Paweł BUCHWALD • Barbara PIONTEK •
Anna ADAMUS-MATUSZYŃSKA • Marcin GAWEŁ

POSSIBILITIES OF IMPROVING THE ENERGY SECURITY AND EFFICIENCY OF SUSTAINABLE SMART VILLAGE MANAGEMENT THROUGH THE USE OF BLOCKCHAIN TECHNOLOGIES AND DECENTRALISED AUTONOMOUS ORGANISATIONS ON THE EXAMPLE OF THE PAŁECZNICA COMMUNE

Paweł BUCHWALD (ORCID: 0000-0003-2537-7085) – WSB Academy
Barbara PIONTEK (ORCID: 0000-0001-7997-5190) – WSB Academy
Anna ADAMUS-MATUSZYŃSKA (ORCID: 0000-0003-3234-4599) – University of Economics in Katowice
Marcin GAWEŁ (ORCID: 0009-0002-4021-6116) – Pałecznica Commune Office

Correspondence address:
Cieplaka Street 1C, 41-300 Dąbrowa Górnicza, Poland
e-mail: bpiontek@wsb.edu.pl

ABSTRACT: The article explores the concept of smart villages, emphasising the integration of information and communication technologies (ICT), blockchain, and decentralised autonomous organisations (DAO) to improve sustainable management in rural communes. It highlights blockchain's role in decentralisation and process automation via smart contracts, offering benefits like improved transparency and reduced administrative costs. A hybrid approach that merges these technologies with traditional methods is recommended to optimise management while valuing human capital. This approach also requires investments in infrastructure, education, and legal adjustments to facilitate integration. A case study of the Pałecznica commune illustrates the successful implementation of a modern energy security management system that can be integrated with blockchain technology. Ultimately, the hybrid model ensures an effective transformation of public administration, increasing transparency, efficiency, and sustainable development in smart villages, as well as improving security in energy management.

KEYWORDS: Smart Village, Sustainable Development, Blockchain, Distributed Governance, DAOs, Internet of Things, energy security management

Introduction

The concept of a smart village is related to rural development and presupposes the utilisation of innovative information and communication technologies (ICT), alongside novel management models, denoting intelligent governance and institutions, and deliberate local development planning. This aims to improve the quality of life of residents, signifying efficient service delivery, sustainable resource management, and the stimulation of social and economic activities in rural areas, indicative of participatory management (Trajer & Trajer, 2021; Nazarko & Bokun, 2024). Unlike the traditional approach, where rural areas were often considered less attractive for investment and development, the smart village concept sees them as dynamic centres of innovation, able to work with cities and regions on a partnership basis rather than as a peripheral. The basic assumption of smart villages is the integration of new technologies with management processes, production, and the provision of public and social services (Kalinowski et al., 2022). These activities may include, among others, the implementation of the broadband Internet, environmental monitoring systems, digital registers and service platforms, smart energy networks, local e-commerce platforms supporting agriculture, and solutions facilitating communication between local government authorities and residents. An important element is also stimulating intersectoral cooperation between local entrepreneurs, farmers, nongovernmental organisations, scientific institutions, and public institutions, leading to the creation of more resilient and innovative communities (Naldi et al., 2015). According to the European Commission documents, smart villages are rural communities that base their development on existing assets (e.g. cultural wealth, natural resources) and effectively use modern technologies and innovative solutions to improve the quality of life and working conditions of residents. This goal must be achieved simultaneously with respect to the natural environment and social integration (European Commission, 2017).

This article seeks to explore the potential applications of blockchain technology in municipal process management with the goal of improving security, transparency, and business continuity. Implementing blockchain-based solutions enables the decentralisation and immutability of data records, increasing the level of trust in the management system and reducing the risk of abuse or manipulation of information. Furthermore, the use of blockchain can improve administrative processes, accelerate resident service, better coordinate activities between organisational units, and reduce costs related to documentation and data logistics. Within this framework, the article attempts to identify specific domains of municipal operations where blockchain technology may be employed to enhance the efficiency and transparency of the management process. It also examines both the advantages and the potential challenges and limitations that arise from the implementation of such solutions (Ølnes et al., 2017). The novelty presented in the article is the concept of an integrated blockchain system with the management infrastructure of the integrated village of Pałecznica, taking into account the existing components of the automation of energy settlement to achieve transparency in information.

An Overview of the Literature

The concept of organisational management is not a homogeneous concept; therefore, it is not possible to find a general definition that precisely outlines what this process involves. According to Griffin, management is a set of activities (including planning and decision-making, organising, leading, i.e., managing and controlling people) directed at the organisation's resources (human, financial, material, and information) and performed with the intention of achieving the organisation's goals in an efficient manner (using resources wisely and without unnecessary waste) and effective (operating successfully) (Griffin, 2016). In management and quality sciences, a distinction is made between the management of business and non-business organisations (i.e. public institutions), which is fully justified because they have different goals and tasks, different sources of income, operate in different conditions, and have a different scope of decision-making independence.

Similarly to private sector enterprises, public sector entities are seeking innovative solutions enabled by advances in contemporary technologies. One such contemporary form of organisation is the concept of a decentralised autonomous organisation (DAO).

DOI: 10.34659/eis.2025.93.2.1076

The development of blockchain and cryptocurrency technologies in the 21st century has led to the emergence of new forms of organisation that operate based on the principles of decentralisation, automation, and transparency. One of the most innovative phenomena in this trend is DAO that is an organisation that operates without a centralised board of directors, in which rules and processes are built into the source code of smart contracts based on blockchain technology, and important decisions are made by community members, usually having specific voting tokens (Wood, 2014). This decentralised structure is designed to eliminate the need to trust individual entities, increase transparency of operations, and improve the effectiveness and efficiency of resource management.

The origin of the DAO idea is associated with the development of the Ethereum network, launched in 2015 by Vitalik Buterin and a team of programmers who created an environment enabling the building and implementation of smart contracts (Buterin, 2014). Ethereum introduced the possibility of creating decentralised applications (DApps), including organisations that do not need a centralised intermediary. One of the most famous initiatives was the DAO, a project launched in 2016 aimed at creating an investment fund fully managed by the community (Jentzsch, 2016). The key properties of a DAO organisation are presented in Table 1.

