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# Blockchain Applications in Renewable Energy: Analytic Hierarchy Process-Based Survey Results

Anete KALNINA[1*], Francesco ROMAGNOLI[2], Maksims FEOFILOVS[3], Gunita MAZURE[4]

[1–3]*Institute of Energy Systems and Environment, Riga Technical University, Azenes street 12/1, LV-1048 Riga, Latvia*

[4]*Faculty of Economics and Social Development, Latvia University of Life Sciences and Technologies, Svetes street 18, LV-3001 Jelgava, Latvia*

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***Abstract*** **– The urgency to reach net-zero emissions until 2050 has created a vast interest in innovative technologies for renewable energy sector. At the same time the need for trusty and unfailing solutions will rise considering the increasing amount of decentralized and decarbonized energy systems. It has previously been described in the literature that the aforementioned characteristics could be combined by blockchain technology. Therefore, this study focuses on the practical side – the opinion of industry experts about the use of blockchain in renewable energy. By using SWOT, PESTLE and analytic hierarchy process analysis, the goal of this study is to develop a methodology for the selection of the most appropriate blockchain applications in renewable energy and to identify and evaluate the possible types of use considering socio-economic, political and legal, technological and environmental factors. The results of this study highlight the important influence of political, legal and technological factors like involvement of government institutions and possible attacks to the system, but considers the economic factors as the least significant for the introduction and use of blockchain technology in the renewable energy sector. The most promising use cases for blockchain would be associated with reliable and immutable certificates of origin for renewable energy and use in smart grid (including smart metering), smart homes and relevant Internet of Things applications. The use of crypto-assets and initial coin offerings for renewable energy development should be viewed with precaution and willingness to inform and educate considering social factors like public opinion and societies' knowledge on crypto-assets.**

***Keywords*** **– Analytic Hierarchy Process (AHP); blockchain; net zero; renewable energy.**

## 1. INTRODUCTION

The crucial need for the rapid development of renewable energy in the European Union (EU) grows every year and is expressed through plans and legislation, the latter clearly being binding on Member States. Since the adoption of the European Green Deal in 2019 [1] and its supplementary measures called Fit for 55 [2], the EU has committed to becoming climate-neutral by 2050 while reducing greenhouse gas emissions by 55 % (compared to 1990) already by 2030 [2]. These measures were written into European Climate Law (2021) [3], thus making those targets legally binding to all Member States. In the pathway to the net-zero

* Corresponding author.
E-mail address: anete.kalnina_2@edu.rtu.lv

target, it is necessary to take into account the geopolitical events happening in 2022–2023, so it is essential to mention here the REPowerEU plan (2022) [4] on ending EU's dependence on Russian energy. Considering this important aspect and the resulting need to speed up the renewable energy transition in September 2023, the EU has adopted a new aim of at least 42.5 % renewable energy (aiming for 45 %) by 2030 [5]. This means that the EU's final renewable energy consumption must be doubled if compared to the 21.8 % level registered for 2021 [6].

At the same time digitalization processes in the economy should play a key role. The policymakers have confirmed this tendency, for example, by adopting the EU's Digital finance package in 2020 [7]. Therefore, increased attention should be addressed to the development and use of new technological solutions, the comparability of data [8], [9] in every EU Member State, as well as the overall efficiency of the system, also including energy self-consumption [10], reliability and other socio-economic, legal and technological factors. As mentioned by [11] digitalization could rapidly develop energy sector by increasing the sustainability, demand response, trust and safety of energy systems. One of the promising technologies for both digital finance and renewable energy development could be blockchain technology [12] [13]. Blockchains constitute immutable and decentralized ledgers, capable of securely archiving digital transactions without the necessity for a centralized governing entity [12]. While operating on a decentralized system (i.e., distributed ledger technology), blockchain with the use of cryptography ensures trustfulness, security and transparency of recorded immutable transactions that cannot be changed by single member of the ledger [14] [15]. As emphasized by Borkovcová *et al*., data integrity is reinforced directly by blockchain operation principles – data storage in encoded blocks [16]. According to Antal *et al*., the use of blockchain could significantly increase the flexibility of small-scale prosumers [17]. European Commission's Joint Research Centre has pointed out the ability of blockchain to enable micro-transactions through machine-to-machine economy thus reducing the costs of such payments [18]. Previous research has shown that blockchain also could be widely used in peer-to-peer (P2P) energy exchange (i.e., trading) – as concluded by Mehdinejad *et al*., P2P markets could revolutionize energy industry by replacing centralized systems and eliminating the intermediaries [19]. As already operating P2P trading projects the Brooklyn MicroGrid and Powerledger should be mentioned [12]. To support the operation of P2P network, smart contracts and smart meters operating on blockchain could be used [20] and the ability of combining blockchain with Internet of Things (IoT) could improve the smart grid operating process [10], [12] as executed in, for example, SunChain and Prosume projects [12]. Authors of this work agree with Mould *et al*. that very important and promising use of blockchain could be in renewable energy certification, carbon credits and their trade [21], [22] (like the Grid Singularity project [12]). In addition to the aforementioned use cases, it should be noted that blockchain could be used in its currently most widespread way of use combined with the renewable energy market development – for the rising of capital via initial coin offerings (ICO) for renewable energy projects, mining of crypto-assets from the surplus renewable energy [22], [23], and other applications (for example, as M-PAYG and SolarCoin projects that foster the use of solar energy via crypto-assets [12]). It is clear that researchers point out to some crucial aspects (like mechanisms to support data security, scalability of the technology, government involvement level etc.) that need to be improved in order to foster more widespread use of blockchain in renewable energy [18].

