

Blockchain in Solar Energy

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Abstract

Blockchain technology disrupts existing business models and practices in different sectors of the economy. It has the potential to revolutionize the way we do business, and it can be combined with other technologies like Internet of Things (IoT) or Artificial Intelligence (AI) to increase its disruptive effect. In this paper we study the impact of the implementation of a blockchain solution in the area of solar energy. The results of this research demonstrate that blockchain technology can disrupt the energy sector in various ways including, among others, disruption in process, product, position and paradigm, and platform innovation.

Keywords: blockchain technology, smart contracts, solar energy, action research, disruptive innovation

Introduction

Just weeks after the September 2008 Lehman Brothers collapse, blockchain technology was first introduced on 31 October 2008 by an author or a group of authors under the nickname Satoshi Nakamoto.⁴ In January 2009, Nakamoto sent the first ten bitcoins to Hal Finney, a bitcoin supporter. Sixteen months later, in May 2010, the first business transaction took place between a pizza restaurant in Jacksonville, Florida and Laszlo Hanyecz. The latter paid 10,000 bitcoins to buy two pizzas, which obviously is the most expensive pizza sale in history if we consider the average bitcoin price for the last 10 years. Soon after that pizza sale, enterprises, banks, universities and governments realized the potential of bitcoin and blockchain (the technology that supports the functionality of bitcoin) and invested in it.

One of the first adopters of blockchain technology in academia and in Cyprus is the University of Nicosia, which since 2014 has established the world's first and largest full academic program in blockchain education,⁵ has accepted bitcoins as

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4 S. Nakamoto, 'Bitcoin: A peer-to-peer electronic cash system', *Bitcoin.org* (2008), available at <http://www.bitcoin.org>.

5 UNIC (2018), available at <https://digitalcurrency.unic.ac.cy>.

tuition fees (since 2014) and publishes its academic certificates on a blockchain. Apart from education, blockchain technology has been adopted in many sectors, including fintech, insurtech, healthcare, land registry, and supply chain management.⁶

In this paper we study blockchain in the energy sector and we introduce an innovative way of doing business through a disruptive application that combines blockchain technology, Artificial Intelligence (AI), Internet of Things (IoT) and smart energy grids.⁷ The proposed application points to drastic changes to the existing business models and introduces a series of new challenges for the energy market and energy companies.

The remaining sections of this paper are as follows: Section 2 reviews blockchain technology, followed by the conceptualization of this research and the research question under investigation. Section 4 presents the empirical data and Section 5 discusses and analyses the data. Conclusions are reported in the last section of the paper.

Literature Review

Blockchain technology has the potential to address integration and interoperability challenges, and it can enable involved parties to securely and trustfully share their data. Blockchain technology is a distributed ledger that saves digital events (transactions) in a chronological order that are shared in a decentralized network and establishes transparency and trust. It is the underlying technology for cryptocurrencies, and it is based on three main components.

Transactions and Blocks: A transaction refers to any digital information (e.g., an encrypted reference to blood test results) that could be stored in a blockchain. Transactions are encrypted and placed in a block in a linear chronological order.

Shared Ledger: The block with the transactions is sent to the shared ledger for

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- 6 L. Cocco, A. Pinna and M. Marchesi, 'Banking on blockchain: Costs savings thanks to the blockchain technology', *Future Internet*, Vol. 9, No. 3 (2017), DOI.org: 10.3390/fi9030025 et al.; P. Cuccuru, 'Beyond bitcoin: an early overview on smart contracts', *International Journal of Law and Information Technology*, Vol. 25, No. 3 (2017), DOI.org: 10.1093/ijlit/eax003; P. Gomber, R. J. Kauffman, C. Parker and B. W. Weber, 'On the Fintech Revolution: Interpreting the Forces of Innovation, Disruption, and Transformation in Financial Services', *Journal of Management Information Systems*, Vol. 35, No. 1 (2018); A. Lei, H. Cruickshank, Y. Cao, P. Asuquo, C. P. A. Ogah and Z. Sun, 'Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems', *IEEE Internet of Things Journal*, 4662(c) (2017); V. L. Lemieux, 'Trusting records: is Blockchain technology the answer?', *Records Management Journal*, Vol. 26, No. 2 (2016).
- 7 G. Li, H. Meng, G. Zhou and Y. Gao, 'Energy management analysis and scheme design of microgrid based on blockchain', *Dianli Jianshe/Electric Power Construction*, Vol. 39, No. 2 (2018), 43–49.; Novo, 'Blockchain Meets IoT: an Architecture for Scalable Access Management in IoT', *IEEE Internet of Things Journal*, Vol. 5, No. 2 (2018).

validation. Once it is validated, it is added to a chain of blocks (shared ledger). After a block is added to the chain it cannot be changed or removed.

