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Greening inventories: Blockchain to improve the GHG Protocol Program in scope 2

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ABSTRACT

The complexity of the supply chain, with a multiplicity of suppliers and organizations imposes challenges to its traceability, affecting the possibility of making it more sustainable. The declaration of Greenhouse Gas (GHG) by companies has been a response to pressures from stakeholders and regulations towards a sustainable supply chain management (SSCM). However, there are still some setbacks. The verification process of the inventories is a time-consuming task and the utilization of traditional renewable energy certificates can cause distortions in the perception of those who are consuming renewable energy but are not buying certificates. A blockchain-based application could address those problems by tracking transparent records of product history. Therefore, we propose a blockchain-based artifact in the form of a level 1 architecture diagram to improve the Brazil GHG Protocol Program inventory process on scope 2, which includes indirect carbon emissions from consumption of purchased electricity, heat or steam; main supply chain components. Using the Design Science Research (DSR) approach, we combine knowledge from business participants and environmental experts to understand the Program problems, propose and evaluate the artifact, and analyze its contributions. We find out that not all actors may want greater transparency in the supply chain and that traditional certificate issuers are expected to resist, while a new generation of blockchain-based certificates challenges the more traditional competitors. Additionally, the economic benefits observed in implementing blockchain points out that the organization and resistance of the actors, therefore, could be as important as costs in the implementation of new technologies in supply chains. There are two main contributions from this study. First, it introduces the discussion on blockchain adoption in the GHG Protocol Program. Second, it uses DSR as an instrument to both articulate a solution around a theoretical artifact and make its potential contribution understandable for actors not familiar with blockchain technologies. We propose that future studies could: (i) produce a proof-of-concept or a pilot implementation of this artifact; (ii) include other actors from the energy and trading certificates chain on the artifact, such as energy producers, regulators and the Brazilian Electricity Trading Chamber (CCEE); (iii) reproduce the same proposition focusing on GHG Protocol's scope 3.

1. Introduction

The use of blockchain in applications that contribute to the sustainable development goals promoted by the United Nations has been a topic of increasing relevance. The secretariat of the Convention on Climate Change (UNFCCC, United Nations Framework Convention on Climate Change), sees an opportunity to employ blockchain technologies to control the concentration of greenhouse gases (GHG) in the atmosphere since these technologies can improve the tracking and production of inventories of greenhouse gas emissions, providing more transparency and preventing double-counting of these emissions.

The most highly regarded guidance for greenhouse gas assessments is the GHG Protocol (Downie and Stubbs, 2013) that uses a methodology developed by two global organizations, the World Resources Institute (WRI) and the World Business Council for

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Sustainable Development (WBCSD). The Brazilian version is run by the Center for Sustainability Studies of the Getulio Vargas Foundation (GVces), since 2008.

The Brazil GHG Protocol Program considers reporting GHG emissions using certificates of renewable energy as an efficient way to promote renewable energy use in the country. Since it is very difficult to guarantee that an energy seller will deliver the exact percentage of contracted renewable energy, there is always the possibility of a certificate not being faithful to the real level of emissions. We consider that blockchain can provide a solution to this problem by creating a validation system between buyers and sellers in the complex market of buying and selling certificates.

There are already several proposals for blockchain-based solutions for the energy sector: Castellanos et al. (2017) perform a simulation of a RECs market based on cryptocurrencies. Tanaka et al. (2017) developed a blockchain-based system for individual energy transactions. Mannaro et al. (2017) introduce Crypto-Trading, which aims to create a decentralized energy market, allowing the producer/consumer (prosumer) to manage their energy and trade their surplus. Imbault et al. (2017) explore the use of blockchain implemented on an industrial operating system for the use of RECs in an eco-industrial district. Andoni et al. (2019) indicate that blockchain can bring benefits to energy system operations, markets, and consumers (some of them turned into prosumers), allowing disintermediation, increased transparency, and empowering consumers and small (renewable) energy producers. These cases of blockchain expand the repertoires of possible solutions and applications in the energy sector.

However, there is a knowledge gap in the Brazilian market about the real potential of blockchain to improve the production of GHG inventories in the country. This can be a barrier to consolidate a solution demanding articulation among many different stakeholders in the renewable energy value chain. This study intends to fill this gap and to contribute to the dissemination of knowledge on opportunities to use blockchain in the production of GHG inventories by posing the following research question: *"how blockchain related technologies can be used to improve the production of GHG inventories?"*

By adopting the DSR, an approach that produces special classes of theories by defining the purpose and scope of a digital innovation project, this study analyzes the potential of a conceptual blockchain artifact, articulates a solution around a theoretical artifact and evaluate its potential contribution by making it understandable for actors not familiar with blockchain technologies. We use the Design Science Research (DSR) approach following a four-step method starting with (1) defining the problem; then (2) proposing the artifact; followed by (3) evaluating the artifact and, finally, discussing (4) the contribution of the artifact to solving the problems identified. We applied the DSR method to contribute to a theory that describes the purpose and range of a digital innovation in the accounting process of scope 2 emissions in the GHG Protocol, which represents reports of emissions related to the acquisition of electricity from third parties either measured directly or based on buying renewable energy certificates (RECs).

Thus, besides creating a theory focused in the design of a solution, we allow actors in the renewable energy market to learn, discuss and evaluate a theoretical blockchain artifact and consider it for a future implementation. By adopting the DSR, an approach that produces special classes of theories by defining the purpose and scope of a digital innovation project, we articulate a solution around a theoretical artifact and evaluate its potential contribution by making it understandable for actors not familiar with blockchain technologies. Thus, besides creating a theory focused in the design of a solution, we allow actors in the renewable energy market to evaluate it and consider it for a future implementation.

The data collected in this study come from on documents and reports from the Brazilian GHG Protocol Program, interviews with three program managers; with employees from six companies that reported or tried to report Scope 2 in their inventories; with two companies that issue RECs; and with experts in blockchain applications. We also participated in meetings organized by the GHG Protocol Program. By analyzing this data, it was possible to gain an in-depth understanding of the information gathering processes for the inventory, the challenges of consolidating this inventory and proposing a conceptual solution to stimulate the implementation of blockchain technologies in the GHG Protocol.

Next, we present a literature review connecting sustainable supply chain management (SSCM), blockchain applications in the energy sector and the renewable energy market. Then we present the Blockchain Protocol and its Brazilian chapter. The following topics present the DSR approach and the research methods used in this study. The results section describes the proposed conceptual blockchain artifact followed by a discussion section that articulates the results of this study with the literature of the renewable energy field, and finally, the conclusion.

2. Literature review

Blockchain is a shared, decentralized and distributed data structure that can capture and store in a digital record, a consistent, immutable and linear event log of transactions between all the actors involved in a network, without a central authority, combining the more efficient information security methods through several cryptographic protocols and information recording in a distributed database. Blockchain uses consensus mechanism to maintain data consistency in this distributed network (Risius and Spohrer, 2017; Zheng et al., 2017; Andoni et al., 2019).