Table 1. Features of a DAO organisation

The most important features of a DAO organisation	
Decentralization	One of the most important features of DAOs is the lack of central authority. Traditional organisations are based on a hierarchy and central decision-making bodies – in DAOs, decisions are made collectively, based on pre-established rules in the smart contract code, and the right to vote usually depends on held tokens or other representation mechanism (Beck et al., 2016). Consensus mechanisms, such as stake-based delegation and vote proof, allow for streamlined and fair governance.
Autonomy	DAOs operate on the basis of smart contracts that automate a number of processes, such as the distribution of funds, code updates, reward payments, and approval of cooperation with other entities. Once established, the rules are impartial and cannot easily be manipulated by individuals. This allows organisations to minimize intermediaries and relieve members of the organisation of routine administrative tasks (Swan, 2015).
Transparency and accountability	Every transaction and decision in the DAO is recorded on the blockchain, which ensures a high level of transparency. Community members can continuously track the use of funds, verify votes, and check the history of changes to the source code. The lack of the ability to arbitrarily change records and the availability of a complete activity history make the DAO characterized by high accountability, which contributes to building trust between stakeholders (Ølnes et al., 2017).
Global reach and inclusivity	DAOs can operate across national borders without the need to create legal entities in individual jurisdictions. Due to this, members, regardless of geographical location, can cooperate, invest, or manage community resources. This global inclusivity supports the diversity of views, competences, and perspectives that shape the directions of the organisation's development (Tapscott & Tapscott, 2016).

Source: authors' work based on Beck et al. (2016), Swan (2015), Ølnes et al. (2017) and Tapscott and Tapscott (2016).

The creation of DAO based on decentralised blockchain technology also led to the need to reorient the definition of management in terms of new challenges. Governance in a blockchain-based DAO refers to a set of mechanisms, procedures, and rules to make decisions, manage changes, and allocate resources in a decentralised, transparent, and automated manner using blockchain technology. Unlike traditional forms of management, in which hierarchical structures and designated leaders play key roles, management in DAOs is based on protocols and smart contracts, as well as on the active participation of the community – members of the organisation have tokens that give them the right to vote on strategic issues, such as determining budgets, code modifications, selection of development directions or admission of new members (Wang et al., 2019). Due to the use of blockchain technology, DAO management processes are transparent and verifiable. Every decision, vote, or transaction is registered, and consensus mechanisms (e.g., Proof of Stake) make it impossible to manipulate voting results without the consent of the majority. Additionally, smart contracts automatically enforce the decisions made, eliminating the need for centralised execution bodies. As a result, DAO governance is strongly based on community, technology and predetermined objective rules,

DOI: 10.34659/eis.2025.93.2.1076

ensuring a high level of decentralisation, security and trust (Beck et al., 2016). Managing DAO refers to a set of mechanisms, structures, and processes to make decisions, allocate resources, and shape development strategies in an environment based on blockchain technology. In DAO, traditional hierarchical management models are replaced by automated rules and smart contracts that define how the organisation functions. Community members – as holders of tokens representing shares or voting rights – can directly influence the direction of changes, vote on proposals, and in some cases hold referenda on key aspects of the business (Wright & De Filippi, 2015).

As a result, the management of DAO is characterised by the followings:

- decentralisation: lack of a central decision-making body, replaced by collective consent or consensus mechanisms,
- transparency: every stage of the decision-making process, voting or flow of funds is permanently and publicly recorded on the blockchain,
- automated rule enforcement: rules and decisions written in smart contracts are executed automatically, eliminating the need for intermediaries and minimising the risk of manipulation,
- social nature: the direction of the organisation is influenced by ecosystem participants who jointly develop proposals and solutions, introducing innovations and responding to changing market and regulatory conditions.

Although the concept of DAOs has not yet been comprehensively examined, rigorously investigated, or universally endorsed by scholars in the field of management, it is important to note that scholarly publications addressing this subject have been consistently increasing over the past several years (Sims, 2019; Ilyushina & Macdonald, 2022; Borgogno & Martino, 2024).

Public organisations and non-profit entities are exploring innovative management solutions within the commercial sector. Consequently, it is reasonable to propose that the DAO concept may represent a contemporary approach to the governance of rural communes, especially smart villages. Table 2 delineates the objectives of the process management carried out within the municipal framework, as well as the managerial objectives relevant to the DAO.

Table 2. Comparison of management goals in the DAO organisation and in the commune

Management aspect	Process Management in the commune	Management in a DAO organisation
Organisational structure	Hierarchical, based on administrative units and local government bodies.	Decentralized, automated, based on smart contracts and token-holding participants
Main goal	Ensuring efficient, effective, and continuous service to residents; Performance of public duties in accordance with the law and social interest.	Ensuring transparent, autonomous, and decentralized decision-making and resource management based on community consensus.
Transparency and accountability	Achieved through the transparency of documents, registers, the control of supervisory authorities, and audits.	Guaranteed by the blockchain, the availability of source code and the transaction history; every step of the process is publicly verifiable.
Efficiency and stability of processes	Key, measurable, among others: service time, costs, and quality of public services.	Important, although understood through the efficient functioning of consensus mechanisms, quick implementation of changes in protocols, and minimization of disputes in the community.
Stakeholder participation	Key, measurable, among others: service time, costs, and quality of public services.	Direct participation of community members in voting on proposals; there are no formal hierarchies, and the voting power depends on the tokens and DAO mechanisms held.
Automated rules	To a limited extent, IT systems support administration, but do not determine all processes; many tasks require the intervention of officials.	High degree of automation – smart contracts and algorithms enforce rules immediately when conditions are met, minimizing manual intervention.
Resistance to manipulation	Limited but provided by law, control procedures and audits; abuses in the interpretation of regulations or data manipulation are still possible.	High degree of automation – smart contracts and algorithms enforce rules immediately when conditions are met, minimizing manual intervention.

Source: authors' work based on Buterin (2014), Trajer and Trajer (2021) and Nazarko and Bokun (2024).

DOI: 10.34659/eis.2025.93.2.1076

When examining the distinctions between process management within a municipal framework and that within a DAO context, it becomes apparent that the management system of a municipality and the organisational structure of a DAO possess distinct characteristics. Municipal governance is founded upon a legal and administrative hierarchy, whereas a DAO functions on the principles of decentralisation and autonomy. Within a municipal framework, procedural operations rely predominantly on the discretion of officials and their interpretation of the governing regulations. On the contrary, in a DAO, the enforcement of established rules is executed through smart contracts and algorithms. Furthermore, trust in a municipal setting is derived from the legal system and oversight by higher authorities, whereas in a DAO, trust is engendered through technological means, specifically through code and consensus mechanisms. Notwithstanding these differences, both types of organisation exhibit certain shared characteristics. The most important are the following:

- Transparency: Both the municipality and the DAO strive for transparency of activities and accountability, although the methods of achieving these goals are different (openness of documents vs. public blockchain register),
- Efficiency and stability of processes: Both systems strive to improve their processes, although the municipality does so by optimising administrative procedures and the DAO by improving the code and consensus mechanisms,
- Stakeholder participation: Both the municipality and the DAO involve the community (residents or token holders) in decision making, although the participation management model is different.

By comparing the goals of both types of organisation, it can be concluded that the DAO organisation can be an inspiring tool and some support in improving selected aspects of municipal management, especially in the field of transparency and civic participation. However, the full adoption of the DAO principles in the local government environment would require adapting the legal framework, providing appropriate technological infrastructure, educational activities, building social trust, and developing hybrid models in which some processes would be automated and decentralised, while others would still require traditional management methods.

