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Research Article

Blockchain Technology in Renewable Energy Certificates in Brazil

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ABSTRACT

Several renewable energy certificate (RECs) applications point out that the blockchain technology can be useful in ensuring the traceability and transparency of transactions, despite some barriers to its implementation, such as the legal and market development. However, it is not clear how the organizational positioning, in relation to its given market, influences the artifact developed. In this study, through design science research (DSR) and case study methodology, we structure the problem space of two different positioned organizations in the sustainability field, with blockchain-based applications to produce and trade RECs. We find out that: (a) the position of the organization in relation to other stakeholders changes the behavior of the technology adoption; (b) the technological solution preceded the perception of the problem; (c) organizations create different representations of the artifact for each stakeholder. We suggest other studies to deepen these findings in order to better develop theories that explain how organizations see their problem when developing technological solutions while using DSR.

Keywords: blockchain; design science research; renewable energy certificates; energy

JEL Code: M15

INTRODUCTION

The need to limit global warming to even 1.5° C above pre-industrial levels demands rapid, far reaching, and unprecedented changes in the current production and consumption model (Intergovernmental Panel on Climate Change [IPCC], 2018). In 2010, 35% (17 GtCO2eq) of global anthropogenic greenhouse gas (GHG) emissions were released in the energy supply sector. When GHG emissions from electricity and heat production are attributed to the final consumer sectors (i.e., indirect emissions), the shares of the industry and buildings sectors represent 31% and 19% of global emissions, respectively (Intergovernmental Panel on Climate Change [IPCC], 2014).

Besides decarbonization, i.e., the necessary reduction in carbon intensity of energy generation, the electrical power systems are being affected also by two other main drivers of change: digitalization of energy trading, which offers opportunities for new business models based on peer-to-peer (P2P) and transparent transactions; and decentralization of power systems, including distribution networks that comprise decentralized generation (most based on renewable energy sources), storage and active participation of the consumers, some of them turned into prosumers, as they also produce energy on the decentralized system (Silvestre, Favuzza, Sanseverino, & Zizzo, 2018).

In energy markets, it is impossible for consumers to distinguish between the consumption of renewable energy (RE) and non-renewable energy. The decarbonization of the electricity generation is addressed by governments through traditional policy tools, such as taxes and subsidies, and through the implementation of certification schemes to promote the use of RE, such as renewable energy certificates (RECs) (Hulshof, Jepma, & Mulder, 2019). RECs are a market-based policy instrument that represents the property rights to the environmental, social, and other non-power attributes of a fixed amount of electricity, usually one megawatt-hour (MWh), generated and delivered to the grid from a renewable energy source (RES), typically covering a range of renewable technologies in an undifferentiated way (Criscuolo, Johnstone, Menon, & Shestalova, 2014; United States Environmental Protection Agency [US EPA], 2017). And although RECs have different characteristics in each country depending on grid and market specificities, as well as on national laws and regulations, there has been criticism of the RECs trade process, particularly due to the existence of double counting of this type of certificate (Frenkil & Yaffe, 2012).

Within this context, the blockchain technology "could contribute to greater stakeholder involvement, transparency and engagement and help bring trust and further innovative solutions in the fight against climate change, leading to enhanced climate actions" (United Nations Framework Convention on Climate Change [UNFCCC], 2017, online). by improving carbon emission trading, facilitating low-carbon energy trading, and enhancing climate finance flows (UNFCCC, 2017). Blockchain was initially identified as the technology used in Bitcoin cryptocurrency (Nakamoto, 2008), thus was first applied in the development of cryptocurrencies. Simply said, blockchain is a decentralized and distributed ledger used to store transactions, contracts agreements in a digital record able to combine the more efficient information security methods by using various cryptographic protocols and by recording information in a distributed database (Kushch & Castrillo, 2017). However, in the last five years, the interest in blockchain application has grown in different areas, including sustainability applied to the energy sector. For instance, blockchain can be a tool to avoid double counting of RECs, by allowing greater traceability and transparency in transactions (Abou Jaoude & Saade, 2019; Pournader, Shi, Seuring, & Koh, 2020; Silvestre et al., 2020), to reduce the operational costs of developing a REC market platform (Castellanos, Coll-Mayor, & Notholt, 2017) and to encourage consumer participation in the RECs trading market on energy systems with a high percentage of RE available (Zhao, Guo, & Chan, 2020). However, certificate trading schemes, such as RECs, based on blockchain applications remain in a nascent stage (Burer, Lapparent, Pallotta, Capezzali, & Carpita, 2019). It is not clear in the literature, however, how organizational positioning in a given market (sustainability and RECs), influences the implementation of blockchain and the artifact developed.

To make a contribution within this subject, in this study, through a review of the issues on blockchain applied to the energy sector, and specially on RECs, and using design science research (DSR) and case study methodology, we structure the problem space (Maedche, Gregor, Morana, & Feine, 2019) to identify how two organizations in the Brazilian sustainability field, with different market positions and backgrounds, understand their problems and propose blockchain-based technological artifacts to produce and trade RECs. Among the aspects considered are traceability, transparency, and the influence of the regulatory and political context for the development of blockchain applications (Brilliantova & Thurner, 2019; Burer et al., 2019).

Additionally, we discuss the impact that blockchain could produce on the Brazilian RE market, in which RES accounted for 46% in the national matrix in 2019, almost triple the global average in 2017 (14%). The electricity generation is predominantly from renewable sources (83%), based mainly on hydropower (65%), followed by wind (8.6%), biomass, such as sugarcane bagasse (8.4%), and solar photovoltaic (1%) (Empresa de Pesquisa Energética [EPE], 2020). Considering the decarbonization commitments assumed by countries under the Paris Agreement, and by companies on a voluntary basis or in response to regulation, the high share of RES in the Brazilian energy matrix makes the country a player with great potential in the global RECs market. At the same time, members of the energy supply chain might benefit from blockchain technology applied to RECs issued in Brazil to attract new participants and turn this market more efficient. By studying the relationship between organizational positioning and blockchain technology, we hope that these findings can guide entrepreneurs in the energy sector in the process of thinking about their business models and its relationship to technological development.