Table 1 summarizes five benefits of blockchain to accelerate our progress towards meeting the Sustainable Development Goals, according to United Nations Development Programme (UNDP). According to it, blockchain brings new levels of efficiency and effectiveness to areas like renewable energy and supply chain management, and helping actors as governments, companies and civil society to establish trust and promote the distribution of resources (Wigley and Cary, 2017).

Blockchain 'functionally similar to a distributed ledger that is consensually kept, updated, and validated by the parties involved in all the transactions within a network' (Risius and Spohrer, 2017). There are three types of blockchain systems: public, private and permissioned. In the public blockchain, consensus determination is carried out by all miners, the reading of transactions is public, data tampering is practically impossible, computational efficiency is low, the blockchain is not centralized and the consensus process is unrestricted (permissionless). In the premissioned and private blockchain the read permission can be public or restricted, there is a possibility of data tampering, the computational efficiency is high and the consensus process requires permission (permissioned). However, there are distinctions between these two types. While in the permissioned blockchain the determination of consensus is given to a selected set of nodes and the centralization is partial; in the private blockchain, only one organization determines consensus and centralization occurs (Zheng et al., 2017).

Next, we discuss the roles blockchain can play in SSCM and, particularly, the energy supply chain and its use to track GHG emissions through supply chains and help companies in their energy buying decisions applied to the renewable energy supply

Table 1
Blockchain benefits.

Blockchain benefit	Description
Immutability	It is not possible to change past transactions since multiple copies of a blockchain are kept across a peer-to-peer (P2P) network.
Security	The cryptographed storage guarantees security due to the fact that what is relatively easy for a network of computers to do (e.g, a cryptographic protocol), in practice, is impossible to undo.
Resilience	Not relying in a single point of storage eases recovering and even if many peers are not available, the information remains accessible.
Transparency	All transactions are available to peers, so these agents can assure the origin and destiny, and its encrypted nature assures privacy.
Verifiability	The combination of transparency and immutability allows full public verifiability: anyone not involved in a transaction can check the integrity of the system.

Source: Wigley and Cary (2017).

chain. We also analyze examples of blockchain applications in the RECs markets.

2.1. Blockchain and SSCM

Companies have faced increasing pressure from stakeholders and regulations to turn their business models towards sustainable development (Engert and Baumgartner, 2016). While the private sector incorporates the sustainability concept, it is also extends beyond organizational boundaries and must consider the entire lifecycle of the product (Seuring and Gold, 2013).

Since supply chains are affected by multiple regulatory policies, different cultural, and human behavior, it is difficult to evaluate information and to manage risks in such supply chains, resulting in a trust shortage and a need for better information and verifiability throughout these networks made even more complex once environmental and social aspect tracking is required (Saberi et al., 2019).

Seuring and Müller (2008, p.1700) define SSCM as 'the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social. These three dimensions derive from customer and stakeholder requirements' and indicate that standards (both environmental and social) are widely used in SSCM to leverage sustainability practices.

Carter and Rogers (2008) consider transparency as one supporting facet of the TBL approach in SSCM, and this concept includes actively engaging and reporting to stakeholders, continuously using their input and feedback to make the supply chain more sustainable. Transparency is another feature possible to improve with the adoption of blockchain in supply chains.

A blockchain-based supply chain can track potential social and environmental conditions through transparent records of product history, assuring that green products are environmentally friendly or that ethically sourced products respect human rights and fair work practices, which increases buyer confidence in these goods. Blockchain incorporation in supply chains can also help decrease resource consumption and reduce GHG emissions. Additionally, blockchain has transformative potential for supply chains once allowing the automated execution of smart contracts, a computerized transaction protocol based on terms of a contract, in P2P networks. Smart contracts, for example, might be designed to be capable of tracking rules and controlling sustainable terms, also enforcing or governing corrections (Zheng et al., 2017; Saberi et al., 2019), thus contributing to optimize complex iterations among several stakeholders (Leng et al., 2019a).

Kshetri (2018) conducted research based on multiple case studies of blockchain projects, considering supply chain management (SCM) key objectives as cost, lead-time, quality, dependability, risk reduction, sustainability and flexibility. In cases of food supply chains (coffee, cocoa, fish and seafood), blockchain applications resulted in increased transparency and made sustainability more quantifiable and meaningful to end consumers through validation of the identities of supply chain members, the detection, measurement, and tracking of key SCM processes, allowing environmental and social claims to be verified. Wang et al. (2019) indicate that blockchain technologies, although in their infancy, are increasingly relevant within SCM to allow organizations and individuals to make and verify transactions without the need for a central authority. This process is predominantly driven by trust - the reliability of the information provided by supply chain members prevents them from behaving unethically or opportunistically. In particular, the combination of carbon-based chemical signature, physical QR code and blockchain helps to prevent counterfeits in sustainable supply chains (Leng et al., 2019b).

Pournader et al. (2020) indicate that 'blockchains will be the core facilitating technology ensuring traceability and thus transparency in supply chains by tracking social and environmental conditions across supply chain tiers'. After a systematic review of the publications in blockchain and supply chain logistics, the authors found sustainability issues arising explicitly in traceability, transparency and trade and in studies concerning energy trade in utility supply networks using blockchain applications, strongly related to facilitating P2P green/renewable energy trading among supply chain tiers. Next, we examine aspects related to blockchain and energy.

2.2. Blockchain in the energy supply chain

A conventional electricity supply chain has the following actors, defined by European law, as well as their subsequent rights and responsibilities: producers, transmission and distribution system operators, suppliers and consumers. In this sector, when implementing blockchain technology, these actor definitions must consider potential changes in the role of consumers, turning from a largely passive market participant placed at the end of the supply chain and subject to a protective legal approach to an actor at the heart of the market (Diestelmeier, 2020). Non-energy sector focal companies willing to increase the sourcing of renewable energies through SSCM might also benefit from this new arrangement by reducing GHG emissions in their supply chains.

Andoni et al. (2019) indicate eight categories of blockchain application for energy, among them: metering, billing and security; decentralized energy trading; green certificates and carbon trading; grid management; IoT, smart devices, automation and asset management. The authors identified that most blockchain research projects and startups refer to decentralized energy trading (33%), which includes wholesale, retail and P2P energy trading initiatives. Green certificates and carbon trading account for only 7% of the projects.

There are already several proposals for blockchain-based solutions for the energy sector: Castellanos et al. (2017) perform a simulation of a renewable energy certificate (RECs) market based on cryptocurrencies. Tanaka et al. (2017) developed a blockchain-based system for individual energy transactions. Mannaro et al. (2017) introduce Crypto-Trading, which aims to create a decentralized energy market, allowing the producer/consumer (prosumer) to manage their energy and trade their surplus. Imbault et al. (2017) explore the use of blockchain implemented on an industrial operating system for the use of RECs in an eco-industrial district. Andoni et al. (2019) indicate that blockchain can bring benefits to energy system operations, markets, and consumers (some of them turned into prosumers), allowing disintermediation, increased transparency, and empowering consumers and small (renewable) energy producers. These cases of blockchain expand the repertoires of possible solutions and applications implemented in the energy sector.