Distributed Network: Each participant of the network has a computer node that stores an identical copy of the blockchain (shared ledger). The additions of new blocks to the shared ledger are reflected in all copies. The network nodes are responsible for validating and certifying network transactions, and participants cannot modify or tamper with transactions/blocks once these are validated and added to the chain.

In addition to these, blockchain technology has the following characteristics:

Consensus: Consensus mechanisms attest that each new block that is appended to the blockchain is a valid one. There are various consensus mechanisms that are used today, like Proof Of Work (PoW), Proof Of Stake (PoS), Delegated Proof Of Stake (DPoS), Proof Of Capacity (PoC) and Proof Of Elapsed Time (PoET).

Provenance: In using blockchain technology, information and cryptocurrencies are traceable, and all participants are aware of the history of the assets or information exchanged (e.g., in a land registry blockchain application we know the full history of a property, from its initial form as a piece a land to the construction of a block of flats and the changes in ownership of this asset over time).

Immutability: A blockchain is an append-only ledger, and thus transactions cannot be changed once recorded.

Finality: The blockchain ledger is trusted by all participants and it is the only source of truth.

Research Question and Methodology

This article investigates blockchain technology adoption in the energy sector and more specifically in solar energy. Solar energy and renewable forms of energy are significant for our planet, but they face some challenges. Specifically, in solar energy there are concerns about its: difficulty to store excess energy supply due to the limitations of the existing equipment used; inability to match supply and demand which is related to the amount of time that the sun shines; the cost of the equipment that is used to generate solar energy.

Today, most solar energy applications are based on a producer-consumer model where the former produces the energy and sells it to the latter. The production and distribution process is based on outdated practices. For instance, solar energy companies deploy thousands of solar units to build their infrastructure and to produce solar energy. The energy is then converted, and it is distributed through an electricity grid to industrial or residential users for consumption. However, the application of a peer-to-peer network for energy is not feasible in many cases for various reasons (technological, legal, etc.).

Even though solar energy is environmentally friendly, it has some limitations that need to be investigated. In this paper, we focus more on the limitations of the existing landscape in solar energy, sharing as our empirical data from that area.⁸ Below is a list of the most important limitations:

- The solar energy price is somehow fixed between producer and clients and there is no negotiation process between them. There are periods of time (e.g., summer time) where daylight and sun light lasts longer, and the production of solar energy is higher, whereas the opposite happens in winter time. In this respect, consumers should be able to buy solar energy at a lower price during periods of high production and at a higher price during times of low production. Such a policy would be fair for clients as in summer, for example, they consume much more energy for air-conditioning, and in winter they might use other forms of energy (e.g., natural gas, fossil fuels) to heat their houses.

- Solar energy production companies are not paid immediately by customers but after one or two months. This has an impact on their cash flow and line of business.

- Solar energy customers have to believe that the energy production companies are truthfully reporting the volume of renewable energy they consume.

In order to investigate the role of blockchain technology as a disruptive one, we formulate the following research question:

RQ1: How do blockchain solutions disrupt the current ecosystem and models in the energy sector?

In an attempt to test our research question, we collaborated with a solar energy company in Cyprus that has presence in various countries in Europe and North America. Part of our collaboration was to propose and develop a blockchain solution for its business activities. For that reason, we adopted an action research approach, which is more appropriate in this case since we had an active role and we took decisions related to the development and testing of the solar blockchain solution.

Use Case Data

The project began in the first half of 2017 and lasted for one year. Due to the nature of the project, we initially searched for similar implementations, but we did not find anything relevant. Then we assessed existing technologies and we finally decided to use Ethereum as the blockchain platform to exchange the data and tokens of our application. For the implementation, we used software tools like Ethereum Request for Comment 20 (ERC20), Remix-IDE, solidity and testRPC. A hierarchical deterministic

⁸ C. Pop, T. Cioara, M. Antal, I. Anghel, I. Salomie, and M. Bertoncini, 'Blockchain based decentralized management of demand response programs in smart energy grids', *Sensors*, Vol. 18 (2018): 162, DOI.org: 10.3390/s18010162.