LITERATURE REVIEW

Blockchain applied to the energy sector

Sustainability became one of the key objectives of energy policy and an important driver of innovation in the energy sector. Energy strategies are built around the following hierarchy in energy options from the most to the least sustainable: energy conservation through improved energy efficiency and rational use of energy, increasing use of RES and exploitation of unsustainable resources using low-carbon technologies (Saygin & Çetin, 2010). Energy systems are undergoing rapid changes to be able to accommodate the increasing volumes of embedded RE generation. RES went through massive development enabled by the unbundling of the energy sector and privatizations, boosted by international and national energy policy initiatives and financial incentives (Andoni et al., 2019), represented in the 2015's United Nations Global Opportunity Report by three distinct avenues of action to address the risk of lock-in to fossil fuels (table 1).

Table 1

Avenue of action on risk of lock-in to fossil fuels by United Nations Opportunity Report

Avenue of Action	Description
Regulated Energy Transition	Regulatory initiatives can accelerate the transition to cleaner energy generation. Redirecting fossil fuel subsidies, trade regulation favoring low-carbon products and services, and setting a price on fossil fuels that reflects their cost to the environment are all prominent tools. Besides pushing for a more sustainable energy system, clear and meaningful regulation can provide dynamic incentives for innovation of new low-carbon solutions.
Energy Autonomy	Autonomous energy generation from renewable sources is a promising means of electrifying off-grid areas. In many high-income countries, small-scale energy systems today are transforming the role of households in national energy infrastructure. This approach generates several added benefits, including the chance to combat energy poverty and increase resilience to extreme weather events.
Green Consumer Choices	Consumers' concerns about the environment and climate change can be translated into sustainable choices. Making the green choices easy and attractive can empower consumers to act and thereby initiate larger structural changes by applying pressure from the demand side.

This scenario leads the energy sector to undergo a far-reaching shift toward decarbonization of energy generation, decentralization of energy supply, allowing increased customer participation and demanding innovation at the distribution level, and digitalization of energy trading, based on by peer-to-peer and transparent transactions. Combined, decarbonization, decentralization, and digitalization (the three Ds) impact the way that electrical power systems are managed and coordinated, as well as its business models (Brilliantova & Thurner, 2019; Silvestre et al., 2018).

Blockchain technologies play an important role in this changing scenario. Andoni et al. (2019) indicate that the energy industry stakeholders, utility companies, and energy decision-makers are interested in blockchain technologies. Thought an analysis of 140 blockchain applications in the energy sector, they identified eight categories of blockchain applications for energy applications: (a) metering, billing, and security; (b) cryptocurrencies, tokens, and investment; (c) decentralized energy trading; (d) green certificates, including RECs, and carbon trading; (e) grid management; (f) internet of things (IoT), smart devices, automation, and asset management; (g) electric e-mobility; and (h) general purpose initiatives developing underpinning technology. Among the applications examined, 33% of the applications concern decentralized energy trade; 19% concern cryptocurrencies; and 7% accounts for green and RE certificates and the carbon market. Blockchain applications expand the possibilities of solutions and applications to be implemented in the energy sector, and indicate that this technology can bring benefits to energy system operations, markets, consumers, allowing disintermediation, increasing transparency, and empowering consumers and small RE producers.

Similarly, O'Donovan and O'Sullivan (2019) also explore the evolution of blockchain applications in energy: of the 129 cases found, only nine (7%) are related to energy certificates and carbon credits. Fields with greater representativity are: 46 (36%) related to decentralized energy transactions, 26 (20%) to cryptocurrencies, and 16 (12%) to IoT and smart devices. Analysis by Andoni et al. (2019) and O'Donovan and O'Sullivan (2019) confirm the low presence of RECs blockchain-based application development in the energy sector.

Analyzing some of these applications, some authors are already able to identify the main groups and objectives of blockchain adoption. According to Abou Jaoude and Saade (2019), blockchain energy applications target four aspects: (a) controlling the inter-machine electricity market, with consumer choice of multiple suppliers; (b) facilitating energy transactions, with the creation of local markets; (c) increasing the security of energy grids; and (d) increasing the supply of low-carbon energy, as schemes such as RECs become more trustworthy.

Brilliantova and Thurner (2019) divide the blockchain energy applications into two groups: the technical ones, addressing the decentralization of power generation and grid management; and the economic ones, which deal with transaction and payment methods. The energy trade using blockchain-based applications, with increased traceability and transparency, facilitates P2P RE trading among suppliers and consumers (Pournader et al., 2020).

Silvestre et al. (2020) divide blockchain applications in the electrical power industry into two classes according to its main concern: electrical energy trading between two parties exchanging electricity against a unit of value (e.g., P2P energy trading), which can be efficiently managed by a grid operator or in a decentralized way; and demand response tracing and RECs, in which blockchain records the amount of RE added into the grid by one site or recognizes the contribution of a prosumer in an aggregation program or a demand response program.

The adoption of blockchain energy applications is not exactly dependent on technological limitations, but the development of the energy industry. Among the risks reported by the authors are: the cost of blockchain distribution; integration challenges between organizations in the energy supply chain; legal uncertainty due to lack of regulation; and manpower requirements (Brilliantova & Thurner, 2019). Regarding legal uncertainty, as the role of consumers could change from a largely passive market participant and subject to a protective legal approach to an actor at the heart of the market as a prosumer, this change demands the current actors' definitions (producers, transmission and distribution system operators, suppliers, and consumers) to be reconceptualized in the electricity law (Diestelmeier, 2020).

Blockchain applied to renewable energy certificates (RECs) schemes

In energy markets, it is impossible for consumers to distinguish between the consumption of RE and non-renewable energy. The energy production often occurs far from consumers and in the electricity grid the distributed energy mixes both sources, which may cause the problem of information asymmetry, leading consumers with low-carbon energy preferences to buy less or none RE. RECs, a market-based policy instrument, were introduced in energy markets to address this information asymmetry, enabling consumers (businesses or individuals) to make better decisions and encouraging the production of RE (Hulshof et al., 2019).