Moreover, blockchain can help reduce GHG emissions by improving the emissions trading process, by providing trust, efficiency and transparency in the commercialization of emissions certificates encouraging participation in a sustainable supply chain for a long-term solution to reduce emissions (Khaqqi et al., 2018).

3. GHG protocol

The Kyoto Protocol in 1997 and its amendment in Doha in 2012 have been ratified by 192 parties of the United Nations Framework Convention on Climate Change (UNFCCC, 2015), requiring countries with binding targets under the Kyoto Protocol to report annually on their emissions (Green, 2010).

The Greenhouse Gas Protocol is a tool used by organizations to build greenhouse gas inventories. This is a methodology developed through the leadership of the World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) in collaboration with several of the largest corporations in the world and is the most highly regarded guide for greenhouse gas assessments (Downie and Stubbs, 2013). This methodology became a global standard for multinational corporations, governments and other institutions to assess their carbon footprint (Patchell, 2018).

The GHG Protocol essentially asks companies to assess their responsibility for GHG emissions distinguishing between three scopes (Fig. 1), representing different sources of corporate GHG emissions (Protocol, 2013):

Scope 1: all direct carbon, including fuels combusted and transport owned by the reporting entity;
Scope 2: indirect carbon emissions of purchased electricity, heat or steam consumed by the reporting entity;
Scope 3: other indirect carbon emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2, (Patchell, 2018).

Declarations in Scopes 2 and 3 (known as ‘indirect’ emissions) are the most complex to declare since they relate to the GHG emitted throughout the value chain of companies (Downie and Stubbs, 2013). For their complexity, Scopes 2 and 3 are constantly under revision to ensure consistency, transparency and accuracy. Scope 2, in particular, represents at least a third of global GHG emissions, since it comprises the largest sources of GHG emissions: generation of electricity and heat (Fong et al., 2015). According to Onat et al. (2014), emissions from direct purchases of electricity (Scope 2) represent 48% of the carbon footprint in U.S. buildings. Besides its quantitative relevance, Scope 2 presents difficulties providing accurate information in GHG reports (Brander et al., 2018).

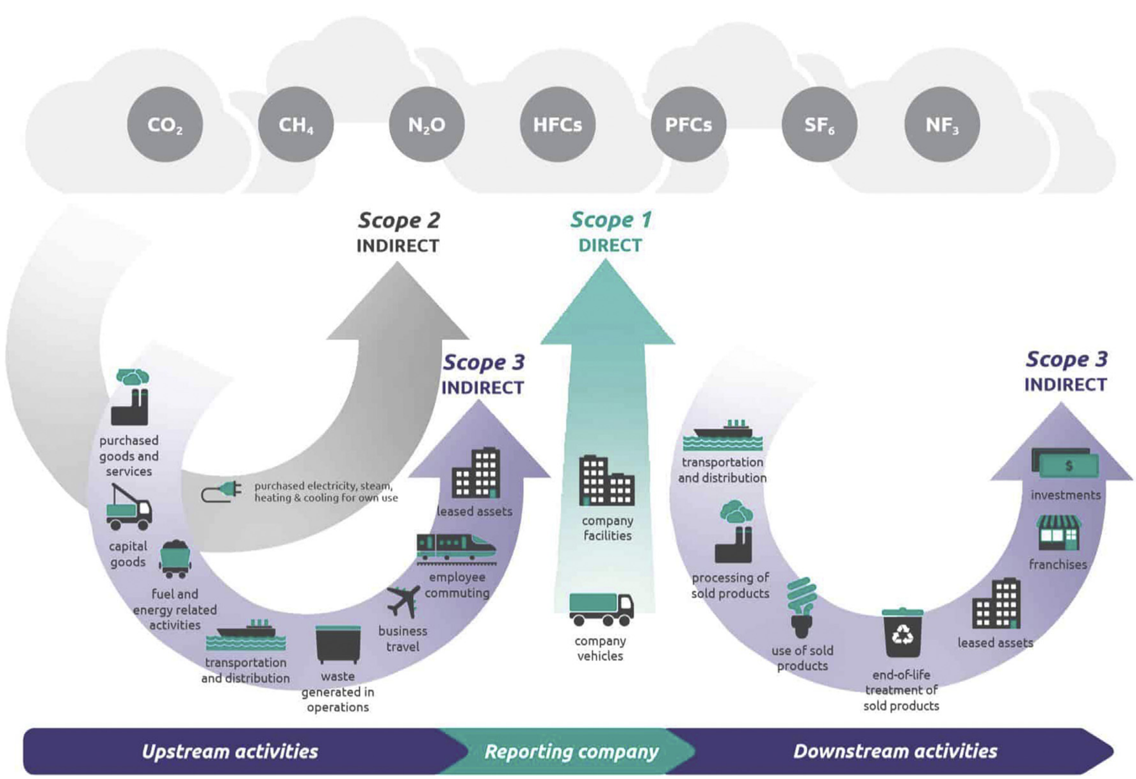

Fig. 1. The GHG protocol Scopes 1, 2 and 3
Source: Protocol (2013).

Gathering data on GHG emissions related to scopes 2 and 3 demands energy supplier engagement and cooperation among members of the supply chain and focal companies. Considering that the reduction of GHG emissions of the overall supply chain is a key objective, companies must continuously give feedback to the chain stakeholders in order to make the supply chain more sustainable. Competences on reducing GHG emissions might be among the criteria for companies to select supply partners.

3.1. Brazil GHG Protocol Program

The Brazil GHG Protocol Program (BGHGPP), started in 2008, the third country after Mexico and the Philippines to develop a national GHG emissions program based on the Greenhouse Gas Protocol (Green House Gas Protocol, 2020). The Center for Sustainability Studies (GVces) of the Business Administration School of Fundação Getulio Vargas (FGV-EAESP) is responsible for the adaptation of the method to the Brazilian scenario. To do this adaptation they also counted with the collaboration of WRI and in partnership with the Ministry of the Environment, the Brazilian Business Council for Sustainable Development (CEBDS), the World Business Council for Sustainable Development (WBSCD) and 27 Founding Companies.

GVces is responsible for classifying organizations by the quality of their declared inventories. Thus, a bronze seal is to organizations with partial inventories; silver to organizations with complete inventories; and gold to the ones with complete inventories verified by a third party. In ten years, the program has grown from 27 pioneering companies reporting to 141 companies, 95% of them submitting a complete inventory, the ones in the gold and silver categories.

Some of the Brazilian program innovating initiatives are an open platform for searching corporate inventories and industry statistics and the creation of the Public Emissions Registry, the latest is considered a pioneer worldwide (BGHGPP, 2015). In addition, the program also provides training for organizations to complete correctly their reports. Fig. 2 shows the evolution in numbers of participants of the program since it started in 2008.