Although blockchain technology and the management approach related to DAO are a new concept, there are numerous examples of its application in the areas of smart village management (Kaur & Parashar, 2021). In smart villages, blockchain technology can be used to track the origin, quality and transport conditions of agricultural products, increasing consumer confidence and facilitating distribution. By registering information about each transaction and transport stage in an immutable register, recipients can gain full insight into the product's history. A systematic exploration of the potential of using blockchain technology to solve problems in the agri-food industry was presented, for example, by De Clercq et al. (2018). In their study, the authors present the functionality of the blockchain and identify problems in the agri-food industry that can be solved thanks to this technology. The commentary focuses mainly on examples of problems in tracking the supply chain of agricultural products, as well as tracking agricultural production to confirm and verify the quality of the received product. In the context of the transparency of transactions confirmed by the blockchain, statements of transaction operations can be a reliable confirmation of the origin of products, which increases consumer trust and leads to the building of the brand of suppliers. The problem of traceability of agricultural products was also addressed in (Kamilaris et al., 2019). The authors of the study point to the use of blockchain to improve the traceability of agricultural products in the context of smart agriculture, which can be translated into the level of functioning of smart villages struggling with the problem of product identification and focused on building their regional brands. Practical systems such as OriginTrail (Slovenia) and AgriDigital (Australia) implement blockchain solutions to manage the supply of grains and other agricultural products.

In smart villages that use renewable energy sources (photovoltaic panels, small wind turbines), the blockchain can be used to monitor and settle energy production and consumption at the local level. Smart contracts enable automatic transactions between nodes of the energy system, which may be households or local government units. Energy management based on local resources can contribute to more efficient resource management. In Zhang et al. (2018), the authors describe a management system for energy microgrids. The presented implementation concerns urban development conditions, but these concepts have also been extended to rural areas, especially those that operate according to the Smart Village initiative. The potential of blockchain in the management of decentralised energy resources was also presented in the study by Lin et al. (2020). The authors analysed 140

DOI: 10.34659/eis.2025.93.2.1076

research projects and start-ups using blockchain, from which a map of the potential and importance of this technology for applications in the energy industry was created. These initiatives were systematically classified into different groups according to the area of activity, the implementation platform used, and the consensus strategy used. The article discusses opportunities, potential challenges and limitations for a number of use cases, ranging from emerging P2P (peer-to-peer) solutions in energy trading and Internet of Things (IoT) applications, through decentralised markets, electric vehicle charging, and e-mobility. The authors noted the technical challenges that blockchain technology can help solve in a given case, as well as its potential disadvantages, such as the lack of sufficient legal regulations. The study concludes with a discussion of the challenges and market barriers that technology must overcome to prove its commercial viability and become widely adopted.

Blockchain can be used to transparently manage information on soil quality, water use, fertiliser, and pesticide use, helping to make informed decisions about the sustainable use of natural resources. In the study by Lin et al. (2020), attention was paid to blockchain technology that is increasingly attracting significant interest in various agricultural applications. These applications can address a variety of needs in the agricultural ecosystem, such as increasing transparency in food safety and control of food product quality based on IoT systems. In addition, it can help trace the origin of products, streamline contract exchanges, and increase transaction efficiency. The complex chain from food producers to the final consumer involves numerous entities that do not necessarily trust each other, including small farmers, food processors, logistics companies, distributors, and retailers. It becomes crucial to achieve an optimal compromise between the efficiency and integrity of agricultural management systems. The authors of the study identified key challenges that occur in many agricultural systems. One of these challenges is to improve food production and the supply chain after the COVID-19 pandemic. This case is an example of the effective use of blockchain technology.

Blockchain technology is also used in transparent crowdfunding and microinvesting. The implementation of smart contracts on the blockchain enables transparent and automatic settlement of funds allocated for infrastructure development, agricultural projects, and social initiatives within the smart village. In the article by Casino et al. (2019), the authors provide an extensive overview of blockchain applications, encompassing both financial and social sectors, which can be tailored to meet the requirements of smart village development. There are also examples of applications of blockchain technology (including NFT – Non-Fungible Token) and virtual reality (VR) in promoting handicrafts and cultural heritage in the context of smart villages. Examples from the literature and scientific studies indicate the possibility of using these solutions both to protect the authenticity of handicraft products and to create engaging virtual environments conducive to education, promotion, and sales. Handicrafts in smart villages can be represented in the form of NFT tokens, which act as digital authenticity certificates. Any product, such as a fabric, sculpture, or basketball product, can be backed with an NFT, which will provide a unique and immutable record of origin, authorship, and quality. In this way, the buyer receives both a physical product and its digital equivalent, guaranteeing transparency of ownership history and originality (Casino et al., 2019; Stublić et al., 2023). The combination of NFT and VR makes it possible to create a virtual fair where visitors from all over the world can 'walk' through the craftsmen's displays, see their products in 3D form, and confirm their authenticity using NFT. In this way, the smart village becomes a global player in the handicraft market, not limited to traditional sales channels.

Blockchain plays an increasingly significant role in achieving sustainable development by supporting the energy transition, reducing greenhouse gas emissions, and promoting environmentally and socially responsible practices. This technology enables the efficient management and tracking of renewable energy sources (RES), such as solar and wind power, facilitating the transition to more sustainable and efficient energy systems. For example, blockchain supports the creation of energy communities that allow local consumers (simultaneous producers and consumers of energy) to exchange energy directly, reducing energy losses during distribution and lowering operational costs (Cai et al., 2024).

In the context of sustainable development, blockchain also supports the realisation of the Sustainable Development Goals (SDGs) of the United Nations, such as increasing access to clean and affordable energy (Goal 7) and reducing greenhouse gas emissions (Goal 13). Research shows that blockchain is particularly effective in promoting transparency and monitoring processes related to

DOI: 10.34659/eis.2025.93.2.1076

renewable energy, contributing to emissions reduction and better integration of sustainable energy sources into global energy systems (Vaccargiu et al., 2023).

Blockchain not only supports technological transformation in the energy sector but also allows greater efficiency in resource and data management. For example, the integration of the Internet of Energy (IoE) with the blockchain allows for more efficient monitoring and distribution of energy in real time, minimising losses and enhancing transaction transparency (Juszczyk & Shahzad, 2022).

Furthermore, blockchain has the potential to reduce its environmental impact through more sustainable energy models. In this context, alternative consensus algorithms, such as Proof-of-Stake (PoS) and Delegated Proof-of-Stake (DPoS), significantly decrease the energy consumption associated with traditional Proof-of-Work (PoW) algorithms. This approach enables the implementation of greener practices while maintaining the integrity of blockchain systems. Blockchain also facilitates the tracking of carbon footprints and greenhouse gas emissions within supply chains. These technologies can be effectively applied in the energy sector to improve transparency and trust in areas such as energy management and certification. For example, Zhang et al. (2024) demonstrate the potential of blockchain in improving supply chain visibility and supporting more sustainable practices in the energy sector (Zhang et al., 2024).