RECs schemes were used since 2001 in countries like Australia, Sweden, Italy, Germany, UK, and India to promote growth of RE under a supportive policy and regulatory regime (Narula, 2013). In the European Union (EU), the guarantee of origin (GO) is defined in the EU Directive 2018/2001/EC as "an electronic document which has the sole function of providing evidence to a final customer that a given share or quantity of energy was produced from renewable sources" (European Union [EU], 2018, online). Member states have been given a duty to develop a reliable GO certificate system in EU Directive 2001/77/EC. Systems may differ in architecture, but each member state has a GO issuing body in charge of implementing it. The Association of Issuing Bodies (AIB), created in 2002, is made up of 28 countries and developed the European Energy Certificate System (EECS), a voluntary scheme in accordance with the EU directive requirements. In 2019, 707 million certificates (707 TWh) were issued (https://www.aib-net.org/ retrieved on July 10, 2021). In the United States and Canada, RECs are supported by different levels of government, regional electricity transmission authorities, and non-governmental organizations, but the certification is completely entrusted to private organizations. Ten regional electronic REC tracking systems ensure that each REC is counted only once by assigning a unique serial number to each MWh of renewable electricity generation (Hulshof et al., 2019; National Renewable Energy Laboratory [NREL], 2015).

Besides the GO tracking system in Europe and the REC tracking system in North America, the International REC Standard (I-REC Standard) scheme has been used in 40 countries in Latin America, Asia, Africa, and the Middle East, including China, India, Russia, South Africa, and Brazil. The I-REC Standard Foundation, a non-profit organization headquartered in the Netherlands, provides the tracking standard to be used around the world. In 2020, 31 million certificates (31 TWh) were issued (International REC Standard Foundation, 2020).

In the private sector, RECs promote the acquisition of electricity produced from RES among companies willing to reduce GHG emissions through the electricity purchased, in addition to investments in energy conservation and energy-efficiency, which in inventories standards such as the GHG Protocol Program is considered as Scope 2 category emission (Chuang, Lien, Den, Iskandar, & Liao, 2018).

Especially when RECs are sold unbundled from electricity, buyers and sellers must ensure that certificates are not double-counted (Frenkil & Yaffe, 2012). Once the data recorded in the blockchain cannot be tampered privately, blockchain technology can improve the trade of RECs by increasing transparency and efficiency in this market ensuring that each unit of RE produced in the electric system can be traced back and is taken into account only once (Gacitua et al., 2018; Hou, Wang, & Luo, 2020; Imbault, Swiatek, Beaufort, & Plana, 2017; Khaqqi, Sikorski, Hadinoto, & Kraft, 2018; Spinnell & Zimberg, 2018).

Once the power system sector might involve several authorities (e.g., grid operators, aggregators, banks, certification entities for equipment providing data, data protection officers) that do not trust each other, the blockchain plays the important role to guarantee, under regulated or non-regulated market, that the system works properly, from the technical authorization for an RE transaction given by the grid operator to the transfer of financial assets of the parties, also keeping their identities safe (Silvestre et al., 2020).

Blockchain applications in RECs are incremental innovations from a regulatory point of view, since they can be introduced in the current legal framework or require minor adjustments. The response of energy and data regulators is adaptive: to award legal recognition of the blockchain as a legitimate source of information on which commercial transactions can be based, including certification schemes (Amenta, Sanseverino, & Stagnaro, 2021).

Castellanos, Coll-Mayor and Notholt (2017) performed a simulation of a RECs market based on cryptocurrencies. The authors conclude that the Ethereum blockchain lowers the operational costs of developing a market platform. Thus, prosumers and consumers can enter the market without a big investment. Code optimization can still lower transitional costs; however, the volatility of gas and ether prices imposes uncertainty.

Burer, Lapparent, Pallotta, Capezzali and Carpita (2019) list some organizations that work in this area: Volt Markets, which integrates energy origination, tracking, and a trading platform that sells both energy and RECs; Ideo CoLab, a solar-panel designer; and the sensor maker Filament.

Zhao, Guo, and Chan (2020) developed a blockchain-based RECs simulation combining theories of social norm and peer effects. They found out that the higher percentage of RE on the market, the more residents are willing to participate in trading RECs. The simulation of the I-Green also shows that improvements can be made on the consensus mechanisms, as the authors developed their proof-of-green protocol, which improved the market liquidity compared to traditional protocols like proof of work (PoW) and proof of stake (PoS).

Through this collection of cases in the literature, we can identify how the application areas of blockchain in sustainability are distributed, pointing out that the REC applications are still in an early stage of development (Andoni et al., 2019; O'Donovan & O'Sullivan, 2019). Others already incipient develop analytical divisions on the application areas (Abou Jaoude & Saade, 2019; Brilliantova & Thurner, 2019; Silvestre et al., 2020). In addition, a third group is studying the consequences of blockchain implementation in a defined context (Burer et al., 2019; Castellanos et al., 2017; Zhao et al., 2020).

METHOD

Due to the early stage of blockchain development and its applications in RECs, we have chosen to use DSR as a way to evaluate these solutions and produce knowledge about the challenges of their application context. DSR is a robust method to study artifacts as answers to classes of problems; consequently, their solutions are not just a punctual answer to a certain problem in a certain context (Lacerda, Dresch, Proença, & Antunes, 2013). Case study is a method suitable for studying real life situations as detailed situations, especially when there are complex issues and there is little prior theory or empirical evidence (Eisenhardt, 1989). Combined, these methods allow us to apprehend the complexity of the context in which the problem is built and the characteristics of the artifacts built as a solution for a given class of problem.

DSR is a method that aims to propose and evaluate IT artifacts that address innovative ways to solve organizational problems (Hevner & Chatterjee, 2010). These artifacts can be defined as: constructs (vocabularies or symbols); models (abstractions or representations); methods (algorithms or practices); or 'instantiations' (systems and prototypes).