Emphasizing the belief in the potential diffusion of blockchain technology within the energy sector, it is relevant that as early as 2016, the German Energy Agency identified the blockchain's capacity to enhance established practices in the energy market [24]. This projection extends to fostering process efficiency, expediting the evolution of IoT platforms and digital applications, and driving innovations in decentralized energy production and P2P trading [24]. Also, an opportunity was seen to improve energy companies' internal processes and customer service and reduce costs by implementing blockchain technology [24], [25]. The utilization of blockchain in renewable energy is a relatively recent and burgeoning subject in the scientific domain, evidenced by the escalating interest as reflected in the number of scientific publications. A search from ScienceDirect using the key words "blockchain & renewable energy" reveals a consistent upward trend, starting from the first publications in 2015 and 2016. The count has steadily risen, reaching 550 publications in 2021 and further expanding to 826 in 2022 [26].

Based on the proposed literature review, the authors of this study identified a gap in publications that adequately support decision-making for a more informed choice and selection of blockchain technology. Therefore, the study aims to develop a methodology for selecting the most suitable blockchain applications in renewable energy to cover this identified gap. It also identifies and evaluates potential use cases, considering socio-economic, political, legal, technological, and environmental factors.

## 2. METHODOLOGY

### *2.1. SWOT and PESTLE Analysis*

To identify the best development scenario for blockchain technology in the renewable energy sector four development scenarios were created based on author's previous research [22] (see section 2.2) implementing SWOT (i.e., Strengths, Weaknesses, Opportunities and Threats) and PESTLE (i.e., Political, Economic, Social, Technological, Legal and Environmental factors) analysis [27]. The SWOT analysis, an acronymic method, systematically gauges a business's market position through the prism of Strengths, Weaknesses, Opportunities, and Threats, drawing on both internal competencies and external market dynamics. Predominantly adopted in energy research [28], its utility in fostering sustainable growth in the renewable energy sector lies in leveraging strengths, rectifying weaknesses, capitalizing on opportunities, and mitigating threats. Additionally, by identification of the aspects contributing to these four dimensions, this analysis provides a strategic framework that allows stakeholders to align their objectives with realities, ensuring more structured and adaptive decision-making. Thorough analysis of each identified aspect should be done – in this case the detailed evaluation was used to define development scenarios (see section 2.2). In the meantime, PESTLE analysis serves as a strategic instrument for evaluating and tracking the multifarious influences of blockchain in renewable energy sector, providing a comprehensive vision of the research topic. It can help to categorize a flexible array of factors into six segments mentioned above – so this methodological approach yields a thorough analysis, interdisciplinary understanding, pinpointing critical elements and their interconnections. It follows from the acronym that it is essential for this analysis to be successful that comprehensive and detailed identification of factors (in this case contributing to a factor group) is performed.

The main factors taken into account in this study are (further defined as groups of factors (e.g., political and legal) that include factors (e.g., privacy)):

- political and legal – regulatory framework and its development, innovative policy planning support, involvement of government institutions, digitalization processes and data security, privacy;
- economic factors – cost-effectiveness, market liberalization, energy tokenization, development of the sharing economy;

- social and environmental factors – electricity consumption to maintain blockchain, development of renewable energy sources (RES), development of crowdfunding, strengthening of communities, public opinion, attraction of talents;
- technological factors – decentralization, transparency and immutability, scalability, compatibility (including with IoT), technology development, attacks [22].

### *2.2. AHP Analysis and Scenario Definition*

The analytic hierarchy process (AHP) method determines the weights of priorities by ranking objectives, groups of factors and factors in a hierarchical structure [29]. It allows to evaluate development scenarios based on a predetermined set of factors and their weight. Thus, the AHP method has so far already been widely applied in decision-making processes in economics, business, management, production, etc. [30]. The AHP analysis in this study consists of:

- setting an objective to be achieved (identification of the most potential blockchain applications in renewable energy);
- expert evaluation of groups of factors that affect the achievement of the objective (the aforementioned PESTLE factors are the groups of factors (see last paragraph in section 2.1);
- importance assessment of each factor (for example, decentralization) in relation to the objective to be achieved and development scenarios evaluation in the context of the influencing factors.

Taking into account previous literature research and SWOT and PESTLE analysis results, the development scenarios used in the analysis are about the blockchain technology use in:

- smart grid and smart homes with IoT;
- P2P energy trading;
- crypto-assets and ICO;
- certificates of origin for renewable energy [22].

Six experts from Latvia were interviewed, whose professional careers are connected to energy, information and communication technologies, law, banking and payments, and experts are familiar with issues related to RES, blockchain technology, and sustainable development. Experts work in the public and private sectors (also representing international clients).

The experts had to perform a pairwise comparison between groups of factors (the results are presented in the Fig. 5), then a pairwise comparison between each factor in a certain group of factors (the results are presented in Figs. 1–4) and after that a pairwise comparison between each of defined development scenario considering each factor (the results are presented in Fig. 7, also more detailed in Fig. 6).