The program aims is to promote a voluntary culture for the identification, estimation and elaboration of GHG emissions inventories. Some of the benefits for participant organizations are as follows:

- Competitive advantage, ensuring sustainability and efficient management.
- Improved relations with stakeholders, since the GHG Protocol reports allow the publication of information in other indicators and reports.
- Historical data record, which would allow the adoption of process improvements.
- Conditions to participate in the carbon market.

Recent revisions on Scope 2 promoted by the Brazil GHG Protocol Program consolidated two approaches (Fig. 3): based on location (average emissions from power generation in a given electrical system, or grid) or based on the choice of purchase (associating generation sources with their origin). Renewable Energy Certificates (RECs), as well as Electricity Purchase and Sale Contracts in the Free Contracting Environment are accepted for tracking emissions (BGHGPP, 2019b). Although the GHG Corporate Standards do not address potential double-counting, implementing a credible and robust system for GHG emission calculation and claims through contractual instruments must guarantee that only one consumer reports the emissions from a given quantity of generation.

As GHG emissions declarations are optional, organizations reporting them are generally concerned with sustainability and transparency among stakeholders of the renewable energy supply chain. Therefore, providing decision support models for organizations to analyze their data would encourage organizations to continue reporting and others to be interested in the process, as they would have access to decision support tools.

4. Research approach: Design Science Research

In this study, we adopt the Design Science Research (DSR) approach to propose a blockchain-based platform to assist the Brazilian GHG Protocol Program. DSR provides conceptual instruments to create design theories (Jones and Gregor, 2007) aiming to explain how digital artifacts can be designed to achieve an expected set of goals (Hevner, vom Brocke and Maedche, 2019).

Design theories produce special classes of theories used in the field of Information Systems (IS) to define the purpose and scope of a digital innovation project (Jones and Gregor, 2007). Originated in the IS field, DSR is being increasingly adopted in studies of sustainability projects (Stiel et al., 2016; França et al., 2020; Baldassarre et al., 2020). (Eidelwein et al. (2018)) and Albizri (2020) also adopt the DSR approach in cases particularly related to the control of GHG emissions.

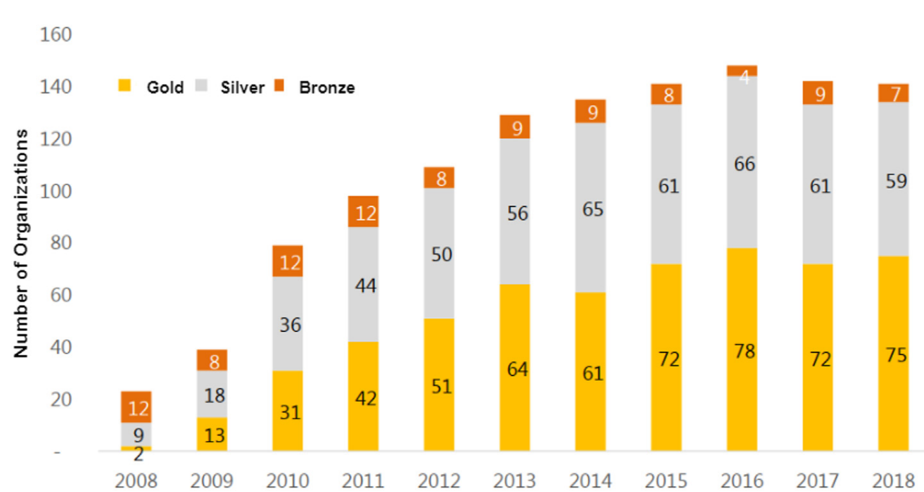

Fig. 2. Brazil GHG protocol program historical EmissionsSource BGHGPP 2019a.

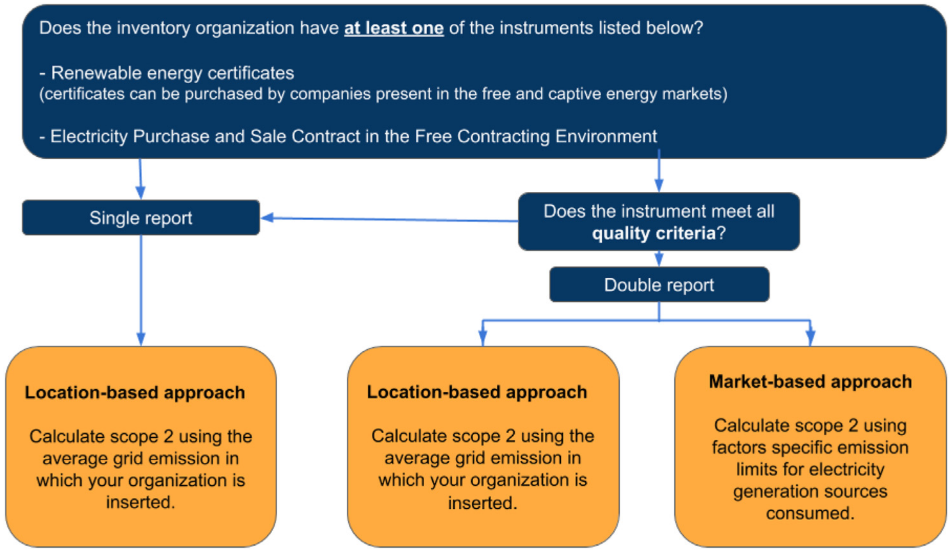

Fig. 3. Scope 2.

Although all those studies adopt different versions of the DSR approach, combining guidelines from Peffers et al. (2007), March e Storey (2008), and Santos, Koerich e Alperstedt (2018), each with a different number of steps to follow. Nevertheless, all of them have the same logic in common that starts with (1) the definition of the problem goes through (2) the proposition of the artifact, then demands (3) the evaluation of the artifact and finally presents (4) the clear contribution of the artifact to solve the identified problems.

Thus, this study will follow these four steps to propose a well-described artifact that addresses the identified problems and will contribute to its future deployment. Hevner et al. (2019) highlight six roles DSR can play to study digital innovation projects. For the authors, the objective of DSR studies in the role zero category help “gain a full understanding of the relevant problem” in order to propose “the pertinent descriptive theories that may inform the design of digital innovations”. In this role, the fundamental nature of a DSR project is to describe and provide elements for further implementation and evaluation of the artifact. In this study, based on interviews with staff from Brazilian organizations involved with GHG Protocol, we adopt the role zero DSR approach to propose a conceptual solution to describe the elements of a blockchain-based artifact that could improve the Brazil GHG Protocol Program.

5. Research methods

To follow the four steps usually adopted in DSR studies, we collected data from semi-structured interviews, documents and active participation in meetings of the GHG Protocol Program. We conducted data collection and analysis based in iterative-incremental cycles as part of an in-depth qualitative field study (Walsham 2006).

To define the problem, we first investigated documents related to the GHG Protocol to understand the whole data collection process related to the annual production of this inventory. We analyzed guidelines for companies, GHG emission calculation tools and dissemination materials of the program. We followed the activities of the GHG Protocol annual cycle, starting every September and going through to August, and participated in four meetings between February and July of 2019 with GVces staff responsible for registering the inventory for the GHG Protocol. In the first meeting, we investigated the Program methods and workflow, in order to define the “relevant problem” that could be tackled with a blockchain-based solution. On the second meeting, we discussed potential blockchain implementations on the Program, and then decided to emphasize the Scope 2, as there is lack of traceability on energy transactions and a need for companies to prove they consume renewable energies.