Blockchain technology also supports new business models based on the principles of sustainable development. As shown by (Calandra et al. 2023), blockchain enables companies to adopt more sustainable practices, such as cost reduction and improved transparency in energy management, while contributing to the achievement of the Sustainable Development Goals (Calandra et al., 2023).

The practical applications of blockchain technology presented indicate that it can contribute to improving the organisation of smart villages. Based on a distributed blockchain, an ecosystem of stakeholder cooperation can be built, which fulfils the role of a DAO organisation, similar to industrial concerns (Buchwald & Pawlak, 2023). Due to its properties, such a system can improve management in many aspects of the operation of a smart village. By fostering transparent, decentralised, and secure energy systems, blockchain addresses the dual imperative of ensuring a reliable energy supply while promoting sustainable practices, making it a critical tool to navigate the energy transition in a sustainable and secure manner.

Research Methods

The research methodology adopted in the presented study is based on a multifaceted approach. It assumes the presentation and comparison of the basic assumptions of process management with the capabilities of today's blockchain systems and DAOs based on it, which are subject to distributed management (Singh & Kim, 2019). Then, it is planned to present selected processes in the commune and problems related to the coordination of these processes and management through the prism of the possibility of their improvement using the blockchain environment. The results obtained in this way are compared with the scientific literature in the field of the application of modern decentralised technologies and smart village solutions.

A case study was chosen as the research method that focuses on a particular issue, feature, or unit of analysis. This method is used especially when the researcher wants to analyse the situation in depth and the issue requires qualitative rather than quantitative analysis (Noor, 2008).

Results of the research

The possibility of using modern information technologies based on decentralised systems is strongly determined by the technical development of the commune and its attitude towards the use of modern information technologies. One of the areas in which significant progress has been made in the application of modern information technologies is the area of energy management, including electricity. This area is of interest for many aspects of smart village management.

Pałecznica Commune is a commune located in Proszowice County in the north-eastern part of the Lesser Poland Voivodeship. It is a typical agricultural commune, and most of its area is covered by agricultural land. Currently, there are approximately 191 business entities operating in the commune

DOI: 10.34659/eis.2025.93.2.1076

(including natural persons conducting business activity and commercial law companies). Service activities are dominant. The mission of the commune is sustainable development achieved through the cooperation of people and efficient management and care for space and the environment (Gmina Pałecznica, 2022).

The Pałecznica commune implements the assumptions of process management in accordance with the concept of a smart village in key areas of operation. The effectiveness of this centre affects other areas of the functioning of the commune, which is the result of the analysis of the smart village management architecture presented in Figure 1.

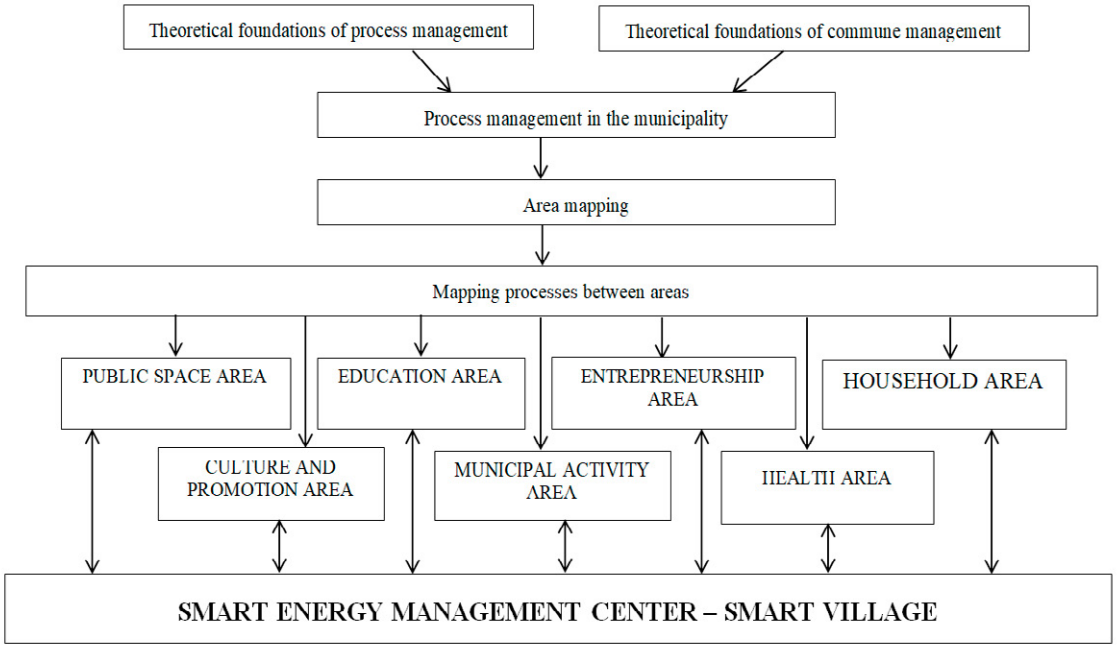

Figure 1. Simplified model of a smart village from a process perspective

Source: authors' work based on Marcin Gaweł: Smart Village Model in a Process Approach to Management in a Municipality. Doctoral thesis written under the supervision of dr. hab. Barbara Piontek, professor of AWSB.

The project of the Centre for Intelligent Energy Management in the Pałecznica commune was implemented as part of the Sokół competition, which focuses on the implementation of innovative environmental technologies. The result of the project is an integrated energy management system in the Pałecznica Commune in the field of public utilities and installations. The development, construction, testing, piloting, and ultimately implementation of this system are aimed at reducing energy consumption (15-20%) and thus reducing emissions and saving natural resources. Furthermore, by better managing the water supply network, it will contribute to reducing water consumption. The value of the project is PLN 2,742,530.00 (fully co-financed by the National Fund for Environmental Protection and Water Management). Therefore, the Pałecznica commune chose the direction of development and reduction of CO2 emissions by investing in renewable energy sources. This direction required knowledge of new technologies and the purchase of large funds for their implementation and use. The concept of energy management implemented in the commune according to the assumptions of a smart village is an open system of interrelated processes and procedures that combine broadly understood information technology, electronics, and the data transmission system to generate, design, operate, maintain and manage processes to support decision-making processes. Decisions of the beneficiaries of a specific structure at all levels in the provision of public services by local governments. Currently, 11 of the most energy-intensive facilities in the Pałecznica Commune are heated with various types of heat pumps, and the energy necessary for their operation is produced from their own distributed photovoltaic installations. The entire system is available online, and the data and software are stored on a server in the building of the Pałecznica Commune Office.