The evaluation used a pairwise comparison scale developed by Saaty [31] that is presented in Table 1 (it must be noted that the term *factor* used in the Table 1 also applies to the group of factors, considering that the comparison between groups of factors was also done as mentioned in previous paragraph). An example on how the experts were provided with a methodology for fulfilling the survey: "Please rate the relative importance of group of factors 1 (aligned horizontally) versus group of factors 2 (aligned vertically) for the use of blockchain technology in the renewable energy sector. Explanation – it is necessary to assess which groups of factors are more important, more significant, assigning a rating from 1/9 to 9, where 9 means that the specific horizontal group of factors has a very strong advantage over the vertical group of factors. And vice versa – 1/9 means that the given vertical group of factors has a very strong advantage over the horizontal group of factors". This means that the group of factors 1 that is placed horizontally (for example, political and legal factors) is assessed against the group of factors 2 (for example, environmental factors) that is placed vertically. The same methodology was applied to the evaluation of factors and scenarios.

TABLE 1. AHP ANALYSIS ASSESSMENT SCALE [31]

| Score | Assessment | Description |
|---|---|---|
| 1 | Equal | Factors are equally important |
| 3 | Moderate | Factor 1 has a moderate predominance over factor 2 |
| 5 | Strong | Factor 1 has a strong predominance over factor 2 |
| 7 | Very strong | Factor 1 has a very strong predominance over factor 2 |
| 9 | Extreme | Factor 1 has an extreme predominance over factor 2 |
| 2, 4, 6, 8 | Intermediate values | Values are used to represent trade-offs between 1, 3, 5, 7 and 9 |
| 1/3 | Moderate | Factor 2 has a moderate predominance over factor 1 |
| 1/5 | Strong | Factor 2 has a strong predominance over factor 1 |
| 1/7 | Very strong | Factor 2 has a very strong predominance over factor 1 |
| 1/9 | Extreme | Factor 2 has an extreme predominance over factor 1 |

The priority vectors of pairwise comparison were calculated according to the formula developed by Saaty [31] and presented in Eq. (1).

$$a\omega = \lambda_{max}\omega , \tag{1}$$

where $a$ is the result of the comparison table, ω – priority vector, $\lambda_{max}$ is the largest Eigen value.

A sample of evaluation process is presented in Table 2 where the expert evaluates groups of factors and considers social and environmental factors strongly predominant over political and legal factors.

TABLE 2. AN EXAMPLE OF SURVEY PAIRWISE COMPARISON

| Factor groups | Political and legal | Economic | Social and environmental | Technological | Coordinates of the priority vector |
|---|---|---|---|---|---|
| Political and legal | 1 | | | | 0.17 |
| Economic | 1 | 1 | | | 0.19 |
| Social and environmental | 5 | 3 | 1 | | 0.56 |
| Technological | 1/3 | 1/3 | 1/5 | 1 | 0.07 |

The example of priority vector coordinates resulting from the evaluation is also provided in the Table 2. In the survey more detailed explanation and information about each factor and scenario was provided. The answers were considered as consistent (logical) if the consistency index value is ≤0.10. After that, the calculations, determining the average, minimum and maximum values of priority vectors were carried out and resulting graphs were prepared.

## 3. RESULTS AND DISCUSSION

In the following section, the results obtained from the AHP analysis are presented sequentially. Fig. 1 shows a more detailed assessment of the political and legal factors.

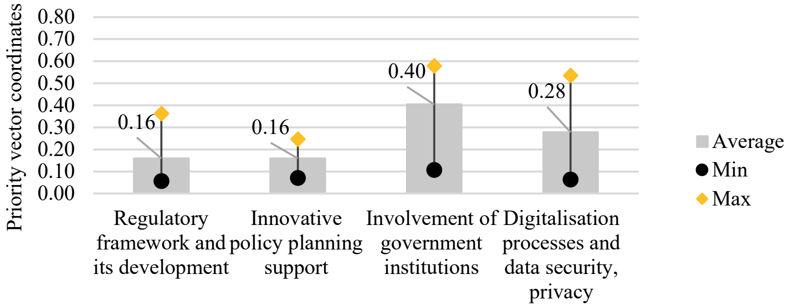



Fig. 1. The importance of political and legal factors for the use of blockchain in renewable energy ($n$ = 6).

Of the four individual factors identified in this group, experts consider the most significant factor to be the *involvement of government institutions* (0.40). Experts stress out that so far it has not been precisely established what is the level of involvement of public authorities, given the decentralized nature of the technology, which does not require the involvement of a third party. This constitutes the relevance of this factor, as it can both hinder and facilitate the use of blockchain technology. It is also important to mention the second most important factor – *digitalization processes and data security, privacy*, which, for example, in the comment provided by one expert is clearly more important than the regulatory framework. This is justified by the fact that the aspects of data security that can be linked to individuals' energy consumption data and their possible use in future can be more important than whether or not a specific framework is currently in force. Also following aspects must be taken into account – the complex process of developing a regulatory framework, the long time spent, the fact that most often, in matters of technology innovation, the regulatory framework is developed after a particular technology is already in use.