We developed a research protocol based on the literature review identified in section 1, on findings about GHG Protocol Program presented in section 2, considering a DSR approach.

We identified ten companies to interview, thereby deepening understanding of the relevant problem. We selected these companies based on the following characteristics: they are all in the Gold category within the program, have reported Scope 2, or failed in reporting Scope 2. Six companies agreed to participate in this study and, in each of them, we interviewed the person responsible for reporting the GHG emissions. The companies were from different sectors: petrochemical, cellulose, meat processing, energy, banking and telecommunications. These interviews were structured in order to identify the motivation of the companies in reporting the scope 2, and if applicable, the reasons for the failure in this objective. We also contacted two organizations that issue RECs, but we interviewed only one of them for the study. The research protocol guided the data collection with these seven organizations. We developed two semi-structured interviews scripts: the first for the GHG reporting companies, and the second to the RECs issuer company. All these interviews happened between April and June 2019 through video calling or over the phone. From these interviews, it was possible to produce an in-depth understanding of the process of gathering information for the inventory, as well as the difficulties encountered in the current process.

To propose the artifact, we had four meetings between April and July 2019 with an expert in implementing blockchain solutions from a technology startup that has deployed different blockchain solutions directed to initiatives for social good (Bartoletti et al., 2018). With this expert, we designed a blockchain-based artifact to improve the GHG Protocol inventory process in the form of a level 1 architecture diagram (Medini and Bourey, 2012). That diagram provides notations to capture system descriptions for future development. This artifact, presented on the third meeting with GVces, and afterwards we had a final discussion on the implications for the future of the Program, in case of implementation of this solution.

To complete the evaluation of the artifact, we first presented it at the Annual Event of the Brazil GHG Protocol Program, held in august 2019 to an audience of hundreds of companies, interested in the program. Then a new cycle of interviews started using two new semi-structured scripts: the first to members of the GHG Protocol Program in Brazil, and the second, to a company that is developing a blockchain solution to issue RECs.

Three members of the GHG Protocol Program in Brazil were interviewed, a coordinator and two researchers, between August and September in 2019, focusing on opportunities and limitations identified in the first cycle. In the company that is developing a blockchain solution to issue RECs, we conducted three semi-structured interviews between October and November 2019 with two of the founders and one with a member of the Information Technology team. In these interviews with the program managers and the certificate issuing company, we evaluated potentialities and limitations of the proposed design considering also implementation issues, providing insights to inform further implementation of this artifact.

The contribution of the proposed artifact is a deep reflection on the three steps performed previously. We considered the profile of interviewed professionals, most of them from the management area and with no specific knowledge of blockchain technologies, which implies describing the problems and proposing solutions with vocabulary close to their field of expertise. Moreover, the interactions with blockchain experts, despite their understanding of the GHG Protocol, none of them were considering full implementation of an artifact with the same proposed scope of this study, which limits their involvement with a definitive solution to the identified relevant problems of the inventory process.

6. Proposing a blockchain-based artifact to the GHG Protocol Program

This section describes the four DSR steps detailing the blockchain artifact designed to improve the inventory process for the Brazil GHG Protocol Program.

6.1. The context and characteristics of the problem

We followed the whole annual cycle of the Brazil GHG Protocol Program that starts every September with updates on the emission calculation tools and ends in August with the annual event that announces the emissions accounted in the country. A team of only three people from GVces takes care of this process, comprising training for companies on the GHG Protocol inventory, assisting them in the program, verifying accounting inconsistencies in the data sent by companies and preparing the final report presented at the Annual Event. After collecting all the data for the GHG inventory, a calculation tool, which is just a standardized spreadsheet, consolidates the inventories sent by companies. Before consolidation, the program managers check for inconsistencies in inventories not verified by external auditors hired by the companies. As this verification process is time-consuming and occurs only in the consolidation stage, inventories do not undergo a thorough review.

According to the workgroup created in 2017 by the Brazil GHG Protocol Program to review the accounting process, Scope 2 emissions stimulate the production of renewable energy due to a number of changes happening in the Brazilian energy market and regulatory scenario, promoting renewable energy purchase (BGHGPP, 2017). This Brazilian scenario results in a strong preference among participating companies to report Scope 2 using the market-based method, either by buying electricity from renewable sources or buying RECs. Thus, the focus of the proposed solution should be facilitating Scope 2 reporting using the market-based method.

However, according to the companies interviewed; the market-based method presents two main problems. First, it is possible to buy certificates and thus reduce the declaration of emissions, without consuming renewable energy, this can cause distortions in the perception of those who are consuming renewable energy but are not buying certificates. Second, there is no way to guarantee that an electricity seller will deliver the exact percentage of contracted renewable energy to each buyer, creating the possibility of a certificate not being faithful to the real level of emissions a company is performing. Cost and complexity cause Scope 2 to be underreported, with declarations decaying over time, as Fig. 4 shows.

Theoretically, blockchain can be a solution to both problems. First, it can create records of the energy produced according to the original source, creating a reliable tracking system that is transparent to the electricity buyer. Second, it can guarantee that the purchased certificate is unique and trustworthy by creating a validation system, checking information from buyers and sellers in the complex international movement of buying and selling certificates by comparing them with the audit systems in which they are being accounted for. The first solution is beyond the scope of this study since we could not include any energy producer in the evaluation stage of the proposed solution.

Thus, in this study, the focus is on the proposed blockchain solution for the validation process of certificates used for emissions declarations in the GHG Protocol Program. It is important to note that neither the program managers nor the companies interviewed have a clear understanding of blockchain technologies. Although they clearly understand the problems they have reporting and consolidating data in Scope 2, they would not be capable of providing elements to propose a blockchain solution for their problems.

6.2. Proposing the artifact

In order to propose a conceptual blockchain artifact to improve data collection in Scope 2 for the GHG Protocol inventory, we seek experts in the implementation of blockchain solutions. This conceptual artifact should be useful in the development of a future MVP (Minimum Viable Product), considering the multiple processes and at least three of the main actors involved: program managers, companies reporting and certificate issuers.

Considering the scope of the study, this proposal should be detailed and clear enough for any non-technical person familiarized with the GHG Protocol inventory to recognize it as a potential tool to improve results of tasks performed during data collection. The option was to design a generic functional model, usually known as Level 1 Architecture (Medini and Bourey, 2012), proposing a diagram of the components and their connections to the GHG Protocol for modeling notations, to support the future development of a blockchain-based platform.