Hevner, March, Park and Ram (2004) formulate a list of seven guidelines to delimit the requirements of research using the design science research method. The first guideline is design as an artifact. The second guideline is the relevance of problems. The third guideline is evaluation design; metrics must demonstrate the utility, quality, and effectiveness of the artifact. The contribution to the area of knowledge is the fourth guideline. The fifth guideline is research rigor. The sixth guideline is design as a process. The last guideline is research communication, which is oriented to management audiences and technology. Other authors conceptualize different stages for the execution of DSR projects (Aken & Romme, 2009; Baskerville, Baiyere, Gergor, Hevner, & Rossi, 2018; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007; Santos, Koerich, & Alperstedt, 2018; Sein, Henfridsson, Purao, Rossi, & Lindgren, 2011). However, even with variations, authors who propose methods for DSR projects focus on defining a problem (a); building a solution (b); evaluating the solution (c); and formalizing the learning or artifact (d).

Several authors are exploring the use of DSR to analyze the relationship between technology and sustainability (Albizri, 2020; Almeida, Borsato, & Ugaya, 2017; Baldassarre et al., 2020; Diniz et al., 2021; Eidelwein, Collatto, Rodrigues, Lacerda, & Piran, 2018; França, Amato, Gonçalves, & Almeida, 2020; Stiel, Michel, & Teuteberg, 2016). Even beginning to be widely used in solution development, especially in the field of sustainability, the theoretical development of DSR was built from the artifact perspective and evaluation, in contrast with the delimitation of the problem that the artifact is trying to solve. Finally, other authors are already applying DSR in studies beyond the field of technology (Bianchi & Ferraz, 2020; Debastiani, Alperstedt, Santos, & Koerich, 2020; Gaspareto & Henriqson, 2020).

Maedche, Gregor, Morana and Feine (2019) found three types of problem formulation in design science based on Kuechler and Vaisnhavi (2012), Peffers, Tuunanen, Rothenberger and Chatterjee (2007), and Sein, Henfridsson, Purao, Rossi and Lindgren (2011). Based on this analysis, Maedche et al. (2019) developed a conceptualization of the main aspects of the problem space in DSR projects, which was not precisely developed in the literature, especially if compared with the artifact analysis. This conceptualization breaks down the problem space into four components: needs, goals, requirements, and stakeholders. The need refers to what is desired by the project in a larger perspective than the resolution of the problem, indicating opportunities that have not yet been delimited as a problem. The goals represent the results or states desired by the project, describing the intentions of the stakeholders. Goals can be conflicting and are more specific in purpose and more abstract than objectives. Requirements refer to technical specificities of software engineering, such as user and system capability, and documented stakeholder needs and goals. Finally, stakeholders would be people or organizations that are directly involved in the project or that are affected positively or negatively by it.

Thus, Maedche et al. (2019) proposed a conceptual model relating problem space and solution space. In problem space, the needs inform the goals needed for the project, which must be satisfied by the requirements; these constructs are communicated among themselves by the stakeholders of the project. From this problem construction, the artifact is proposed. The model organizes and structures the process of analysis and description of the problem, in contrast to literature that presents variant terminology. The author proposes that the model can be extended by sub-concepts or new concepts can be introduced.

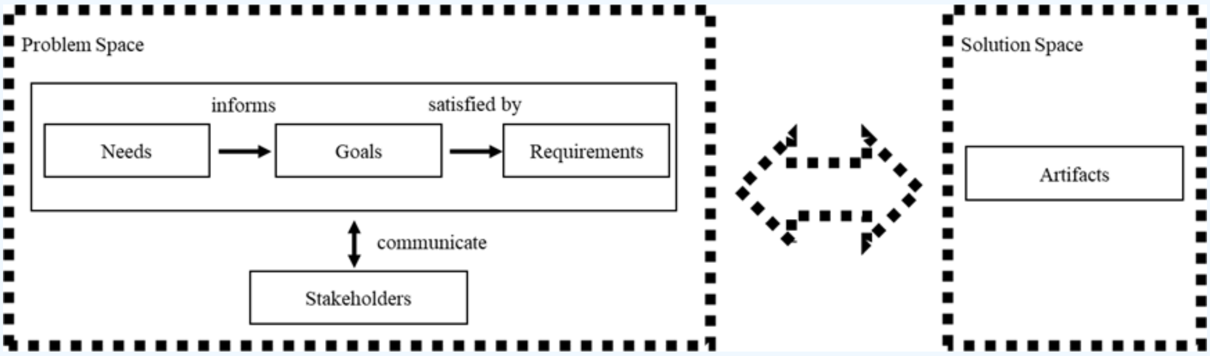

Figure 1. Problem space model based on Maedche et al. (2019).

In this study, we use the framework proposed by Maedche et al. (2019) to relate each artifact (solution space) to the problem space, conceptualizing the organizational needs, goals, requirements, and stakeholders. Through semi-structured interviews, we identified how organizations understand the constructs related to their application of blockchain. This effort highlights the kernel knowledge boundaries that provide understanding of the problem and the organizational context (Hevner, Brocke, & Maedche, 2019). We expect to contribute on how the market position can influence the understanding of blockchain in the RE system, so we selected two organizations with different market positions and backgrounds to explore similarities and differences, relying on theoretical sampling (Eisenhardt & Graebner, 2007).

All company and product names have been anonymized. ALL is the biggest certificate issuer in Brazil, not only in environmental topics. The organization is the local issuer of I-REC, regarding RECs, and implemented a blockchain-based system in 2019. BC-Company is an organization created by the environmental investment group Credit-C, which started in April of 2019 its operations on RECs through blockchain.