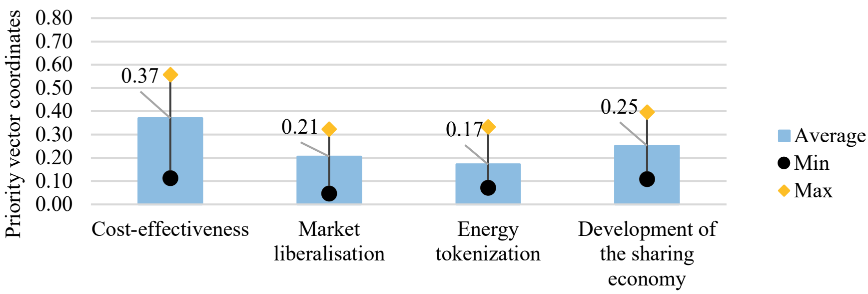



Fig. 2. The importance of economic factors for the use of blockchain in renewable energy ($n$ = 6).

From the group of economic factors (see Fig. 2) the most significant factor is *cost-effectiveness* (0.37). This suggests that the benefits of using blockchain technology, such as securing payments of small amounts should be highlighted. Taking into account the fact that there is no need for administrative expenses, for example, for drawing up a single household electricity bill or drawing it up in the case of P2P energy trading, financial resources are saved, which in this way also forms the most important economic factor – *cost efficiency*.

The most insignificant factor in the expert assessment is *energy tokenization* (0.17). Consequently, so far, in the experience of experts, the fact that with the blockchain technology it is possible to assign a value to a digital asset that can be used to pay for energy or, for example, to collect initial capital for starting a project, has not been significant, which indicates the novelty and early phase of tokenization (value of an asset of the physical environment reflected in the digital environment). The gradual increase in the importance of tokenization in the future is pointed out by a researcher of the Bank of Latvia who was not interviewed within the framework of the AHP analysis, but who sees benefits from the economy and further development of tokens, emphasizing the formation of a more democratic and efficient financial system [32]. Thus, it can be concluded that the use of tokens in the renewable energy sector should also be developed (and supported). According to the authors of the paper, also social and environmental factors must be an important group of factors to be taken into account in developing the use of blockchain technology specifically in the renewable energy sector.

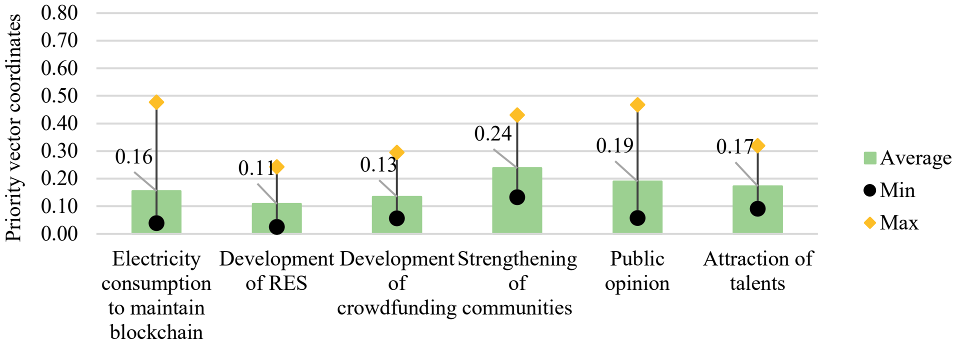



Fig. 3. The importance of social and environmental factors for the use of blockchain in renewable energy ($n = 6$).

Fig. 3 shows the opinion of experts, considering the importance of the factors in the social and environmental factor group. The most significant factor is *the strengthening of communities* (0.24), which means that experts see the potential to build solutions using blockchain technology that create closer interactions between members of a particular community in the energy sector (e.g., energy communities). *Public opinion* (0.19) is also significant, which is explained by the public's possible distrust of blockchain technology due to its use in crypto-assets, considering that (especially initially) there was a lot of negative information related to money laundering, etc. It should be noted that this social factor, especially when applying blockchain solutions on a larger scale, can be particularly important when consumers make choices, such as from whom and how to buy energy, so the authors believe that companies which would like to use blockchain technology, in parallel with its deployment, should perform information and education activities to promote public confidence in these solutions.

Experts have rated *the development of RES* as a less significant factor in this group of factors, which is explained by the fact that, in the opinion of experts, either the factor is not significant, since the use of RES will be developed in any case, or the combination of blockchain technology with the use of these resources is not so relevant, or it has been difficult for experts to link the development of blockchain technology and RES. The authors of the study disagree with this assessment, given that the *development of RES* as an environmental factor would in any case be significant in the application of blockchain technology in the RES sector, since it would directly or indirectly contribute to development. With the development of blockchain solutions, it is possible that a larger part of the public could purchase renewable energy (with an immutable certificate of origin) that for some reason cannot be produced by themselves (e.g., there is no financial means available for the installation of equipment, there is no suitable place to install equipment, etc.). The existence of such an opportunity in society would potentially contribute to environmental awareness, at the same time facilitating the economy's adaptation to the nature of RES (making fuller use of renewable energy). The opinion of experts on the factors forming the technological factors is analysed below.