Regarding the application, the blockchain solution has a web interface allowing companies and certificate issuers to register and validate their data, besides extracting reports from the platform. Since the focus is Scope 2, companies in the program would declare their inventories, and the platform itself checks buying and selling activities from both sides of the purchased energy. This qualification logic applies the business rules embedded in the backoffice, based on the KYC (Know Your Customer) profile information and, therefore, executed by the Hyperledger Fabric chaincode. Under the articulation of the data entered, it could whether be accepted or not, and if there were inconsistencies in any declared inventory, the program managers would be notified to conduct a revision. Certificate issuers would also enter data on the certificates sold in the market.

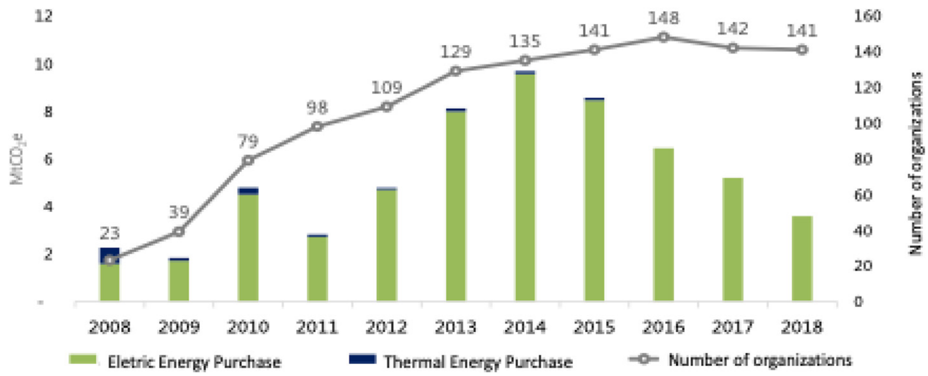

Fig. 4. Scope 2 declarationsFrom Public Emissions Registry.

The platform could comprise Scopes 1 and 3 as an extension of the artifact discussed here, if certificate issuers and energy distributors could register data from Electricity Purchase and Sale Contracts in the Free Contracting Environment (CCEAL). In this case, certificate issuers could enter their certificate information into the system that would ensure data consistency of CCEAL contracts and issued certificates registered on the blockchain platform. Based on these data, there would be a consolidation of the greenhouse gas inventories of the participating companies and inclusion in the Public Emissions Registry. Although possible within the proposed design, this extension is out of the scope of this study, since we kept the focus on Scope 2, where the more relevant problem of producing the inventory is concentrated.

The diagram presented in Fig. 5 represents the workflow of information to build the GHG Protocol inventory. Starting from the KYC point in the diagram, pre-registered users have access to the system identified by their profile, which could be a user from a company filling up the inventory, starting by defining three main types of users: program managers, companies declaring their inventories and certificate issuers.

Companies uploading their inventories will first choose the scope they want to upload to the system and the smart contract represented as Chaincode 1 in the diagram runs, with definitions for the location-based method pre-loaded at the blockchain settings of the Hyperledger Fabric framework, as well as the necessary rules for the market-based method. Certificate issuers will upload the information on certificates sold into the system the same way. As a tool to facilitate the smart contracts deliberation, Hyperledger Composer will check and validate the uploaded information, providing alerts to the program managers about inventories with problems through running Chaincode 2, already identifying the type of problem. Program managers access the uploaded data on the Backoffice, fixing problems, excluding or returning inappropriate inventories to companies, and making them ready for publication in the ledger, where data can no longer be replaced. At this point, the information entered through the application interface will already have all feedback from the Backoffice (performed by Chaincode 2 rules in connection with the respective KYC), and once standardized, it allows leaving the private scope of the records, to appear as a public record in the inventory.

The Stellar module will be used to tokenize and create units of the certify sources of energy by connecting distributors with the Energy Certifier that guarantees the sources are trustworthy. The tokenization allows each certificate to have its unique registration, eliminating the double-spending problem, quite common in the industry. Moreover, this tokenization information is entered by the blockchain framework of Hyperledger Fabric through Chaincode 3, which prints out the settled GHG Protocol network rules of tokenization and substantiates the Stellar token with its proper metadata. In the token cycle, the representation will count for scope 2 in the provision of the companies' inventory, offering all data entered by certificate issuers. This will be a trackable module to guarantee the origin of the energy consumed and declared to the GHG Protocol. Although considered in this diagram, this module was not under evaluation within the scope of this study.

The blockchain characteristic of allowing and facilitating the increment of processes in the current system through smart contracts, in this case, contracts governed by the Hyperledger Network (thus, called Chaincodes 1, 2 and 3), will enable the proposal represented by the blockchain solution. The web application represents the digitalization process of a methodology practiced currently, giving greater speed and self-validation (once validated by a conditioning Backoffice) to the information entered. Thus, the permissioned blockchain infrastructure provided by Hyperledger Fabric allows interdependence and connection between users, conditions, and even protocols - since it aims at tokenization too.

In this study, an application empowered by a blockchain model that facilitates the reporting process acts as a starting point to move from a manual to a more automated reporting process, improving information tracking and eliminating identified problems, such as conflicting values in tables and double sale of certificates, which consists of issuing RECs in different markets. This can offer models for data science since, as noticed by the interviewees, the report is used to make decisions on reducing emissions and purchasing electricity and RECs.

6.3. Evaluation of the artifact

The proposed artifact is an active element to discuss possible ways of improving data collection for the GHG Protocol Program with blockchain. It is worthwhile remembering that both the GHG Protocol and blockchain relates to the validation, accuracy and transparency of public records. Thus, the proposition of this artifact is to create opportunities to discuss blockchain in the GHG Protocol processes.

It is important to highlight that this artifact articulates the management of the program in Brazil, the companies that voluntarily build their inventories according to the GHG Protocol guidance, and the certificate issuers, companies that mediate the process of buying and selling in the renewable energy market. This artifact does not cover the internal processes of companies participating in the GHG Protocol: the expensive and time-consuming internal processes of producing the inventory within the companies, the location-based method, and the processes of