Regarding data collection, as a first step we used reports and semi-structured interviews with researchers to understand the Brazilian RE ecosystem. In this process, we decided to collect data from additional organizations that are part of the ecosystem, ABC, Trading, and EnergyS, allowing us to better apprehend the problem space (Maedche et al., 2019) and to triangulate with ALL and BC case studies (Patton, 1999). ABC's core business is the generation and commercialization of energy through large assets enabling the corporation to provide affordable, sustainable energy. In Brazil, it had the concession in the south region and in São Paulo City. Recently, ABC (the Brazilian branch) sold both to resume its original goal toward generation and commercialization of energy. Not long ago, ABC wanted to improve the I-REC system with blockchain technology. EnergyS is a RE generator in Brazil with São Simão Hydroelectric Power Plant, Vale dos Ventos Wind Complex, Millennium Wind Farm. They have an opinion against RE certification. Trading assists businesses to enter the free energy market; and recently, they implemented a blockchain system for bilateral short-term contracts in energy purchase. To enrich our understanding of this phenomena and bring perspectives from other players (Patton, 1999), the interviewees were chosen for their knowledge and interests on the topic of RECs, for their direct participation in the process of defining the problem/solution of the blockchain-based artifact for the generation of RECs, or for their technical knowledge in the creation or implementation of such an artifact, which increases the credibility of the study (Lincoln & Guba, 1985). Actors from different organizations and hierarchical levels are unlikely to engage in converging retrospective views on context (Eisenhardt & Graebner, 2007). Data was collected from semi-structured interviews conducted with 12 professionals (Appendix A) among managers, directors, and founders of the organizations.

Regarding data analysis, to be able to capture an appropriate understanding and description of the underlying problem space in the creation of ALL's and BlockC's artifacts, we decided to focus on the needs, goals, requirements, and stakeholders that define it, following Maedche et al.'s (2019) framework, through within-case and cross-case analysis (Eisenhardt & Graebner, 2007), allowing the transferability of the results for other contexts (Lincoln & Guba, 1985). We, therefore, reach our research objective by identifying how different positioned organizations understand their problems and propose their technological artifacts applications on RECs (Table 5), which grants dependability to this study, and shows that the results can be replicable (Lincoln & Guba, 1985).

After that, we triangulate data with Trading, EnergyS, and ABC to discuss the implications to the blockchain application literature and DSR theory, to grant the study's confirmability (Lincoln & Guba, 1985). Finally, we discuss how the energy market will change in future years with new technological applications.

RESULTS AND DISCUSSION

In this section, we provide a clear description on the case analysis through the Maedche et al.'s (2019) framework, with illustrative quotes. Tables 3, 4, and 5 represent our conclusions about the model concepts in the cases analyzed.

Case 1: ALL

ALL was founded in 2003 as an accreditation company on quality accounting and work safety. In 2013, it launched a REC created at the request of the Brazilian Clean Energy Generation Association (Portuguese acronym ABRAGEL) and the Brazilian Wind Energy Association (Portuguese acronym ABEEólica), which were looking for an instrument that could highlight both social and environmental attributes of the RE generated in Brazil. Once the certificate had international quality, in 2016, ALL was accredited as a local issuer of RECs in Brazil by the I-REC Standard.

During the first two years as an I-REC issuer, ALL issued a low volume of certificates, which allowed a simplified control and a manual issuance procedure. However, in 2019, with an increase in the volume of certificates issued, from 100 thousand to millions, the organization started to have problems in its traditional way of working. The increase in workload was felt, since auditing work is a time-consuming task and highly dependent on human analysis resources. Those internal workload issues became how ALL framed its needs (Maedche et al., 2019). Other kinds of certifications do not prioritize IT investments in ALL's perspective, as they require a low work volume.

Due to the founders' interest in new technologies and the market's confidence in blockchain, the system was created in a way that could be compatible with it. There were other requirements (Maedche et al., 2019) for the implementation of the blockchain, mainly investments in technology and human resources. Currently, an internal IT team manages the platform. Each condition needed to be fulfilled in order to construct the system.

In December 2019, ALL put the new system (without blockchain) into operation with a good performance. It facilitated the issuance of RECs directly by authorized companies. In 2020, they could put the complete database on blockchain technology and the implementation was designed to add more security to the certification process, increasing the quality of the I-REC product. The blockchain technology could also provide a greater traceability on the I-REC and ensure that there is no double beneficiary on the certificates. ALL intended to consolidate itself as a reference in the market.

> "For the companies that acquire the [blockchain-based] certificates, the advantage is that they have one more security layer, although this was never a requirement; because, when a consumer presents a RECs statement with the ALL logo, as we have a whole governance process, we are audited, thus, we have a whole control here, this was never questioned, that's why I'm realizing that it is one more security layer. It's not because it was unsafe, but it became safer, so that's the advantage." ALL interviewee A.

Comparing these goals (Maedche et al., 2019) with the reported needs of the company, we notice a disconnection in how these two factors are explained. While the needs are described as internal inefficiencies in the company, its objectives are described as additions to its final product, thought mainly from the customer's perspective. In an artifact perspective, those blockchain qualities of transparency and traceability do not demonstrate the artifact utility for solving the workload problem as indicated by Hevner and Chatterjee (2010).

In 2020, ALL has 95% of the RE generated in Brazil registered on its blockchain, for that it uses data from the Electric Energy Trading Chamber (Portuguese acronym CCEE) and from distributed electricity generators. According to an interviewee of ALL:

> "This is important because to issue a certificate you must have the evidence that the electric RE was generated. In order to comply with international standards, we asked that this evidence be evaluated, checked, verified by an independent third party. Invariably this information sent by clients came from CCEE, through reports sent by companies from which the manual issue of RECs would be made." ALL interviewee B.

The CCEE is a private entity, established by law. It is a private association with several functions; one of them is to take stock of energy contracts. To sell or to buy energy on the free market it is required to have a user, an associate of CCEE. Thus, the shared data contains both information about the energy sold and its seller and information about the energy bought and its buyer.

With the digitalization of RECs issuance process, ALL started to capture this generation information directly from the CCEE databases. Therefore, companies no longer have to send the evidence, once ALL already has this evidence captured directly from CCEE, and, consequently, all energy generation companies able to generate RECs have a checking account. Energy (in MWh) can be added by ALL to the company's checking account every month based on CCEE data.

