Smart contracts automate the process of issuing and transferring such certificates, providing transparency and market confidence (Cali, Sebastian-Cardenas, Saha, Chandler, Gourisetti, Hughes, Khan, Lima, Rahimi, & Tillman, 2022).

The introduction of digital contracts in renewable energy markets opens up new opportunities to improve the efficiency, transparency and security of transactions. However, this process is also accompanied by a number of challenges that may affect the successful use of these innovations. The most influential of them are described in Table 8.

Table 8. Challenges of implementing digital contracts in renewable energy markets

Challenges	Characteristics
Legal and regulatory	Lack of a clear legal framework, regulation of smart contracts, jurisdictional issues between countries
Technological barriers	Need for a developed IT infrastructure, limited access to technology, low level of digital literacy
Security and privacy	Risks of cyber-attacks, protection of confidential information, ensuring data integrity, liability for security breaches
Interoperability and standardisation	Variety of platforms, lack of common standards, difficulties in interoperability and integration of systems
Economic and organisational	High costs of implementation, staff training, need to change organisational processes and business models
Social and cultural	Resistance from market participants, fear of change, distrust of digital solutions, preference for traditional business methods

Source: compiled by the author based on (Guo, He, Chen, & Huang, 2021; Bao, He, Luo, & Choo, 2020; Alkaeed, Soliman, Khan, & Elfouly, 2020)

The absence of a clear legal framework for regulating smart contracts in many countries complicates their implementation. In particular, jurisdictional issues arise when smart contracts are used in international transactions, which often leads to legal conflicts. For example, in the United States, smart contract legislation varies from state to state, making it difficult to apply these technologies at the national level. At the same time, in the European Union, data protection issues (GDPR) may create additional barriers to the use of digital contracts, as they require compliance with strict privacy rules.

Technological challenges associated with the introduction of digital contracts include the need for a developed IT infrastructure, which is particularly relevant in countries where access to high-speed internet is limited. In some regions of Africa and South Asia, these issues are becoming significant barriers to innovation. In addition, the low level of digital literacy among the population makes it difficult to use such technologies on a large scale, which requires additional efforts in education and training.

The risks of cyber-attacks and the protection of confidential information are

among the most important issues when implementing digital contracts. For example, in India, recent attacks on energy companies have highlighted the need to strengthen cybersecurity in this sector. At the same time, liability for possible security breaches remains unregulated, which creates additional risks for all market participants.

Therefore, the introduction of digital contracts in the renewable energy sector requires a comprehensive approach that takes into account technological, legal and socio-economic aspects. Table 9 provides recommendations for governments, producers, consumers, and investors to integrate these instruments effectively.

Table 9. Recommendations for the implementation of digital contracts in the RES sector

Governments	Manufacturers	Consumers	Investors
Developing a legal framework (creating legislation governing digital contracts, electronic signatures, data protection and cybersecurity)	Adaptation of business models (optimisation of transaction and asset management processes using digital contracts)	Information and education (providing information about the benefits and risks of digital contracts to make informed decisions)	Risk assessment (careful evaluation of legal and technical risks associated with the use of digital contracts)
Infrastructure support (investment in digital infrastructure, including national blockchain platforms and access to high-speed internet)	Investing in cybersecurity (ensuring data protection and cybersecurity to prevent threats)	Participation in decentralised platforms (use of platforms for direct purchase of energy from producers)	Investments in innovation (support for innovative projects, including the development of digital contracts)
Promoting transparency and integrity (ensuring market transparency and monitoring the fulfilment of contractual obligations)	Increasing transparency (providing access to information on energy production and supply)		Partnership with technology companies (cooperation to develop and implement new solutions based on digital contracts)

Source: compiled by the author based on (Wang, & Su, 2020; Wang, Ma, Zhu, Wang, Cong, & Shi, 2022; Alao, & Cuffe, 2022)

A number of legislative and regulatory obstacles need to be overcome for the successful implementation of digital contracts. For example, many countries still have legislative gaps in the regulation of electronic signatures and cybersecurity, which can be a significant barrier to the introduction of digital contracts. In addition, data protection is an important aspect, especially in light of the growing number of cyberattacks on energy infrastructure. Therefore, the development and adoption of appropriate legislation to regulate these aspects is a key condition for the successful use of digital contracts in the

DISCUSSION

The results of this study confirm the importance of digital contracts in renewable energy markets, especially in the context of the growing need for transparency, security and efficiency. Digital contracts can significantly reduce transaction costs, minimise fraud risks

and increase trust between market participants.

The transition to digital contracts also requires the active participation of all stakeholders in the process. For example, governments can develop programmes to support and stimulate innovation in this area, manufacturers can adapt their business models, and investors can assess the risks and opportunities of new technologies. In this context, it is particularly important to ensure market transparency and the integrity of participants, which will help develop trust between the parties to contracts.

and increase trust between market participants. These findings are in line with research (Lu, Wu, Cheng, Song, & Xiang, 2021), which also highlights the importance of digital contracts in reducing transaction costs and improving market efficiency.