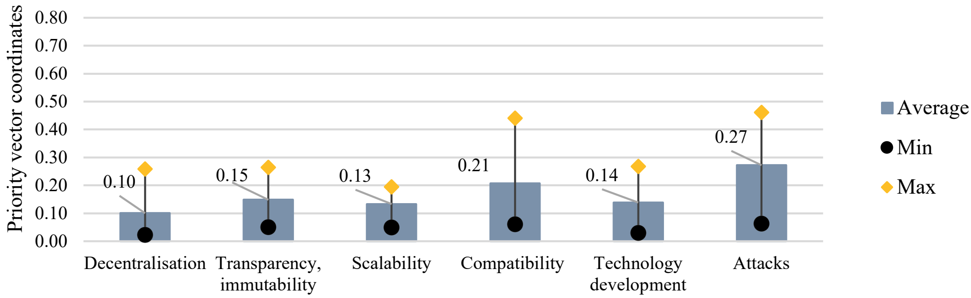



Fig. 4. The importance of technological factors for the use of blockchain in renewable energy ($n = 6$)

From the group of technological factors, experts indicate *attacks* (0.27) as the most significant factors (see Fig. 4). As the application of blockchain technology increases, so does the need to strengthen the system against unwanted attacks. While it is difficult for blockchain-based solutions to carry out successful attacks, the additional information provided by the experts states that it is necessary to ensure that consumers are protected from the illegal use of their energy consumption data, as well as other aspects of cybersecurity, e.g., sharing consumption data in real time (such as through smart metering) should be highlighted because it can create a system in which a potential attacker may be aware of when, how much and where energy is consumed. Experts also point to aspects of *compatibility* (0.21), thus drawing attention both to the different ways of developing solutions and the principles of operation, and to the need to unify them so that technological solutions can work in complementarity with each other.

According to the authors, *decentralization* is rated as the most insignificant technological factor (0.10), since it is the basis of blockchain technology and the use of technology is impossible without it. As for the technological factors, in the assessment of experts it is necessary to determine how the responsibility will be distributed, and therefore the charge for energy losses occurring in the network. Since operation with zero losses is impossible, but the P2P energy trading provides for the settlement of a certain amount produced and consumed, without the involvement of a third party (the network manager, which traditionally includes losses in the tariff calculation), such a model does not take into account losses, which until now have not been extensively studied and analysed in the P2P network.

To conclude, Fig. 5 shows that political and legal factors (priority vector coordinates – 0.30) are the most important among the groups of identified factors for the application of blockchain technology in the renewable energy sector, while the next most important group of factors is technological ones (0.28).

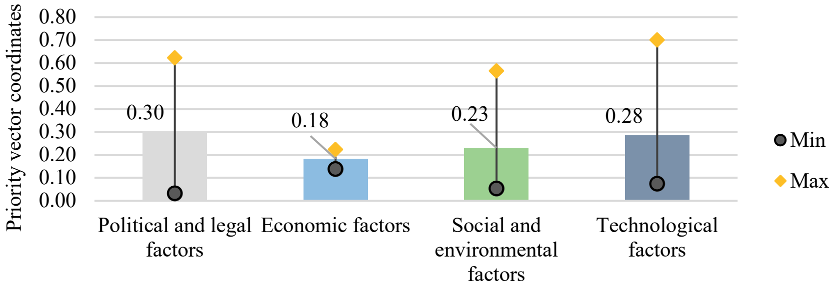
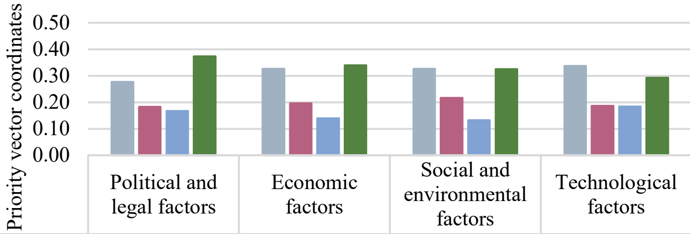



Fig. 5. Comparison of groups of factors influencing blockchain use in renewable energy ($n$ = 6).

Economic factors are evaluated as the most insignificant. Such a division is naturally explained by the experience of experts in the topic – experience with how important the common policy of the country is regarding the implementation of technological innovations, as well as the technological specificities, limitations and advantages of blockchain technology as such. The individual factors from each group of factors are analysed below.

The expert opinion on each of the factor groups in the four possible development scenarios is further evaluated, respectively, Figure 6 shows how the coordinates of the priority vectors are distributed within each group of factors for each of the four possible development scenarios.




| | Political and legal factors | Economic factors | Social and environmental factors | Technological factors |
|---|---|---|---|---|
| Smart grid and smart homes with IoT | 0.28 | 0.33 | 0.33 | 0.34 |
| P2P energy trading | 0.18 | 0.20 | 0.22 | 0.19 |
| Crypto-assets and ICO | 0.17 | 0.14 | 0.13 | 0.18 |
| Certificates of origin for renewable energy | 0.37 | 0.34 | 0.32 | 0.29 |

Fig. 6. Scenarios for the use of blockchain in each factor group in renewable energy ($n$ = 6).