However, the relationship with stakeholders (Maedche et al., 2019) could change due to the implementation of the blockchain. ALL intends to acquire some RE generation plants looking to become independent from CCEE data, reducing the one-month delay. The purpose is to have plants in which generation is connected by the internet to be able to use the internet of things (IoT) to feed the database directly. The CCEE and other regulators of the energy sector are being called to be validators on the blockchain platform. Thus, data providers would become data validators. The formation of these alliances is a process in which ALL communicates their product and vision for the market, further developing relationships.

Table 3

ALL — Synthesis of the problem space, based on the interviews

	ALL
Stakeholders	Industry regulators and other organizations participate in the platform. Search for other validators. Plan to use IoT so as not to depend on data from regulatory agencies. As it is already a third party, companies are more comfortable sharing the data. Market confidence on blockchain. Some organizations on other projects do not understand the meaning of the blockchain.
Needs	Growth in work volume. Time-consuming audit work. Chains with little data volume do not need blockchain.
Requirements	Resources for investment in technology and people. Companies need RECs to prove that they consume RE, reducing GHG emissions through the electricity purchased. IT team already manages the platform. IT system had already been built before without blockchain.
Goals	Consolidate itself as a reference in the market. Quality increase in the existence service, with: (i) one more layer of security, (ii) greater traceability, and (iii) no double beneficiary. IT system of REC.

In ALL's case, its objectives are related to the characteristics of its products, such as adding a security layer to the certification service, a new feature for the consumer. Moreover, the old work routines do not change after the implementation of the blockchain. Thus, the implemented technology is not a solution to ALL's needs, but the market consensus about the blockchain has a greater influence on the company's decision regarding implementation. ALL identifies that it is necessary to search for projects that understand (already existing) meanings of the blockchain.

Case 2: BC-Company

BC-Company belongs to a group of companies, all of them derived from Credit-C Brazilian Company, which develops projects related to the carbon market. Cofounder A, one of the Credit-C founding partners and owner of other companies in the group, works since 2000 in the RE sector through companies that have direct and indirect participation in businesses associated with the increase of RE supply and the reduction of GHG emissions. In 2017, considering that the investment in RE was something that was already widespread, Credit-C decided to experiment with the development of new technology-based business models through involvement with other stakeholders (Maedche et al., 2019). Credit-C hired a company focused on technology projects that identified the blockchain's potential to support companies toward more sustainable business models, including carbon markets. It resulted in a process of experimentation with the technology and two companies were created: XC2, a platform specialized in carbon credits, and BC-

Company, based on a system that allows companies to map their emissions throughout their entire value chains. The IT technical knowledge, business experimentation, and experience in the sustainability sector were the main requirements (Maedche et al., 2019) for the development of new companies.

Credit-C's greatest needs (Maedche et al., 2019) were related to its internal work process. In the view of the interviewees, the growth in labor productivity was linked to the work time of auditors, which made data verification activities costly and could demand a long time to be performed. In the business model of BC-Company, the blockchain will be used to ensure the validity and traceability of the emission mapping. This system would be fully automated and therefore would depend on as little audit labor as possible for data verification.

> "This sustainability advisory business has a capacity for growth, like any other consultancy. And the consultancy is a business that grows with man-hours. So, it was a business decision. These two friends talked like this: We won't be able to make a business explode, unless I'm willing to explode my labor force, because I only sell hours; so, I have to have hours to sell. Thus, they started to think about a new business model, and presented the blockchain technology, which they came to the conclusion that, if they are right, it will be the reason why this research started." BC-Company interviewee A.

However, the complete system, the company's objective (Maedche et al., 2019), is being built in stages. In addition, BC-Company prioritizes the mapping of specific production chains, in which there is an interest of the market for its traceability. Blockchain's technology, for giving traceability to transactions, was identified as a possible solution to BC-Company's needs (Maedche et al., 2019). Moreover, these blockchain-based by-products have a specific market meaning for each stakeholder. BC's role in this case would be to create this representation and, from it, to generate a process of convincing of its importance to the market.

> "The company has to design effectively what is the searched value by each of those involved in that representation, on that entity that is creating the blockchain. Being it [the representation] an informational registration or a possession right." BC-Company interviewee B.

One of these by-products is BC-REC, a blockchain-based REC that does not follow the I-REC Standard. To issue the certificates, BC-Company would certify the entire documentary process of the distributor, which delivers the energy. For that, data integration with other stakeholders, mainly with CCEE, is needed (Maedche et al., 2019). The system would search CCEE website for data on the energy production of generators to issue the certificate. In other words, when acquiring a certain amount of energy from a wind generator, for example, and, in turn, a customer-consumer bought, when acquiring an MWh certificate, it must be equal to or less than the amount that the generator sold to the distributor. With blockchain, this certificate can be inviolable, thus there is no possibility for the generator to sell the same energy certificate to two different people, that is, there is no double counting. Additionally, the marginal cost of each certification decreased expressively after the implementation of the system, due to the lack of audit work for the data verification.

BC-Company's founders believe there is a demand for initiatives capable of tracking companies "emission reductions, more specifically, tracking companies GHG emissions," as several companies have committed to make GHG emissions inventories. They see weaknesses in the mapping and traceability of GHG inventories. One of the partners explains: "As the main characteristic of blockchain technology is immutability/inviolability, for me it becomes extremely interesting for any use case linked to traceability. But, mainly, for those cases where the information is transmitted by means that you do not control and in which there is no established trust relationship. So, you use technology precisely to ensure that there is no possibility of the information being modified by one of the agents participating in the chain. And, consequently, it does not get lost or defrauded." However, obligations regarding GHG emissions inventories are necessary for more companies to embrace the use of RECs.

> "No, I don't think so, because I think that while there is no compliance program, some legal requirement, companies will always do very little. It is very complicated for companies to spend money without showing, in an unequivocal way, the results of this money invested." BC-Company interviewee C.