DOI: 10.34659/eis.2025.93.2.1076

Control and monitoring of the installation was planned based on freely programmable controllers with Modbus RTU communication, which can execute programs in the field of calendar functions, time programs, trends and trend supplementation, monitoring and transmitting alarms, time synchronisation, integration of MODBUS devices and data from other external MODBUS devices, control and monitoring of circulation pumps via the GENIbus protocol. The network controllers installed in the control cabinets were established to communicate through at least four ports. Their structure included an interface between the LAN/WAN network and the system's object elements, enabling global supervision of the functions of devices connected to the controller. The drivers had to be compatible with the Modbus RTU standard. Integration of additional devices was carried out via the RS485/MODBUS bus, e.g., inverters, photovoltaic inverters, heat pumps, electricity meters, etc. Data exchange speeds range from 2400 to 230400 b/s. (The Modbus Organisation, 2006).

The use of measurement systems, control automation methods, and modern data acquisition systems in energy management showed the possibilities of tracking processes that affect the functioning of a smart village. Therefore, the concept of monitoring and analysing data can be implemented not only for energy management needs, but also to manage other types of processes that are implemented by municipal stakeholders.

The use of IT systems for monitoring is consistent with the idea of the Internet of Things. Data on the implementation of business processes in the organisation can be stored in distributed registers based on local blockchain networks or global distributed registers. The choice of appropriate decentralised technology depends on the need to distribute the collected data and the need to analyse it. The need to use public data registers in the blockchain architecture determines the implementation of mechanisms to ensure information security.

ICT security for distributed blockchain-based systems is guaranteed by internal operating mechanisms, but when designing a management system based on these technologies, it is necessary to ensure compliance with legal standards regarding the security of the organisation itself. In many cases, modern decentralised technologies based on blockchain architecture do not have strict legal guidelines, which may make such a task difficult. One of the concepts to solve the above problems may be to create a hybrid system for tracking the implementation of key business processes in the commune. Such a system on the side of public blockchain registers would guarantee high anonymity. Through integration with conventional databases maintained by offices, information collected in decentralised registers could be used to examine and assess the effectiveness of processes. This integration scenario shows great potential to solve the acquisition of key data between units operating within the smart village, but also outside of it. The architectural concept of a decentralised IT system based on the above assumptions is presented in Figure 2.

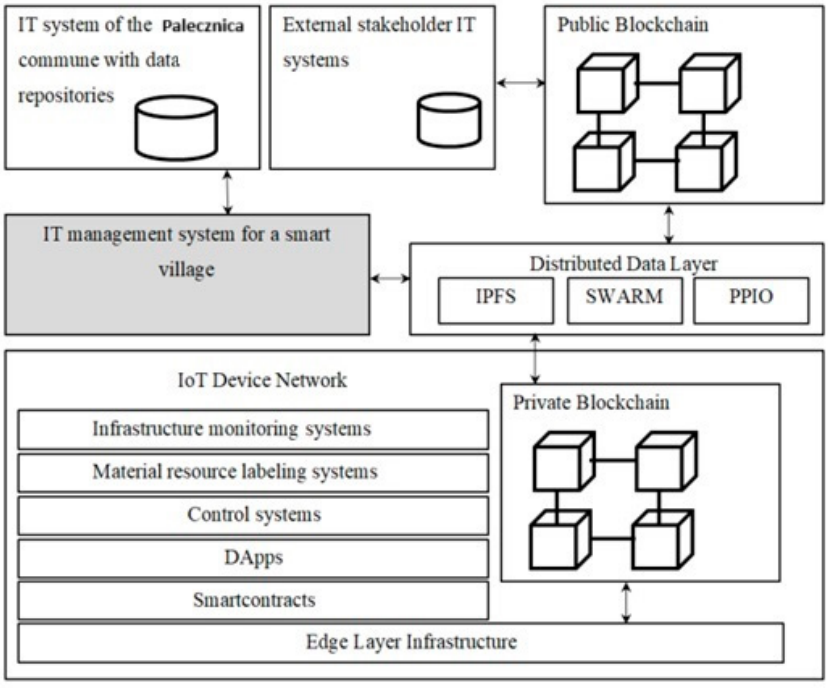

Figure 2.
Conceptual architecture of a decentralised smart village management system

DOI: 10.34659/eis.2025.93.2.1076

The diagram presents an integrated architecture of a smart village management system, where IT systems, IoT device networks, blockchain technologies, and a distributed data layer function together as a unified ecosystem. At the core of this system is the IT management system for the smart village, which collects and processes data from two main sources: the IT system of the Pałecznica commune, which contains internal data repositories, and the external IT systems of various stakeholders. These data are then transferred to the distributed data layer, which is powered by decentralised storage technologies such as IPFS, SWARM, and PPIO. These technologies ensure secure, tamper-proof, and distributed data storage.

The IT management system also interfaces with the IoT device network, which operates on the edge layer infrastructure. This network includes infrastructure monitoring systems, material resource labelling systems, control systems, decentralised applications (DApps), and smart contracts. These devices generate a continuous stream of data, which is stored and secured on a private blockchain. This private blockchain provides a secure environment for managing sensitive local data and executing smart contracts reliably.

The distributed data layer plays a dual role by connecting to both the private and public blockchains. While the private blockchain ensures local data integrity, the public blockchain allows selective sharing of data with external stakeholders. This improves transparency, trust, and accessibility without compromising local data sovereignty.

Overall, this architecture creates a coherent digital framework for smart village management, where data is securely gathered, stored, and shared through a decentralised and transparent system, allowing efficient and trustworthy digital governance.

Discussion/Limitation and future research

The technological challenges related to the implementation of the proposed system require the use of modern solutions and tools that are already available on the market. However, they are used in IT systems that comply with the assumptions of Web 4.0. Although these assumptions determine the future of Internet operation, the selected tools and technologies related to this concept are already publicly available. They are briefly presented in Table 3.

Table 3. Technologies and tools to build a distributed management system

Technology/tools	Brief Characteristics
Private Blockchain	A private blockchain is a closed network in which only selected entities can participate in the verification of the transaction and view data. Unlike a public blockchain (where anyone can join the network), a private blockchain offers greater control over access and permissions, which is especially important in business and enterprise applications where confidentiality is key. Popular tools and platforms of this type include: Hyperledger Fabric – developed by the Linux Foundation – allows for flexible definition of permissions and consensus rules. R3 Corda, designed specifically for the financial industry, allows private transactions between trusted parties. Quorum (based on Ethereum) combines the advantages of Ethereum with additional privacy features and data access control.
IPFS	IPFS (InterPlanetary File System) is a protocol and peer-to-peer network that is used for distributed file storage and sharing. Instead of using traditional URLs (based on server location), IPFS uses the so-called "content addresses" (hashes). In this way, you only need to know the unique hash of a file to access it regardless of where it is stored. In the context of blockchain applications, IPFS is often used to store larger data (e.g., documents, multimedia files) that would be inefficient and expensive to store directly on the blockchain. The blockchain itself then only stores a hash (reference) to the data in IPFS, which allows for the following: • Low costs: Transaction fees in the blockchain network apply only to recording short information (e.g., hash), not entire data. • Immutability of content: changing the file would generate a different hash, making it easier to verify integrity. • Scalability – data can be distributed across multiple IPFS nodes, ensuring better availability and performance.