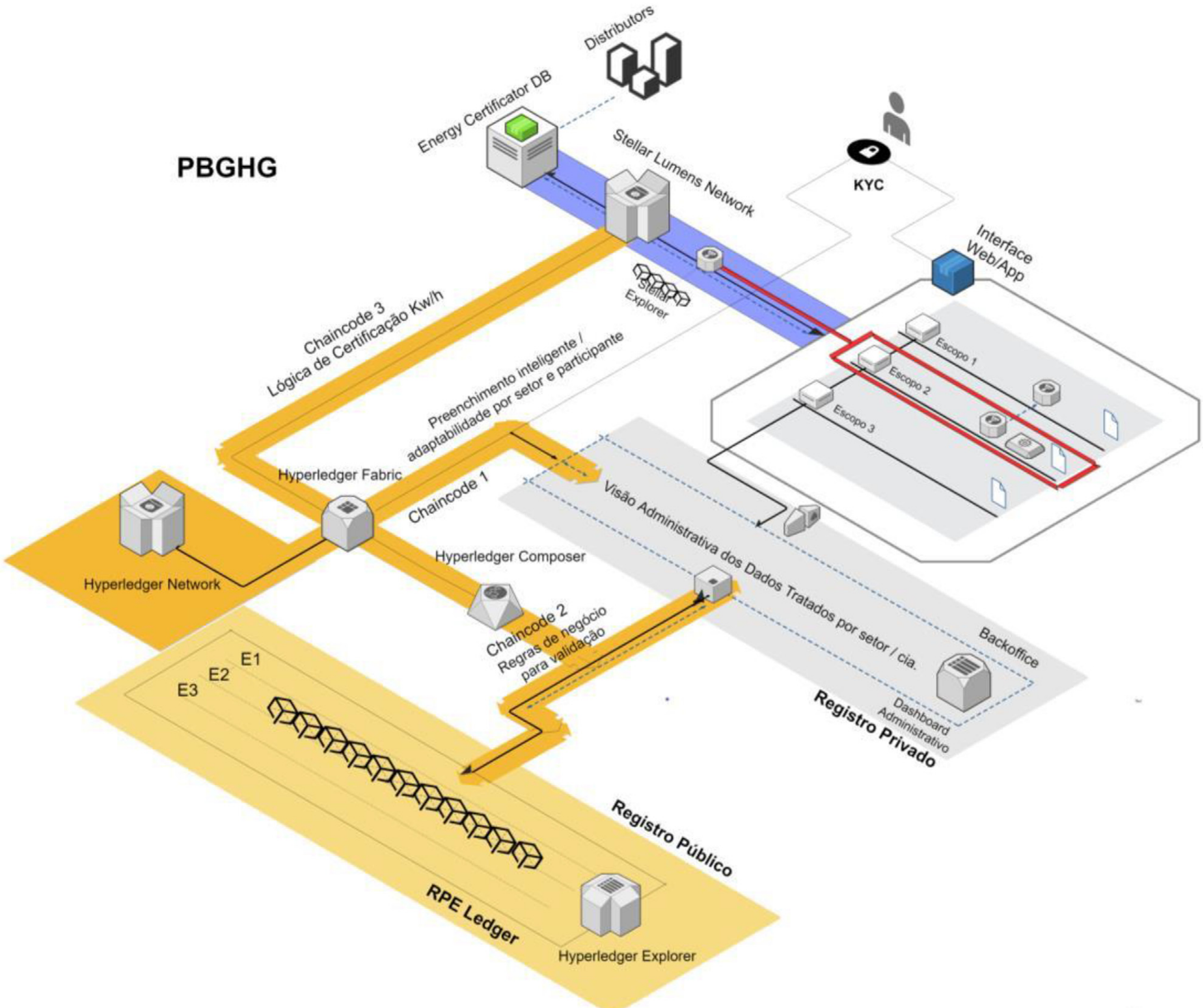

Fig. 5. Workflow and Architecture Level 1
Source: The authors.

certifying renewable energy in order to commercialize it, performed by certificate issuers.

The artifact was first presented to the program stakeholders at the Annual Event in August 2019. This presentation had the objective of stimulating the discussion on the potential of blockchain technologies to improve program adoption and the accuracy of the GHG inventories in the country. Since most of the audience was not familiar with blockchain, the artifact helped raise awareness of the potential of integrating actors involved in inventory aggregation. At the time, the main questions from companies participating in the program related to how the proposed artifact would help reduce the costs involved in inventory production.

To answer this important question, from the perspective of the companies producing the inventories, particularly in Scope 2, it is necessary to understand the two main cost types involved. The first relates to the location-based method, which is the accounting of emissions coming from all electricity sources supplied over a given period to the company. However, as previously mentioned, the location-based method is out of the scope of this study.

The second source of costs in Scope 2 relates to the market-based method, which involves buying certificates and contracting auditing national and international companies to validate the inventories before submitting them to the GHG Protocol system. Theoretically, it is possible to reduce the need for hiring external auditors, since data from companies and certificate issuers consolidate in the system by the rigorous blockchain validation methods. However, it is not clear whether certificate issuers would be willing to enter their data into the system as it is in the proposed artifact, since they usually not play this role. Besides that, certificate issuers can also develop their own blockchain system to reduce their own costs and keep selling certificates as they do today.

From the two certificate issuers participating in this study, one of them is already developing a prototype to issue the certificate via a blockchain platform. Therefore, we interviewed blockchain experts from this company. Although the company already has a minimum viable product, they still do not have an online marketplace in which companies and energy producers could register to purchase and sell certificates. Their system creates, certificates based on data scraping from the Electric Energy Trading Chamber (CCEE) website to verify the amount of energy produced by the producer. As blockchain fully automates the process, the cost of minting certificates will be extremely low, making the selling of certificates much more attractive than it is today, besides producing certificate quickly and precisely.

However, these experts believe that the blockchain system proposed by their company could reduce the role of CCEE and electricity distributors in tracking renewable energy, which could create obstacles for the dissemination of their business model in the market. On the other hand, with the adoption of blockchain systems to issue certificates, these systems can plug into the blockchain artifact designed in this study, creating incentives to certificate issuers operating blockchain platforms to participate in the GHG Program by simply uploading their data to consolidate information in the inventories, something they do not do today.

Another aspect to evaluate is how the artifact influences the program manager's workload. The artifact, therefore, would solve one major problem identified in the interviews, which is the time spent by the Brazilian GHG Protocol Program today checking inventory data. In the opinion of the program managers, the possibility of reducing their operation workload, their central role in processing inventories will remain related to the strategic coordination of the whole GHG Protocol process in Brazil.

Thus, the proposed artifact can be useful for the main participants of the market-based method in Scope 2. For the companies producing inventories, it can help lower the cost of the certificates, simultaneously making them more accurate and promptly available. For certificate issuers, the artifact enables participation directly in the process, by entering the data of certificates sold in the system. At the same time, this can encourage them to improve their internal processes by creating their own blockchain network to produce better and cheaper certificates, which can help attract more companies to participate in the GHG Protocol Program. For the managers of the program, the blockchain artifact will reduce their operational workload, which can create opportunities for them to have more time to play their strategic role in the program, which they believe is their true vocation.

6.4. Contribution of the artifact

The theoretical artifact designed in this study provoked a discussion with relevant actors about the possibilities of blockchain to improve the GHG Protocol, although the development of any prototype was not in the scope of this study. The artifact meant to demonstrate the usefulness of blockchain to the GHG Protocol, not to produce an explicit technical proposal towards implementation. This strategy was also a way to explain the blockchain features to managers not familiar with this technology and thus investigate the antecedents of possible future implementation, as well as to encourage actors to consider this technology in the field of the energy chain.

Some questions raised during the presentation of the artifact to interviewees were not possible to answer within the scope of this study. We do not know, for example, whether companies would stop hiring auditors to check their inventories, whether this new platform could weaken the relationship between GVces and other organizations in the energy sector, or even whether the certificate issuers would be willing to enter this system. The contribution of the artifact presented in this paper becomes clear for the interviewees when they recognize that, for them, it could solve relevant problems of the Brazil GHG Protocol Program, however it can bring others to the table.