Table 4

BC-Company — Synthesis of the problem space, based on the interviews

	BC
Stakeholders	Recognition of the company in the sustainability market.
	Negotiations depend on the market network.
	Search for IT knowledge in other organizations.
	Mandatory GHG emissions inventories are necessary for more companies to embrace the use of RECs.
	There is a process of convincing about the importance of technology.
	Blockchain can assure the reliability of data that the organization does not control or trust.
	Data by regulatory agencies is used.
	Blockchain can offer an alternative to the I-REC certification standard in the Brazilian context, with its large RES matrix. The technology must have a business meaning that varies according to the stakeholder; the company must design that representation.
Needs	Labor productivity growth.
	Better data integration between platforms.
	Time consuming and high cost of audit work.
	Versatility of technology to track different chains.
	Fragility in mapping and tracking these inventories.
Requirements	Technical IT knowledge.
	Experience in the sustainability sector.
	Market influence for prospecting clients.
	Need for experimentation and testing with the technology before release.
Goals	Mapping the emissions throughout the value chain.
	Specific by-products, such as RECs.
	Greater speed, reliability, and lower cost of the company's value proposal.
	REC with ballast in public information for greater credibility.

In BC-Company's case, the blockchain is intrinsically connected to explore possibilities of internal work organization, since the company has a limitation in the labor force. Within these possibilities, the company tries to create blockchain-based products, exploring the versatility of the technology. However, for this to occur there is the requirement of specialized IT knowledge that is shared by external organizations.

Other organizations researched

In this section, we present the solutions of the supplementary interviewed companies. From them, in the following section, we triangulate this information with the vertical analysis of ALL and BC-Company, with the purpose of reflecting on the DSR model used.

ABC also had a market leader behavior regarding the creation of new products. The organization understood that there was market demand for RECs, so much so that it decided to certify its own plant for the generation of I-RECs not depending on ALL as an I-REC issuer anymore. However, likewise, from a technological reading of the market, they want to improve this specific process of generating RECs by using blockchain technology to guarantee the reliability of the source and reduce the time it takes to authenticate and generate the certificate, by not needing to review the entire chain. However, they chose to not create a new certificate, but improve the I-REC certification. They identify, therefore, two products already understood by the market, the I-RECs and the blockchain technology, and try to mix them.

> "Our option to continue with the I-REC certification, specifically, is because it is already established, it is already a recognized certificate and we did not want to create a market, or a proposal to renew the market, as a first step. We are taking this first step to optimize the process of generating I-RECs, specifically, because it is already a recognized certificate in the country." ABC interviewee A.

However, there are risks in creating new products based only on the reputation of their attributes. The employees interviewed at EnergyS, for example, were critical about RECs. They understood that RE trading contracts would already prove the origin of the energy. In addition, they considered that a large part of Brazilian energy would already be renewable due to the high participation of hydroelectric plants. These reasons would make customers not so interested in the certificates. New solutions in the sustainability market, therefore, would be imported from other countries, without considering if they would make sense in the Brazilian context.

Trading also does not see a demand in the area of RECs. Following the logic that energy purchase transactions would already prove the RES, the company carried out a project to implement the blockchain in bilateral short-term contracts. However, regarding the certificates, the company states that the implementation of blockchain means an evolution of the already existing certification method. Nevertheless, Trading had to create a separate company to develop these new technology projects, TEC-Trading, with specialized knowledge.

Cross-case analysis

The application of the framework (Maedche et al., 2019) in the case of ALL and BC-Company, combined with the analysis of other organizations, gave us data to identify the limits of the concepts and the relationship between them in theory. We present an analysis model triangulated for the organizations and, from this analysis, a reading of how the cases in depth can contribute to the theory of DSR.

Table 5

Cross-case analysis — Synthesis of the problem space, based on the interviews

	Cross-case Analysis
Stakeholders	Market leader (ALL, ABC, Trading) wants to identify a blockchain product that is already understood by other market stakeholders. Market challenger (BC-Company) wants to create a new representation of blockchain technology to offer to stakeholders.
Needs	Audit tasks are costly and time-consuming and the market challenger (BC-Company) wants to achieve a competitive advantage through blockchain. The market leader (ALL) wants the coexistence of old and new practices.
Requirements	Human and technological knowledge are necessary for the development of blockchain applications (BC-Company, ALL, Trading). However, the market challenger (BC-Company) must experiment with new business models to ensure the creation of new representations of blockchain for the market.
Goals	The market leader (ALL, Trading, ABC) wants to add a security layer to an existing service. Market challenger (BC-Company) wants to create new services around the blockchain.

First, the companies in the study cannot clearly separate their needs and objectives from the needs and objectives of their clients. In ALL's case, they argue about the low productivity of internal manual audit work; and, as Spinnell and Zimberg (2018) state, blockchain can make the recording of RE more cost-efficient. However, when they think about their objectives, they emphasize the usefulness of the artifact for their client, that is, the characteristics of traceability and transparency of the blockchain, aspects already identified by the literature (Gacitua et al., 2018; Khaqqi et al., 2018; Pournader et al., 2020; Silvestre et al., 2020; Spinnell & Zimberg, 2018). This shows that there could be a theoretical separation of the needs and objectives of each stakeholder for understanding the problem space (Maedche et al., 2019). Most other models do not have this conceptual separation (Hevner & Chatterjee, 2010; Kuechler & Vaishnavi, 2012; Peffers et al., 2007).

Second, stakeholders not only have a role in communicating the needs, requirements, and objectives of companies, but depending on market positioning, each organization can follow a distinct path in developing blockchain solutions. Some authors point out that the adoption of blockchain technology is dependable on the market and regulatory development (Brilliantova & Thurner, 2019; Burer et al., 2019). Furthermore, we contribute to the literature of blockchain applications on RECs on how the regulatory context and the market positioning of the organization influence the blockchain implementation. In this study, we identify that leading organizations expect a consensus from stakeholders regarding new technologies and then implement them; this was the case in ALL, Trading, and ABC. However, other organizations, seeing these perspectives of other stakeholders, decide not to implement this technology consensus, as in the case of EnergyS, while the challenging one, BC-Company, produced through trial and error new possibilities of representing technology to convince stakeholders of its utility. There is, therefore, a direct link between the artifact and the stakeholder, which is not present in the model of Maedche et al. (2019).