DOI: 10.34659/eis.2025.93.2.1076

Technology/tools	Brief Characteristics
SWARM	SWARM is a decentralized data storage and distribution platform tightly integrated with the Ethereum network. Like IPFS, it uses a peer-to-peer architecture and content-addressed storage because files are not dependent on a specific server but are accessible through unique hashes.
PPIO	Peer-to-Peer I/O is a decentralized data storage and sharing platform that combines blockchain techniques with a distributed peer-to-peer network. As with solutions such as IPFS or SWARM, data are shared and replicated between nodes, increasing fault tolerance and censorship.
IoT networks	The Internet of Things is a concept and set of technologies that enable the connection of various types of devices (sensors, machines, and systems) to the Internet and the mutual communication between them. As a result, an ecosystem is created in which intelligent equipment – from simple temperature or lighting sensors to advanced industrial systems – exchanges data, enabling automation, optimization, and the creation of new services and solutions.
DApps	Decentralized Applications – These are applications operating in a decentralized way, most often using blockchain technology or other distributed ledgers. Unlike traditional, centralized applications (e.g. typical web applications, where logic and databases are kept on servers belonging to specific companies), DApps operate on the principle of a peer-to-peer network and do not have one main node controlling the whole.
Smart Contracts	Smart contracts are fragments of computer code operating on blockchain technology, which automatically perform specific actions when pre-defined conditions are met. To put it simply, they can be compared to „digital contracts" that are self-enforcing thanks to transparent and immutable rules written in code.

The integration of blockchain technology and DAO into the smart village IT system offers several significant advantages over conventional IT architectures, particularly in terms of data transparency, security, decentralisation, and stakeholder empowerment. Traditional IT solutions typically rely on centralised servers, where data management, validation, and decision-making are controlled by a single administrative authority. This structure often leads to limited transparency, vulnerability to data breaches, and restricted stakeholder participation. In contrast, the smart village system depicted in the diagram leverages a hybrid blockchain architecture (both private and public) and a distributed data layer (IPFS, SWARM, PPIO), which enables secure, decentralised, and transparent data handling.

Blockchain and DAO technologies reduce administrative overhead and increase trust through automated processes. Smart contracts deployed on the private blockchain can handle routine operations such as resource allocation, infrastructure monitoring, and service agreements without manual intervention. This automation minimises bureaucracy and ensures verifiable and tamper-proof records. In addition, DAOs can provide a governance framework in which administrative decisions are transparent and traceable, enhancing credibility and accountability.

Residents of the smart village benefit from increased transparency, participation, and ownership of data. In traditional systems, citizens have limited insight or control over how their data is used. With blockchain integration, commune members can interact with DApps, vote on proposals via DAO mechanisms, and verify public records themselves. They become active participants rather than passive data subjects. Furthermore, the use of edge-layer IoT infrastructure ensures that local data is processed efficiently and remains under local control.

The public blockchain interface allows external stakeholders to access selected, verifiable data without relying on intermediaries. This promotes trust and accelerates decision-making in partnerships or investments. For example, NGOs can audit how environmental monitoring is conducted, or investors can verify infrastructure performance through immutable blockchain records. Smart contracts also allow external parties to enter into agreements with the commune in a secure and automated manner.

At first glance, if data is stored in a centralised database, the role of blockchain technology might seem limited. However, blockchain does not replace traditional databases; it complements them by adding an additional layer of security, transparency, and trust, especially in systems involving multiple stakeholders. The blockchain acts as an immutable audit trail. While operational data may reside in centralised databases for speed or cost reasons, critical events such as data changes, decision approvals, transactions, or voting results are recorded immutably on the blockchain. This enables full traceability and makes manipulation significantly harder. The blockchain allows the implementation of smart contracts that automate and enforce the rules of the system, such as resource distribution,

DOI: 10.34659/eis.2025.93.2.1076

data access, or service approvals. These mechanisms reduce reliance on central authorities and minimise the risk of abuse or mismanagement. In ecosystems like a smart village, where data is shared across various parties (local administration, residents, external organisations), blockchain serves as a shared, trusted verification layer. Even if the data itself is stored off-chain, the blockchain confirms its authenticity, ensures immutability, and enables direct verification by stakeholders.

In summary, replacing traditional IT with a blockchain and DAO-based system in smart village governance significantly improves transparency, resilience, efficiency, and inclusivity. This technological shift empowers all stakeholders: administrators, residents, and external actors, by decentralising control and ensuring that integrity and governance of data are built into the system by design.

The primary limitation of the presented considerations lies in the use of the case study method. The selected commune, like any other, is characterised by distinct economic, cultural, social, and technological attributes. Consequently, the depiction of the implementation of DAO within this commune serves merely as an illustrative example and should not be construed as a basis for generalisation. Thus, while the case study method provides comprehensive insight, it possesses certain limitations. First, there is a constraint in generalizability, as the selected case pertains to a specific commune functioning within a particular context. This specificity poses challenges in extrapolating the findings to a larger population. Second, there is the potential for subjectivity and researcher bias, given that one of the researchers holds the position of mayor within the commune. The personal interpretations and predispositions of the researcher can influence the analysis and inferences derived from the case study. Third, due to the distinctive nature of the case under examination, replicating this case study might prove challenging, if not implausible. The absence of reproducibility can impede the verification of findings and the establishment of a robust collection of knowledge.

In DAO-based systems, a low number of participants can pose several challenges. Firstly, low turnout and limited participation can result in decisions being made by a very small fraction of the population, undermining democratic legitimacy. Second, with only a few active nodes (eg validators or voting participants), the blockchain network becomes more vulnerable to manipulation, such as 51% attacks, where a small group could take control over consensus and tamper with outcomes. Moreover, the small scale of the community can hinder the sustainability of DAO governance. Managing funds, updating protocols or resolving disputes requires a minimum level of participant activity and technical capability. In small rural communes, these human or technical resources may be insufficient to support fully decentralised operations. To mitigate these risks, hybrid governance models should be considered, combining decentralised logic with some central oversight. Furthermore, mechanisms such as voting quorum, delegated voting, or minimum participation thresholds can help ensure fair and secure decision-making even in low-population settings. This approach allows the system to retain the benefits of transparency and automation while remaining realistic and resilient within a small-scale context.

In many hidden applications, blockchain is used outside of the distributed file system (DFS) data storage resources due to the high technical costs of storing data on the blockchain itself. This concept was also adopted in the presented solution. However, this approach raises practical concerns regarding the handling of real-time and continuous data streams, such as IoT device recordings. IoT data is typically generated continuously, often in real time, making it impractical to treat it as static files. A more realistic approach involves buffering data locally at the edge layer and periodically uploading it to the DFS in batches. Once stored, a hash of each batch or file fragment can be written to the blockchain at set intervals (e.g., hourly or daily). This design supports incremental updates, allowing the system to handle ongoing data streams without requiring simultaneous bulk uploads.