Experts consider the political and legal factors in the certificates of origin for renewable energy scenario to be the most significant (0.37). This includes, according to experts, both the need to include the preparation of certificates of origin using blockchain technology in the regulatory framework at national level, and to harmonize such use in the EU so that they are developed according to the same principles in each EU Member State and it would be legal to certify the origin of renewable energy uniformly across the EU. Less important political and legal factors are in the P2P energy trading scenario, given that the frameworks for energy communities are being developed in some countries, other regulatory acts are also being improved, so developments in this area are taking place, and for other development scenarios this group of factors is more significant.

Economic factors are most significant in the scenario of certificates of origin and smart grids and smart homes with IoT, where experts see opportunities for market liberalization, given the increase in decentralized energy producers resulting from the development of the use of RES. Similarly, social and environmental factors are most relevant in the two scenarios mentioned above, given that the development of certificates of origin and the introduction of smart metering in the home are closely linked to the public opinion on blockchain described previously.

Technological factors are the most important group of factors in the smart grid and smart homes with IoT scenario (0.34), which naturally points to expert considerations about technology interoperability, the need to standardize and unify the solutions used, as well as concerns about the security of user data. The authors of the work agree that technological factors are the most significant in this scenario, given that the compatibility of technology with smart metering devices and the ability to perform successful attacks are very important aspects that needs attention when developing technological solutions, which is also indicated by other researchers in scientific works [13]. Fig. 7 shows the overall assessment regarding possible scenarios for the use of blockchain technology.

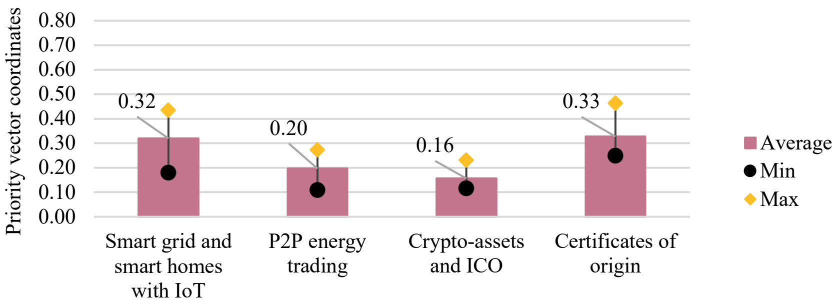



Fig. 7. Overall assessment of blockchain application scenarios in renewable energy ($n$ = 6).

The most significant scenario is the use of blockchain technology in certificates of origin (0.33), followed by the smart grid and smart homes with IoT (0.32). Experts considers the use in crypto-assets and ICOs as the most irrelevant (0.16). At this point, the system of certificates of origin for renewable energy in theory works in many countries, but the way how the energy produced is inspected is based on individual inspections, and not on continuous monitoring. Consequently, significant potential is seen in this area to improve the process of proving origin. This would make it possible to manage renewable energy more efficiently, as well as to sell it, for example, to other countries, creating even more confidence in the way the energy is generated, if the data were cryptographically recorded on the blockchain, would not be changeable and all renewable energy producers would work in this way. This use of the technology should, in the opinion of experts, be accepted at the EU level in order to ensure a common methodology and technical process for the preparation of evidence.

The authors of the study express the opinion that in the context of the trade in certificates of origin, countries that already use relatively high percentage of renewable energy (like Latvia) should use the existing advantage to produce renewable energy (for example, there are areas available for the development of wind farms, it is possible to continue the generation of hydropower etc.) in order to sell it to countries that currently consume less renewable energy, thus promoting both the progress of these countries towards climate neutrality (incl.

an increase in renewable energy in final energy consumption) and to develop the country's own economy, becoming an exporter of renewable energy.

Experts also evaluate smart grids and smart homes with IoT as an important development scenario, so issues such as efficient use of energy based on previously collected data are especially relevant. According to the authors, this is due to high energy prices in 2022–2023, 5G coverage development (especially in Latvia – where the interviewed experts live and work), as well as the experts' vision of the general need for a reduction in total energy consumption (energy efficiency) in order to build a more sustainable energy sector and thus the entire national economies. This scenario, according to the authors of the work, should be developed in parallel with other uses, for example, to ensure the P2P energy trading in case renewable energy production takes place in a particular building (or near it). If the entire system operated using blockchain technology, the data would be comparable with each other and compatible, thus reducing technological barriers.

In the opinion of the authors, the use of real-time consumption data metering devices (i.e., smart metering, use of sensors) could potentially be developed in countries with advanced 5G network coverage, which, for example, would not be such a priority scenario in countries where 5G network coverage is not so developed. However, when developing this scenario, it is necessary to pay great attention to data security issues, as indicated earlier. In connection with this scenario, emphasis should also be placed on the possibility of developing automatic invoicing, which could reduce the resources consumed, especially for the electricity billing of households [12], [33].

The most insignificant scenario, according to experts, is the use of blockchain in crypto-assets and ICOs (0.16), which is explained by the established distrust of crypto-assets due to the rapid changes in their value in 2022–2023 [34] and public opinion described above. Consequently, in the opinion of experts, the use of renewable energy and the development of its production using crypto-assets should not be considered as a priority development scenario.

