Energy smart contracts in smart cities: technologies, advantages and future prospects

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***Abstract*—Energy smart contracts in smart cities automate and make energy transactions transparent, promoting peer-to-peer exchanges, efficiency and sustainability. This innovative technology supports decentralised energy management, reduces costs and intermediaries, and promotes more resilient and participatory energy communities.**

Keywords— energy, smart contracts, smart cities, efficiency, sustainability.

I. Introduction

A smart contract is a computer protocol that facilitates, verifies and automatically enforces the negotiation or execution of a contract. It is programmable code that runs on a blockchain, a distributed and immutable network. Smart contracts eliminate the need for intermediaries, as contractual clauses are self-executing when certain pre-set conditions are met.
In the energy sector, these digital contracts can automatically regulate transactions between producers and consumers, manage micro-payments, incentivise virtuous behaviour and ensure a more equitable distribution of the energy produced, especially when it comes to renewable sources and decentralised systems such as smart grids.

II. Smart Cities and Smart Energies

Smart cities are characterised by the integration of information and communication technologies (ICT) into urban services. Among these, the energy system is of primary importance. Smart grids, or intelligent electricity networks, are the backbone of energy management in smart cities. They enable real-time monitoring of energy flows, automatic regulation of supply and demand, and connection between different actors, such as domestic photovoltaic systems, storage batteries, electric vehicles and homes.
In this context, the adoption of smart contracts takes the concept of 'intelligence' to a higher level, creating a truly autonomous, transparent and participatory energy network.

III. Applications of energy smart contracts

1. Peer-to-Peer (P2P) energy trading: one of the most interesting applications is the possibility for citizens to trade energy directly, without going through a central authority. A solar panel owner can sell excess energy to their neighbour through a smart contract, which automatically regulates the transaction when the agreed conditions are met: amount of energy, price and time of day. Pilot projects in Australia, Germany and the Netherlands demonstrate the effectiveness of these systems.
2. Payment and billing automation: with smart contracts, it is possible to automate payments in real time based on actual consumption. IoT sensors collect consumption data and transmit it to the blockchain. The smart contract automatically executes the payment each time consumption reaches a pre-set threshold, ensuring accuracy, transparency and reduced administrative costs.
3. Incentives for energy saving: local authorities can use smart contracts to incentivise virtuous behaviour by citizens, for example through micro-payments or discounts on bills for those who consume less energy at peak times or for those who use only renewable sources.
4. Decentralised management of energy communities: renewable energy communities are groups of citizens, public bodies or businesses that share locally the energy produced by collective plants. Smart contracts can regulate how energy is shared, establish rules for access to energy and ensure a fair distribution of economic benefits.

IV. Advantages of smart contracts in the energy sector

1. Transparency and traceability: all transactions recorded on the blockchain are immutable and verifiable by anyone. This ensures total transparency between the parties involved and reduces the risk of fraud.
2. Reduction of intermediaries: the elimination of intermediaries reduces transaction costs, speeds up processing times and increases the efficiency of the system.
3. Greater efficiency and automation: automated processes reduce the margin for human error and enable dynamic energy management based on real-time needs.
4. Security and reliability: smart contracts are protected by encryption and distributed across a decentralised network, making them difficult to tamper with or hack.

V. CHALLENGES AND CRITICAL ISSUES

Despite the advantages, the adoption of smart contracts in the energy sector presents some
challenges:

- Legislation and regulation: many countries lack clear regulations that recognise the legal validity of smart contracts, making their large-scale implementation difficult.
- Technological interoperability: different technologies (blockchain, IoT, energy networks) need to be integrated in a harmonious and secure manner.
- Accessibility and digital divide: not all citizens have easy access to these technologies due to a lack of digital skills or adequate infrastructure.
- Scalability: traditional blockchains can have scalability issues and consume a lot of energy, although solutions such as green blockchains are emerging.

VI. FUTURE PROSPECTS

The future of energy smart contracts in smart cities is promising. Integration with artificial intelligence, for example, could improve demand forecasting and resource optimisation. In addition, growing interest in distributed and sustainable energy models will encourage local authorities to invest in these technologies.

Regulatory developments are also moving in the right direction: the European Union, with its CleanEnergy Package, is promoting the creation of energy communities and self-production of energy, paving the way for the use of smart contracts as a governance tool.

VII. CONCLUSION

Smart contracts are a key tool for making the energy system in smart cities more efficient, fair and sustainable. They enable secure, automated and transparent transactions between citizens, businesses and institutions, contributing to the democratisation of energy and the reduction of environmental impact. Despite the technological and regulatory challenges that still need to be overcome, the transformative potential of smart contracts in the energy sector is enormous, and their role will become increasingly central to the ecological and digital transition of our cities.