To ensure data integrity and auditability, each batch should carry a unique hash and a timestamp. This allows the system to verify individual segments, reconstruct data sequences if needed, and track the chronological data flow.

DOI: 10.34659/eis.2025.93.2.1076

Conclusions

The article discusses the concept of a smart village as an innovative approach to the management of rural areas, ICT, blockchain, and DAO. The aim of these solutions is to improve the quality of life of residents, the efficiency of resource management, the transparency of processes, and sustainable development. The article pays special attention to the use of blockchain technology, which enables decentralisation, immutability of data records, and process automation thanks to smart contracts. Potential benefits are described, such as improving transparency, reducing administrative costs, and improving municipal management. Complete adaptation of blockchain technology in the management of municipalities and smart villages requires a hybrid approach that combines modern technologies with traditional administrative methods. The use of good aspects of traditional management methods in a hybrid approach allows the use of personal characteristics of employees and the value of human capital in the organisational development process. The hybrid approach is a compromise between process automation thanks to blockchain and the maintenance of traditional management elements that are still necessary in current legal and organisational realities (Knosala et al., 2024).

A hybrid approach requires appropriate investments in technological infrastructure, expansion of the IoT device network (Buchwald et al., 2022), staff education, and adaptation of the legal framework to enable cooperation between modern blockchain systems and traditional management methods. Furthermore, it is necessary to build social trust in new technologies, especially in the context of data protection and security. Technologically, many municipalities in Poland are prepared to automate management processes by introducing blockchain technology.

The article presents an example of the Pałecznica commune, where an integrated energy management system was implemented. This system uses blockchain to monitor energy production and consumption, while relying on traditional control systems and local servers that enable effective management of processes at the municipal level. The most important advantages of the hybrid approach are the following:

combines the best features of both systems: the automation and transparency of the blockchain with the flexibility and compatibility of traditional methods,

- reduces costs and increases the efficiency of administrative processes,
- increases community trust in the actions of local authorities through transparency,
- accelerate the adaptation of new technologies within existing legal and administrative structures.

In summary, the hybrid approach to integrating blockchain with traditional management methods provides a practical and effective solution that can be widely used in smart cities and towns. It allows for a gradual transformation of public administration, increasing transparency, efficiency, and sustainability of activities. Blockchain not only supports technological and ecological transformation but also introduces new models of energy management and sustainable consumption. With its characteristics such as transparency, decentralisation, and energy efficiency, this technology plays a crucial role in the advancement of global sustainable development goals and the construction of a more resilient energy infrastructure. Future research and investment in this technology could further enhance its contribution to the achievement of sustainability worldwide.

The contribution of the authors

Conceptualisation, B.P., M.G. and P.B.; literature review, A.A.M., M.G. and P.B.; methodology, A.A.M., M.G. and P.B.; formal analysis, B.P., M.G. and P.B.; writing, A.A.M. and P.B.; conclusions and discussion, A.A.M., P.B., M.G. and B.P.

The authors have read and agreed to the published version of the manuscript.

References

Beck, R., Czepluch, J. S., Lollike, N., & Malone, S. (2016). Blockchain–the gateway to trust-free cryptographic transactions. *Proceedings of the Twenty-Fourth European Conference on Information Systems (ECIS),* İstanbul, Turkey, 1-14. https://www.researchgate.net/publication/302589859_BLOCKCHAIN_-_THE_GATEWAY_TO_TRUST-FREE_CRYPTOGRAPHIC_TRANSACTIONS

Borgogno, O., & Martino, E. (2024). Decentralised autonomous organisations: targeting the potential beyond the hype. Law, Innovation and Technology, 16(2), 392-431. https://doi.org/10.1080/17579961.2024.2392933

DOI: 10.34659/eis.2025.93.2.1076

Buchwald, P., & Pawlak, B. (2023). Zastosowanie technologii łańcucha bloków i arkuszy kalkulacyjnych do udostępniania danych korporacyjnych na potrzeby analizy i raportowania. In R. Knosala (Ed.), *Inżynieria Zarządzania Cyfryzacja Produkcji Aktualności Badawcze 5* (pp. 13-23). Warszawa: Polskie Wydawnictwo Ekonomiczne. (in Polish).

Buchwald, P., Granosik, G., & Gwiazda, A. (2022). *Internet Rzeczy i Jego Przemysłowe zastosowania.* Warszawa: Polskie Wydawnictwo Ekonomiczne. (in Polish).

Buterin, V. (2014, May 6). *DAOs, DACs, DAs and more: An incomplete terminology guide.* Ethereum Foundation Blog. https://blog.ethereum.org/2014/05/06/daos-dacs-das-and-more-an-incomplete-terminology-guide

Cai, Z., Chen, J., Fan, Y., Zheng, Z., & Li, K. (2024). Blockchainempowered Federated Learning: Benefits, Challenges, and Solutions. *arXiv preprint arXiv:2403.00873*.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. Telematics and Informatics, 36, 55-81. https://doi.org/10.1016/j.tele.2018.11.006

Calandra, D., Secinaro, S., Massaro, M., Dal Mas, F., & Bagnoli, C. (2023). The link between sustainable business models and Blockchain: A multiple case study approach. Business Strategy and the Environment, 32(4), 1403–1417

De Clercq, M., Vats, A., & Biel, A. (2018). *Agriculture 4.0: The Future of Farming Technology.* https://www.bollettinoadapt.it/wp-content/uploads/2019/12/OliverWyman-Report_English-LOW.pdf

European Comission. (2017). *EU action for Smart Villages.* https://ec.europa.eu/enrd/news-events/news/eu-action-smart-villages_en.html

Gaweł, M (2024). Smart Village Model in a Process Approach to Management in a Municipality. Doctoral thesis written under the supervision of dr. hab. Barbara Piontek, professor of AWSB.

Gmina Pałecznica. (2022). *Pałecznica Commune Development Strategy 2030.* https://palecznica.pl/attch/article_attch-113-218-1689162219.pdf (in Polish).

Griffin, R. W. (2016). *Fundamentals of management.* Boston: Cengage Learning, Inc.

Ilyushina, N., & Macdonald, T. (2022). Decentralised autonomous organisations: A new research agenda for labour economics. The Journal of The British Blockchain Association, 5(1), 50-53. https://jbba.scholasticahq.com/api/v1/articles/35367-decentralised-autonomous-organisations-a-new-research-agenda-for-labour-economics.pdf

Jentzsch, C. (2016, August 24). *The History of the DAO and Lessons Learned.* Medium. https://medium.com/slock-it-blog/the-history-of-the-dao-and-lessons-learned-d06740f8cfa5

Juszczyk, O., & Shahzad, K. (2022). Blockchain technology for renewable energy: principles, applications and prospects. Energies, 15(13), 4603. https://doi.org/10.3390/en15134603

Kalinowski, S., Komorowski, Ł., & Rosa, A. (2022). *The Smart Village Concept: Examples from Poland.* Warsaw: Instytut Rozwoju Wsi i Rolnictwa PAN. (in Polish).