This trial and error process, which was not present in Meadche et al. (2011), can be found in Sein et al. (2011), at the principle of reciprocal shaping. Thus, the IT artifact implemented and the organizational context would be inseparable. The application design, for example, can change the business environment understanding and vice versa. Even so, the different representations of technology for stakeholders are not present in the model of Sein et al. (2011).

Finally, leading companies, after waiting for stakeholder consensus on the new technology panacea, can implement technologies without a clear sense of what needs they are having. This consensus is subsequent to the increase in RE produced (Empresa de Pesquisa Energética [EPE], 2019), and the consequent market development and entry of new players into the market (Zhao et al., 2020). This may be one of the causes of the disconnection between needs and objectives already reported by ALL and ABC. However, in the model (Maedche et al., 2019), the path to understanding the problem is only taken from the needs to the objectives, which presents a limitation in contexts where there is an euphoria for the use of new technologies without a clear justification.

In Kuechler and Vaishnavi (2012), we can make a parallel with the awareness of the problem and the development of the artifact; with needs and goals (Maedche et al., 2019). In this science design model (Kuechler & Vaishnavi, 2012), reasoning is viewed in DSR as a cycle. Thus, suggestions and the development of the artifact can indicate new forms of awareness of the problem, with the cycle continuing its steps later. Even so, we still cannot identify the process of creating meaning, in which the consensus of the adoption of new technology finds a justification in the organization, as a solution in search of a problem, but without a subsequent reflection or change in the design of the solution. Other models only express a one-way rationalization direction between problem identification and solution objectives (Aken & Romme, 2009; Peffers et al., 2007) and others present no clear way of rationalization between them (Hevner & Chatterjee, 2010).

In case studies via DSR, either in the sustainability field (França et al., 2020; Stiel et al., 2016) or in other areas (Bianchi & Ferraz, 2020; Debastiani et al., 2020; Gaspareto & Henriqson, 2020), there is a clear rationalization between the problem to be solved and the solution proposed or analyzed, always in a direction in which the problem induces the solution. However, in the case analyzed the ways in which organizations justify the implementation of their solutions and the resolution of their problems are built in a different way: organizations, whether leaders or challengers, choose the blockchain as a panacea and apply it to the resolution of several problems by trial and error in an attempt to justify the resolution of problems that are not actually solved, such as the traditional forms of auditing that remain without internal changes, that are intrinsic and dependent on the policy and regulatory context (Burer et al., 2019). It is speculated how DSR theories can be compatible in these environments with disconnection between the needs and objectives of companies, which resemble behaviors understood in the garbage can model (Cohen, March, & Olsen, 1972).

As for practical implications in public policy, this behavior is mirrored in the multiple streams model (Kingdon, 2011); in this case, blockchain policy entrepreneurs can influence its implementation in areas without reflection, which occurs in the problem stream. Therefore, it is also important to analyze the stakeholders' interpretation of the technology, which is not present in the reviewed DSR models.

CONCLUSION AND FUTURE STUDIES

The objective of this study was to identify how different positioned organizations understand their problems and propose their blockchain technological artifacts in the RECs market. Using a case study methodology and design science research (DSR), we analyzed the problem space (Maedche et al., 2019) of two different organizations that propose blockchain-based applications to produce and trade RECs. We confirmed that blockchain can make the recording of RE more cost-efficient (Spinnell & Zimberg, 2018). In addition, entrepreneurs emphasize the characteristics of traceability and transparency of the blockchain (Gacitua et al., 2018; Khaqqi et al., 2018; Pournader et al., 2020; Silvestre et al., 2020; Spinnell & Zimberg, 2018).

We also contribute to the literature of blockchain applications on RECs by identifying ways in which the organization's market context influences blockchain adoption and development. We found that depending on the market positioning of the organization, its behavior regarding the development of the blockchain solution will be different. While leading organizations expect market consensus on technology adoption, challenger organizations use experimentation processes to create new technological products, which involves creating technology representations for different stakeholders. In addition, organizations implement the technology without a clear notion of the problem to be solved, which may lead to failures in business models and coexistence of analog and technological processes. These findings can guide entrepreneurs in the process of thinking through their business model and its relationship to technology development.

We contribute to the literature of DSR by providing an in-depth description of the cases based on the model (Maedche et al., 2019) and we point out inconsistencies that can be explored in future studies to improve the theory. More specifically, we found that: (a) the position of the organization in relation to other stakeholders changes the behavior of the technology adoption: leaders and challengers have different behaviors; (b) the technological solution preceded the perception of the problem, as leading companies, after waiting for stakeholder consensus on the new technology panacea, can implement technologies without a clear sense of what needs they are having; (c) organizations create different representations of the artifact for each stakeholder to persuade them of its efficacy.

We suggest other studies to deepen these findings in order to develop theories that explain how organizations see their problem when developing technological solutions while using DSR. Not only due to the use of the case study methodology, but also due to the specific regulatory and economic context, this research has limited potential for generalization. Nevertheless, studies from other developing countries or investigations on other technologies in Brazil could find similarities.

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2nd author: conceptualization (equal), formal analysis (supporting), investigation (equal), methodology (equal), resources (equal), validation (equal), writing-original draft (supporting), writing-review & editing (equal).

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APPENDIX A

Table A1

Interviews and interviewees

Interviewee		Interview		
Institution	Position	Date	Format	Duration
ALL	Founder and director	March 06, 2020	Online video call	27 min
ALL	Administrative analyst	September 23, 2020	Online video call	20 min
BC-Company	Co-founder and COO	December 21, 2019	Online video call	31 min
BC-Company	Co-founder	December 3, 2019	Online video call	23 min
BC's technology advisory	Software services director	December 4, 2019	Online video call	43 min
EnergyS	Trading director Business development and M&A specialist	July 21, 2020	Online video call	45 min
ABC	R&D and innovation coordinator Senior R&D and innovation analyst	July 30, 2020	Online video call	32 min
Trading	Relationship manager[1]	July 27, 2020	Online video call	22 min
Trading	IT infrastructure manager	September 25, 2020	Online video call	16 min

Note. [1] Information was not provided, but interviewees belong to the same department as the relationship manager.