According to the experts, the development of scenarios will be affected by demand factors, which are especially applicable to the country's specific ongoing development, notably in the field of regulatory framework. For example, in the case of Latvia, P2P energy trading scenario could develop in the context of the ongoing coordination and harmonization process of energy communities' regulation as well as the increase of decentralized energy (especially solar) generation. It should also be noted that the results of this study show that smart grid and smart homes with IoT scenario is very close to the certificates of origin scenario in terms of significance, which means that if the study was repeated with a different number of experts in a different country, as well as at a different time, the results could be different.

According to the authors of the paper, in any case, it will be necessary to develop renewable energy management systems, e.g., P2P energy trading solutions, based on the fact that in 2023 climate neutrality issues are only becoming more relevant globally, as clearly evidenced by the sixth report published by the Intergovernmental Panel on Climate Change on 20 March 2023, which points to an already existing increase in global surface temperature of 1.1°C in 2011–2022, compared to 1850–1900 [35], as well as the immediate need to reduce GHG emissions. As a result, a transition to climate-neutral energy production will be necessary at the global level and, in the opinion of both the experts surveyed and the authors of the work, it would be possible to promote it using blockchain technology.

## 4. Conclusion

AHP analysis for the possible types of blockchain technology use in renewable energy was performed and according to the experts, the most significant scenarios are the use in certificates of origin (0.33) and use in smart grid, smart homes with IoT (0.32), while the most insignificant scenario is the use in crypto-assets and ICOs (0.16), which indicates the need for greater use of blockchain technology in energy management systems, without focusing only on increasing the amount of renewable energy and financial investment objects.

The most significant factors influencing the use of blockchain technology in the renewable energy sector in the expert assessment are political and legal (0.30) and technological (0.28), pointing to the difference in the principles of operation of blockchain technology from the traditionally used solutions, as well as the need to strengthen the regulatory and policy planning framework for the successful development of technology in the renewable energy sector.

To facilitate the use of blockchain solutions in smart grid and smart homes it would be recommended for the policy makers to direct the inclusion of smart contracts necessary for the operation of smart grid and smart homes in the regulatory framework in order to make smart contracts compliant with legal requirements and consumer data protection regulations. In general, it is advisable to define the involvement of authorities in the management of the use of blockchain technology, taking into account at the same time the decentralized nature of the technology and the absence of third-party involvement, as well as the need to protect consumer rights.

It is recommended to develop a common blockchain-based solution for issuing certificates of origin for renewable energy at the EU level to ensure a common, immutable and unchangeable system for issuing certificates in real time in all EU Member States. In order to ensure better comparability of data, as well as to prevent possible differences, for example in certificates of origin, authors suggest to promote standardization in the applications of blockchain technology in the EU. In order to reduce possible negative attitudes from society towards the introduction of this technology in the field of energy it is advisable to inform the society about blockchain technology, its nature and capabilities.

Future research questions should be connected with agreements on how the charge for energy losses in the network is calculated, taking into account that in reality it is not possible to ensure the full efficiency of the network and so far there are no widely addressed questions in the scientific literature on how to distribute the cost of losses in the P2P network.

## References

[1] Communication From the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of the Regions. The European Green Deal. Brussels, 2019. [Online]. [Accessed 22.11.2023.]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

[2] Communication From the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of the Regions. Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, Brussels, 2020. [Online]. [Accessed 22.11.2023.]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0562&from=EN

[3] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). *Official Journal of the European Union*, 2021: L 243/1.

[4] Communication From the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of the Regions. REPowerEU Plan. Brussels, 2022 [Online]. [Accessed 22.11.2023.]. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF

[5] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 *Official Journal of the European Union* 2023. [Online]. [Accessed 22.11.2023.]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105

[6] Eurostat. Shedding light on energy – 2023 edition [Online]. [Accessed 22.11.2023.]. Available: https://ec.europa.eu/eurostat/web/interactive-publications/energy-2023#renewable-energy

[7] Communication From the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of the Regions on a Digital Finance Strategy for the EU. Brussels, 2023, [Online]. [Accessed 22.11.2023.]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0591

[8] Alam S. *et al.* Blockchain-based Initiatives: Current state and challenges. *Computer Networks* 2021:198:108395. https://doi.org/10.1016/j.comnet.2021.108395

[9] Gawusu S., Zhang X., Ahmed A., Jamatutu S. A., Miensah E. D., Amadu A. A., Osei F. A. J. Renewable energy sources from the perspective of blockchain integration: From theory to application. *Sustainable Energy Technologies and Assessments* 2022:52:102108. https://doi.org/10.1016/j.seta.2022.102108

[10] Choobineh M., Arab A., Khodaei A., Paaso A. Energy innovations through blockchain: Challenges, opportunities, and the road ahead. *Electricity Journal* 2022:35(1):107159. https://doi.org/10.1016/j.tej.2021.107059

[11] Asif M. Decarbonization in the Energy Sector. *The 4Ds of Energy Transition*, vol. 1. New York: Wiley, Hoboken, 2022. https://doi.org/10.1002/9783527831425.ch3

[12] Andoni M., Robu V., Flynn D., Abram S., Geach D., Jenkins D., McCallum P., Peacock A. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews* 2019:100:143–174. https://doi.org/10.1016/j.rser.2018.10.014

[13] Dorfleitner G., Muck F., Scheckenbach I. Blockchain applications for climate protection: A global empirical investigation. *Renewable and Sustainable Energy Reviews* 2021:149:111378. https://doi.org/10.1016/j.rser.2021.111378