Kamilaris, A., Fonts, A., & Prenafeta-Boldú, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. Trends in Food Science & Technology, 91, 640-652. https://doi.org/10.48550/arXiv.1908.07391

Kaur, P., & Parashar, A. (2021). A systematic literature review of blockchain technology for smart villages. Archives of Computational Methods in Engineering, 1-52. https://doi.org/10.1007/s11831-021-09659-7

Knosala, R., Buchwald, P., Kostrzewski, M., Oleszek, S., & Szajna, A. (2024). *Zastosowania Innowacyjnych Technologii Informatycznych.* Warszawa: Polskie Wydawnictwo Ekonomiczne. (in Polish).

Lin, W., Huang, X., Fang, H., Wang, V., Hua, Y., Wang, J., Yin, H., Yi, D., & Yau, L. (2020). Blockchain technology in current agricultural systems: From Techniques to Applications. *IEEE, 8,* 143920-143937. https://doi.org/10.1109/ACCESS.2020.3014522

Naldi, L., Nilsson, P., Westlund, H., & Wixe, S. (2015). What is smart rural development? Journal of Rural Studies, 40, 90-101. https://doi.org/10.1016/j.jrurstud.2015.06.006

Nazarko, J., & Bokun, K. (2024). *Smart Villages. Koncepcja i próby wdrożenia.* Białystok: Oficyna Wydawnicza Politechniki Białostockiej. (in Polish).

Noor, K. B. M. (2008). Case study: A strategic research methodology. American Journal of Applied Sciences, 5(11), 1602-1604. https://doi.org/10.3844/ajassp.2008.1602.1604

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. Government Information Quarterly, 34(3), 355-364. https://doi.org/10.1016/j.giq.2017.09.007

Sims, A. (2019). Blockchain and decentralised autonomous organisations (daos): The evolution of companies? New Zealand Universities Law Review, 28, 423-458. https://dx.doi.org/10.2139/ssrn.3524674

Singh, M., & Kim, S. (2019). Blockchain technology for decentralized autonomous organisations. In Advances in Computers, 115, 115-140. https://doi.org/10.1016/bs.adcom.2019.06.001

Stublić, H., Bilogrivić, M., & Zlodi, G. (2023). Blockchain and NFTs in the cultural heritage domain: A review of current research topics. Heritage, 6(4), 3801-3819. https://doi.org/10.3390/heritage6040202

Swan, M. (2015). *Blockchain: Blueprint for a New Economy.* O'Reilly Media.

DOI: 10.34659/eis.2025.93.2.1076

Tapscott, D., & Tapscott, A. (2016). *Blockchain Revolution: How the Technology Behind Bitcoin Is Changing Money, Business, and the World*. New York: Portfolio Penguin.

The Modbus Organisation. (2006). *Modbus Application Protocol Specification v1.1.b.* https://www.modbus.org/docs/Modbus_Application_Protocol_V1_1b.pdf

Trajer, B., & Trajer, M. (2021). Koncepcja smart villages w rozwoju obszarów wiejskich. Turystyka i Rozwój Regionalny, (15), 117-127. https://doi.org/10.22630/TIRR.2021.15.11 (in Polish).

Vaccargiu, M., Pinna, A., Tonelli, R., & Cocco, L. (2023). Blockchain in the Energy Sector for SDG Achievement. *Sustainability*, *15*(20), 14843. https://doi.org/10.3390/su152014843

Wang, S., Ding, W., Li, J., Yuan, Y., Ouyang, L., & Wang, F.-Y. (2019). Decentralized Autonomous Organisations: Concept, Model, and Applications. *IEEE Transactions on Computational Social Systems,* 6(5), 870-878. https://doi.org/10.1109/TCSS.2019.2938190

Wood, G. (2014). Ethereum: A secure decentralised generalised transaction ledger. Ethereum Project Yellow Paper, 151, 1-32.

Wright, A., & De Filippi, P. (2015). Decentralized blockchain technology and the rise of lex cryptographia. SSRN, 1-58. https://dx.doi.org/10.2139/ssrn.2580664

Zhang, C., Wu, J., Zhou, Y., Cheng, M., & Long, C. (2018). Peer-to-Peer energy trading in a Microgrid. Applied Energy, 220, 1-12. https://doi.org/10.1016/j.apenergy.2018.03.010

Zhang, J., Lin, Z., & Chen, J. (2024). Leveraging Blockchain for Enhanced Visibility and Sustainability in the Energy Sector Supply Chain. International Journal of Electric Power and Energy Studies, 2(2), 17-26. https://doi.org/10.62051/ijepes.v2n2.03

Paweł BUCHWALD • Barbara PIONTEK • Anna ADAMUS-MATUSZYŃSKA • Marcin GAWEŁ

MOŻLIWOŚCI POPRAWY BEZPIECZEŃSTWA I EFEKTYWNOŚCI ENERGETYCZNEJ ZRÓWNOWAŻONEGO ZARZĄDZANIA INTELIGENTNĄ WIOSKĄ POPRZEZ WYKORZYSTANIE TECHNOLOGII BLOCKCHAIN ORAZ ZDECENTRALIZOWANYCH ORGANIZACJI AUTONOMICZNYCH NA PRZYKŁADZIE GMINY PAŁECZNICA

STRESZCZENIE: W artykule omówiono koncepcję inteligentnych wiosek, kładąc nacisk na integrację technologii informacyjno-komunikacyjnych (ICT), blockchain i zdecentralizowanych organizacji autonomicznych (DAO) w celu usprawnienia zarządzania zrównoważonego w gminach. Artykuł podkreśla rolę blockchain w decentralizacji i automatyzacji procesów za pośrednictwem inteligentnych kontraktów, które oferują korzyści takie jak lepsza przejrzystość i zmniejszone koszty administracyjne oraz bezpieczeństwo energetyczne. Podejście hybrydowe które łączy łańcuch bloków z tradycyjnymi metodami, jest zalecane w celu optymalizacji zarządzania przy jednoczesnym wykorzystaniu kapitału ludzkiego. Podejście to wymaga inwestycji w infrastrukturę, edukację i dostosowania prawne w celu ułatwienia integracji. Studium przypadku gminy Pałęcznica ilustruje udane wdrożenie nowoczesnego systemu zarządzania energią, który może być zintegrowany z technologią łańcucha bloków. W świetle przedstawionej analizy model hybrydowy zapewnia skuteczną transformację administracji publicznej, zwiększając przejrzystość, efektywność i zrównoważony rozwój w inteligentnych wioskach.

SŁOWA KLUCZOWE: inteligentna wioska, rozwój zrównoważony, łańcuch bloków, rozproszona administracja, organizacje DAO, Internet Rzeczy, zarządzanie bezpieczeństwem energetycznym