Moreover, it is possible to consider opportunities to expand the original scope of the artifact proposed in this study. More complex than creating an operational platform that improves GHG Protocol processes is strengthening the bonds among stakeholders of the program, bringing together companies and certificate issuers, with conflicting interests, and with different perspectives on how to promote renewable energy consumption. As blockchain operates with agreements around a validation consensus, one important aspect not discussed in this study is governance of the artifact, meaning the decision-making process that would control the evolution of this platform (Tiwana, 2014).

Some relevant actors in the renewable energy scenario did not take part of this study, such as regulators, the CCEE and the many groups of energy producers, since we could not access them for the interviews.

The focus on the market-based method of Scope 2 is a result of the choice of actors in the study. From the understanding of the processes related to the GHG Protocol, we developed the study for the three groups considered predominant to the program. If the artifact can only partially help companies already participating in the GHG Protocol program, it is because we focused on the problems that limit the participation of a larger number of companies. The proposed artifact helps solve critical problems that are preventing access of new companies to the program.

Table 2
Summary of the DSR analysis.

Design Science Principles	Perspectives	Blockchain Implementation in the GHG Protocol Program
Defining the problem	Organization problem	Low productivity in inventory auditing, particularly in Scope 2, since time-consuming document checking is necessary
	Market problem	Traceability limitations in the energy market, costs and complexity for filing the inventories resulting in reduced reporting of Scope 2 and low attractivity for new companies
Artifact proposition		Blockchain-enabled inventory system with data consistency evaluation and verification of renewable RECs and energy purchases. Users: companies reporting inventories, certificate issuers, and program managers; In the future, there will be opportunities to attract energy producers/sellers to the system
Artifact evaluation	Organization evaluation	The artifact would reduce the workload of the program managers from GVces
	Market evaluation	Companies can save time and money on declaration and have more accurate inventory, enabling a better assessment of their emissions, and contributing to more accurate sustainability planning. A high risk of harming relationships between traditional certificate issuers and auditors. Adoption is uncertain, especially among certificate issuers, since some also audit for the companies reporting inventories.
Artifact contribution	Method contribution	The artifact proposition and its subsequent evaluation show the need to understand the solution from the constraints of the organization that will implement the technology. The artifact also worked as a trigger for the discussion on potential blockchain contributions to the GHG Protocol declarations
	Market contribution	The artifact shows the need for better traceability of transactions in the energy sector and more productivity in the sustainable audits process. Design of a governance model for the blockchain platform is an issue to be considered in future implementations
	Literature contribution	Proposing and demonstrating a viable blockchain application on the renewable electricity market, describing the positioning of different involved actors.

Source: The authors.

7. Discussion

The artifact proposed in this study innovates in aggregating knowledge from the GHG Protocol Program staff, companies reporting inventories, certificate issuers and blockchain experts who contributed to the proposed solution. Nevertheless, there are still barriers in the full adoption of such an artifact. Wang et al. (2019) point out that not all actors may want greater transparency in the supply chain. For example, we do not know the implications of the total disclosure in the GHG Protocol Program of certificate trade by companies buying or selling energy. Moreover, dominant market organizations may be afraid of losing their revenue channels (Michelmen, 2017). Additionally, Wang et al. (2019) state that the blockchain may extinguish old intermediaries and create new ones in the supply chain. Therefore, traditional certificate issuers might resist, while a new generation of blockchain-based certificates challenges the more traditional competitors.

As suggested by Hoek (2019), new blockchain applications in supply chains must start with only a small group of interested stakeholders. In this study, delimitation started in the evaluation of possibilities for implementing blockchain in Scope 2 of the GHG Protocol, which came from understanding the local context of the application by the program specialists, a few participating companies and only two certificate issuers, only one of them with a clear understanding of the technology.

For mindful implementations, applications must solve problems from the perspective of the organizations involved, making the relationship between technology and sustainability specialists a relevant factor (Verhoeven et al., 2018). Not surprisingly, some interviewees in this study commented that blockchain could be a solution in search of a problem. Nevertheless, the proposed artifact may contribute to facilitating the further development of crucial capabilities in organizations, breaking down barriers and promoting indirect learning to other actors along the value chain (Garcia-Torres et al., 2019). Therefore, this study can bring future benefits to the entire network of organizations around electric power transactions, helping to disseminate a "blockchain culture" within this market.

Another aspect of the case presented in this study is the DSR approach itself, adopted in several other sustainability studies. Using DSR, we could analyze the definition of the problem and proposition of the solution, and the necessary requirements for further implementation, while improving the understanding of its potential by the three main actors participating in the GHG Protocol Program. Table 2 summarizes the analysis, following the DSR steps adopted in this study.

Even if the use of blockchain can contribute to greater transparency and reliability in energy supply chains (Andoni et al., 2019), the case analyzed indicates that organizations, as certificate issuers, can still resist technological changes. In addition, the economic benefits observed in implementing blockchain may undermine the existing trade-off between costs and sustainable performance in SSCM (Saberi et al., 2019). The organization and resistance of the actors, therefore, could be as important as costs in the implementation of new technologies in supply chains.

8. Conclusion

Although there are other studies on the use and application of technologies as a solution to reduce greenhouse gas (GHG) emissions, there is a growing interest in using blockchain as a core technology for its disruptive potential and ability to reshape the electrical system (Buth et al., 2019). Thus, there are two main contributions from this study. First, it introduces the discussion on blockchain adoption in the GHG Protocol Program, by identifying where this technology can improve processes related to emissions inventory accounting. Second, it uses DSR as an instrument to both articulate a solution around a theoretical artifact and make its potential contribution understandable for actors not familiar with blockchain technologies.

The relatively small number of companies approached to discuss the potential of the artifact is one of the limitations in this study. We did try to include more interviewees in these two stages of the research, both from companies reporting and certificate issuers, but it was difficult to get more opinions due to the unavailability of these actors.

Several future studies can follow the one presented in this paper. First, more actors should express their opinion about either the problem definition stage or the artifact evaluation, to refine conclusions presented in this paper. Second, since this study produced just a conceptual proposition, a proof-of-concept or a pilot implementation of this artifact could be the next stage to deepen understanding for a full solution to improve the GHG Protocol Program. Third, since this study could make some actors from the renewable energy chain more aware of blockchain, one next step could include other actors from this chain, such as energy producers, regulators the and CCEE for trading certificates, creating opportunities to blockchain applications for Scope 1 and 3, as well as the location-based method in Scope 2. These future studies could consolidate the real incorporation of blockchain technologies into the realm of GHG Protocol.

CRediT authorship contribution statement

Eduardo H. Diniz: Conceptualization, Funding acquisition, Methodology, Project administration, Writing. **João Akio Yamaguchi:** Validation, Formal analysis, Investigation, Data curation, Writing. **Teresa Rachael dos Santos:** Validation, Investigation, Data curation, Writing. **André Pereira de Carvalho:** Writing. **André Salem Alégo:** Resources, Visualization. **Mateus Carvalho:** Investigation.

Declaration of competing interest

There are no known conflicts of interest.

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