(HD) wallet was also used to facilitate the exchange of tokens in our Ethereum based solution. Smart contracts were developed to handle agreements between different parties and to reduce the role of the middleman. Smart contracts save data about an application and automate the token transfer between users, based on an agreement.

The blockchain solution that was developed for the purposes of this research automates the following scenario:

- Solar panels are installed on the roof of home users to produce energy;The solar energy that is produced is stored locally using smart batteries;Smart batteries use Internet of Things (IoT) to enhance their functionality;The battery owner sets the price and the quantity of the energy s/he wants to sell, based on competition and the weather conditions;When s/he reaches an agreement with a potential buyer, s/he discharges the electricity from the battery to the energy grid;Smart meters are used to calculate the quantity of the electricity sold and the transaction is completed using smart contracts and paid for using cryptocurrencies. All relevant transactions are put in a block that is sent for validation;Proof of work is used as a consensus mechanism to validate the block, and the block is finally attached to the blockchain;Using the smart grid, the buyer receives the energy purchased and consumes it at home or uses it to charge his/her electric car.

Currently we design Artificial Intelligence (AI) algorithms to improve the performance and to enhance decision-making. Upon completion of these algorithms, the smart battery will automatically be able to:

- decide whether to sell or buy energy;
- analyze existing and historical data to define the selling price;
- operate on a machine-to-machine (M2M) mode with no or limited human intervention.

Data Analysis and Discussion

In order to test our research question, we used the 4Ps framework proposed by Tidd and Bessant that investigates innovation at Product, Process, Position and Paradigm levels.⁹

Product innovation deals with improvements in the products or services that a firm offers, for example a new product design. From the empirical data, it appears that our blockchain solution resulted in the development of decentralized trust services and smart contracts that have a disruptive effect in the existing line of business. Moreover, the combination of IoT, smart contracts, blockchain, tokens and security mechanisms results in product innovation.

⁹ Tidd and Bessant (2013).

Process innovation refers to changes in the ways in which processes are created and delivered. Our blockchain solution for solar energy achieves process innovation in various ways like: (a) governance, which is now based on consensus mechanisms instead of a single point of control; (b) the use of tokens, which forms an innovative way to do business; and, (c) early experiments using AI algorithms with the IoT incorporated in the battery and our blockchain solution demonstrate that, with the completion of all AI algorithms, we will be in position to support machine-to-machine financial transactions based on tokens as well as automatic decision-making (to sell or to buy solar energy).

Position innovation reports changes in the way the product or service is positioned / introduced in the market. Take, for instance, the case of Amazon, which, based on continuous product and process innovation, has managed to reposition itself in the market (i.e., it went from being an online retailer to a cloud provider). In our case, we can see changes in position innovation in terms of decentralized governance, initial coin offerings (ICOs) and autonomous economic agents.

Paradigm innovation focuses on changes in issues related to the underlying business models, among others. The research findings illustrate a change in the business model used. Applying blockchain technology to solar energy, we managed to build a peer-to-peer communication environment, which changes the relationships among the involved parties. The underlying business model has shifted from producer-consumer to prosumer. In such a model, a user with solar panels installed in his/her property can become a solar energy producer who sells energy to the other users through the smart grid. In case of need, the same user can buy energy from other solar energy producers on the grid. This is a fundamental change in the business model, but it cannot currently be applied in Cyprus due to legal and regulatory barriers. For that reason, the organization that collaborated with us on this experiment is now exploring the possibility to introduce this system in countries like United Kingdom or Netherlands, where the regulatory framework is friendlier to such business models.

Conclusion

In this paper we explored the development and introduction of a blockchain solution for a Cyprus-based solar energy company. In doing so, this article focused on the investigation of the research question: *How do blockchain solutions disrupt the current ecosystem and models in energy sector?* To test the research question, we collaborated with our use case organization and built a blockchain application using Ethereum. The results reveal that the development of our blockchain solution in solar energy has disrupted the current ecosystem and models in that sector. The business model of prosumer has emerged and it can now replace the previous model of producer-

consumer. Not only is the underlying business model changed, but we are in a position where producers of energy can negotiate the price of solar energy with their clients and receive payment immediately. These were significant limitations of the practices that do not use blockchain technology. In addition, our application has resulted in a series of disruptive innovation in the areas of product, process, paradigm and position innovation. However, due to the legal and regulatory framework, the proposed solution cannot be adopted in the Cyprus energy market at the moment, which indicates that regulators should improve and transform their regulatory framework as soon as possible.

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