[14] Han D., Zhang C., Ping J., Yan Z. Smart contract architecture for decentralized energy trading and management based on blockchains. *Energy* 2020:199:117417. https://doi.org/10.1016/j.energy.2020.117417

[15] Jaradat M., Jarrah M., Bousselham A., Jararweh Y., Al-Ayyoub M. (2015) The internet of energy: smart sensor networks and big data management for smart grid. *Procedia Computer Science* 2015:56:592–597. https://doi.org/10.1016/j.procs.2015.07.250

[16] Borkovcová A., Černá M., Sokolová M. Blockchain in the Energy Sector – Systematic Review. *Sustainability* 2022:14(22). https://doi.org/10.3390/su142214793

[17] Antal P. C. *et al*. Blockchain Based Decentralized Local Energy Flexibility Market. *Energy Reports* 2021:7:5269–5288. https://doi.org/10.1016/j.egyr.2021.08.118

[18] European Commission's Joint Research Centre. Blockchain solutions for the energy transition. 2022. [Online]. [Accessed 22.11.2023.]. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC128651

[19] Mehdinejad M., Shayanfar H., Mohammadi-Ivatloo B. Decentralized blockchain-based peer-to-peer energy-backed token trading for active prosumers. *Energy* 2022:244. https://doi.org/10.1016/j.energy.2021.122713

[20] Mazumdar A., Modi C., Vyjayanthi C. Designing a blockchain-enabled privacy-preserving energy theft detection system for smart grid neighborhood area. *Electric Power Systems Research* 2022:207:884. https://doi.org/10.1016/j.epsr.2022.107884

[21] Mould K., Silva F., Knott S. F. O'Regan B. A comparative analysis of biogas and hydrogen, and the impact of the certificates and blockchain new paradigms. *International Journal of Hydrogen Energy* 2022:47(93):39303–39318. https://doi.org/10.1016/j.ijhydene.2022.09.107

[22] Mazure G. Kalnina A. Analysis of Potential Application of Blockchain Technology in Renewable Energy Sector. *22nd International Multidisciplinary Scientific Geoconference SGEM*, 2022. https://doi.org/10.5593/sgem2022/5.1/s21.066

[23] Kalnina A. Mazure G. Opportunities for the Use of Crypto-assets in the Renewable Energy Sector Within the European Union Legal Framework. Engineering for Rural Development: Proceedings of the 22nd International Scientific Conference, Jelgava, Latvia. 2023:24–26:378–383. https://doi.org/10.22616/ERDev.2023.22.TF082

[24] Burger C. *et al*. Blockchain in the energy transition. A survey among decision-makers in the German energy industry. 2016. [Online]. [Accessed 22.11.2023.]. Available: https://www.researchgate.net/publication/341441255_Blockchain_in_the_energy_transition_A_survey_among_decision-makers_in_the_German_energy_industry

[25] EU Blockchain Observatory and Forum. Smart Contracts. 2023. [Online]. [Accessed 22.11.2023.]. Available: https://www.eublockchainforum.eu/sites/default/files/reports/SmartContractsReport_Final.pdf

[26] ScienceDirect. Blockchain renewable energy 2023 [Online]. [Accessed 22.11.2023.]. Available: https://www.sciencedirect.com/search?qs=blockchain%20renewable%20energy%20

[27] Aguilar. PESTLE analysis. Scanning the business environment: some conceptual issues. [Online]. [Accessed 22.11.2023.]. Available: http://www.irantahgig.ir/wp-content/uploads/10051.pdf

[28] Elavarasan R. V., Afridhis S., Vijayaraghavan R. R., Subramaniam U., Nurunnabi M. SWOT analysis: A framework for comprehensive evaluation of drivers and barriers for renewable energy development in significant countries. *Energy Reports* 2020:6:1838–1864. https://doi.org/10.1016/j.egyr.2020.07.007
[29] Bernasconi M., Choirnat C., Seri R. The Analytic Hierarchy Process and the Theory of Measurement. *Management Science* 2010:56(4):699–711. https://doi.org/10.1287/mnsc.1090.1123
[30] Sluser B., Plavan O., Teodosiu C. Chapter 10 – Environmental impact and risk assessment. *Assessing Progress Towards Sustainability* 2022:189–217. https://doi.org/10.1016/B978-0-323-85851-9.00004-3
[31] Saaty T. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* 1977:15(3):234–281. https://doi.org/10.1016/0022-2496(77)90033-5
[32] Fiļipovs D. Tokenu ekonomika (Token economy). 2021. [Online]. [Accessed 22.11.2023.]. Available: https://www.bank.lv/aktualitates-banklv/publikacijas/zinas-un-raksti/raksti/12551-tokenu-ekonomika (In Latvian).
[33] Guo Y., Liang C. Blockchain application and outlook in the banking industry. *Journal of Financial Innovations* 2016:2:24. https://doi.org/10.1186/s40854-016-0034-9
[34] Binance. Crypto prices. [Online]. [Accessed 22.11.2023.]. Available: https://www.binance.com/en/price/
[35] Intergovernmental Panel on Climate Change. AR6 Synthesis Report 2023. [Online]. [Accessed 22.11.2023.]. Available: https://www.ipcc.ch/report/ar6/syr/