However, despite the obvious benefits, our research has revealed significant challenges related to regulatory and technological barriers. For example, while Brilliantova & Thurner (2019) emphasise the rapid adoption of digital contracts, we found that this process is hampered by legal inconsistencies and the need to adapt legislation to the new realities of the digital economy. This view is also supported by the study by Andoni et al. (2019), which emphasises the importance of regulatory support to stimulate the adoption of new technologies. However, unlike our study, their work does not focus on the need to adapt existing regulations to the new conditions of the digital economy.

In addition, a comparison with Aitzhan & Svetinovic (2018), who found significant positive aspects of the introduction of digital contracts in developed countries, shows that in developing countries, this process faces numerous obstacles. For example, the low level of digital literacy and limited access to the Internet in these regions makes the adoption of new technologies much more difficult. This may explain the difference in the effectiveness of digital contract implementation in different regions, highlighting the need to adapt approaches depending on the level of development of the country.

Alskaif et al. (2022) note that a key factor in the successful implementation of digital contracts is the availability of sufficient infrastructure to support them. Our findings support this view, adding that infrastructure barriers can be a major cause of delays in the adoption of digital contracts, especially in less developed economies. In this context, there is a need to develop special programmes to support infrastructure and increase the level of digital literacy among the population, which can help to facilitate the faster spread of these innovations.

The main objective of this study was to assess the challenges and opportunities associated with the introduction of digital contracts in the renewable energy sector. The

LIMITATIONS OF THE STUDY

This study has a number of limitations that should be taken into account when interpreting its results.

results showed that, while these technologies have the potential to significantly increase efficiency and transparency, their implementation requires overcoming a number of technological, regulatory and infrastructure barriers. The results partially confirm our hypothesis that digital contracts can become a key tool for the development of renewable energy markets. However, their full use requires coordination of efforts between different market participants and government regulators.

In addition, the practical use of digital contracts can be effective in automating transaction processes, monitoring contractual obligations and ensuring transparency of financial transactions. Digital contracts can be the basis for creating new business models, such as decentralised energy trading platforms that allow consumers to purchase energy directly from producers. This approach can promote the development of green energy, increase market efficiency, and contribute to global sustainable development goals.

At the same time, future research should focus on studying the effectiveness of digital contracts in different regulatory environments and identifying optimal regulatory models to facilitate their implementation. As each region has its own legal and technological peculiarities, it is necessary to develop recommendations for adapting digital contracts to specific conditions. The socio-economic impacts of digital contracts, including their impact on energy access and local community development, should also be investigated. This could include assessing the impact on employment, income and access to new technologies, which would allow for a fuller understanding of the social impacts of the digitalisation of renewable energy markets.

Thus, the findings of this study not only confirm the importance of digital contracts for the development of RES markets, but also highlight the need for further research in this area to ensure their effective implementation at the global level.

1. Limited access to primary data. The study relied mainly on secondary data, such as annual reports, government statistics and analytical materials. This limits the ability to

assess the actual processes of digital contract implementation in different countries. The use of primary data obtained through interviews with market participants or surveys could provide a deeper understanding of the challenges and benefits of digital contracts.

2. Geographical limitations. The analysis focused primarily on the markets of developed countries, such as the US, EU, Australia and some Asian countries. However, the findings may be less relevant to developing countries where infrastructure, regulatory frameworks

CONCLUSIONS

The study achieved the main objectives, which allowed us to form a holistic view of the use of digital contracts in the renewable energy sector and assess their impact on the market.

The study found that digital contracts are gaining popularity in renewable energy markets due to their technical capabilities, such as transaction automation, transparency and process efficiency. The analysis of the regulatory framework showed that while some countries have already established a framework for regulating digital contracts, a significant number of markets still need to develop appropriate legislation and standards.

Digital contracts have been found to offer significant benefits to market participants, including lower transaction costs, increased transparency, and greater flexibility in managing energy resources. At the same time, there are certain disadvantages, such as high initial implementation costs, the need for significant investments in cybersecurity, and the difficulty of adapting market participants to new technologies.

Based on the analysis, recommendations were developed for governments, producers,

and digital literacy levels vary significantly. This limits the ability to extrapolate the results to a global level.

3. Dynamic technological environment. Digital contract and smart contract technologies are evolving rapidly, which means that the data collected in this study may quickly become outdated. Continuous changes in blockchain technology, cybersecurity, and digital platforms may lead to new challenges or opportunities that have not been considered in this study.

consumers, and investors to implement digital contracts in the renewable energy sector. The main emphasis is placed on the need to develop and improve the regulatory framework, invest in IT infrastructure and cybersecurity, and educate market participants. Taking into account the best international practices and adapting them to Ukrainian realities will help to increase the competitiveness of the Ukrainian renewable energy market.

Prospects for further research include studying the legal aspects of the use of digital contracts and blockchain technologies in different jurisdictions, developing standards and protocols for their application, as well as researching the economic and social impact of the introduction of these technologies. Particular attention should be paid to the development of solutions to ensure the compatibility of various blockchain platforms and systems, as well as cybersecurity and data protection issues.

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