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Cleantechs and Digital Solutions for Sustainability in the Brazilian Energy Sector

Cleantechs e Soluções Digitais para a Sustentabilidade no Setor de Energia Brasileiro

Matheus Eurico Soares de Noronha[1]
Escola Superior de Propaganda e Marketing - ESPM
math.euriconoronha@icloud.com

Leonardo Reis Longo[1]
Escola Superior de Propaganda e Marketing - ESPM
leozinlongo@gmail.com

André Themoteo da Silva Melo[2]
Universidade Federal do ABC – UFABC
themoteo.andre92@gmail.com

Renata Benigna[1]
Escola Superior de Propaganda e Marketing - ESPM
rebenigna@gmail.com

Felipe Mendes Borini[3]
Universidade de São Paulo - USP
fborini@usp.br

Abstract: This paper aims to map the main digital solutions practiced by entrepreneurs of Cleantech companies. Entrepreneurs from 12 Cleantech (Clean Technology) companies in the Brazilian energy sector were interviewed, using a qualitative research approach. Big Data & Data Analytics, Internet of Things and Artificial Intelligence were identified as digital technologies enablers of a sustainable energy transition for the sector. The study presents the relation and behavior of each technology with the

[1] Escola Superior de Propaganda e Marketing — Vila Mariana – CEP 04018-010 – São Paulo (SP) – Brasil
[2] Universidade Federal do ABC — Bangú – CEP 09210-580 – Santo André (SP) – Brasil
[3] Universidade de São Paulo – Butantã – CEP 05508-900 – São Paulo (SP)

sustainability triple bottom line and introduces a framework on how digital solutions contribute to solving the main bottlenecks in the electricity sector in a sustainable way. Research shown that Cleantechs also operationalize digital technologies like Blockchain and 5G to enable energy transformation as it has emerged as research findings. Additionally, technology and digitalization in conjunction with entrepreneur's capacity for innovation are driving mechanisms for companies in the initial stage of the energy sector, exploring regulatory loopholes and putting their business models into practice.
Keywords – Digitalization; Cleantechs; Energy.

Resumo: Este artigo tem como objetivo mapear as principais soluções digitais praticadas por empresários de empresas de tecnologia limpa. Foram entrevistados empresários de 12 empresas de tecnologia limpa (Cleantech) do setor de energia brasileiro, por meio de uma abordagem de pesquisa qualitativa. Big Data & Data Analytics, Internet das Coisas e a Inteligência Artificial foram identificadas como facilitadores das tecnologias digitais de uma transição energética sustentável para o setor. O estudo apresenta a relação e o comportamento de cada tecnologia com o *triple bottom line* da sustentabilidade e apresenta um quadro de como as soluções digitais contribuem para resolver os principais gargalos do setor elétrico de forma sustentável. A pesquisa mostra que as Cleantechs também operacionalizam tecnologias digitais como Blockchain e 5G para permitir a transformação de energia conforme emergiu como resultados de pesquisa. Além disso, a tecnologia e a digitalização em conjunto com a capacidade de inovação do empreendedor são mecanismos motrizes para empresas em estágio inicial do setor de energia, explorando brechas regulatórias e colocando em prática seus modelos de negócios.
Palavras-chave – Digitalização; Cleantechs; Energia.

Introduction

Digital technologies have been the main driver of business model innovation and can be classified into three major categories: automation, extension and transformation (AET). Automation refers to the digital technologies automating or improving existing activities and processes. In extension, digital technologies focus on supporting new ways of operating a business, which complement, but do not replace, existing activities and processes. In addition to it, transformation refers to digital technologies enabling new ways of operating a business, replacing traditional ones (Li, 2020). As a consequence, digital technologies contribute to the value creation in the three sustainability dimensions - economic, social and environmental - including energy efficiency (Felsberger, & Reiner, 2020).

An important stakeholder introducing sustainable digital technologies in the electric sector are Cleantechs, being companies in early stage linked to clean and sustainable technologies (Cumming, Henriques, & Sadorsky, 2016). Some of these Cleantechs have their business model based on digital technologies focused on the electricity sector, solving issues related to storage, generation of residential and industrial energy, solutions for businesses and even efficient data management (Weiß, Kölmel, & Bulande, 2016). As an example, entrepreneurs have already explored the energy market with distributed energy generation solutions, big data and data analytics solutions for the maintenance of wind and solar farms data centers and even the sale of energy quotas (Scott Cato, Arthur, Smith & Keenoy, 2007). The digital technologies implemented by Cleantechs can be precursors of a more sustainable business environment in the electric sector (Gibadullin, Pulyaeva, & Yerigin, 2018; Gielen et al., 2019; Felsberger, & Reiner, 2020).

However, the literature does not explain how the digital technologies introduced by Cleantechs collaborate sustainably with the bottlenecks in the electricity sector. Taking the Brazilian electricity sector as a reference, the main challenges are in the segments of energy generation, distribution and transmission, energy efficiency, storage, decentralization, consumption and commercialization of renewable sources, consumer behavior analysis and even mitigation of periods with greater variability in the renewable sources generation (Grubler, & Wilson, 2014; EPE, 2020). Thus, understanding whether the digital technologies introduced by Cleantechs solve these bottlenecks in a sustainable way is important both for the overall efficiency of the electricity sector, as well as to attest to the contribution of Cleantechs in the sector. And, above all, to incorporate into the literature the debate on problem solving in a sustainable way provided by digital technologies and their stakeholders, such as Cleantechs.

Starting from the presented problem and narrowing the analysis to the Brazilian market, the research question of this article is: "*How have Cleantechs been using digital solutions to offer a sustainable transformation to the energy sector?*". The objective of the article is (a) to map the main digital solutions used by entrepreneurs of Cleantechs companies, and (b) to present how digital solutions contribute to solving in a sustainable manner the main bottlenecks in the electricity sector. Specifically, in this article, we will use the Brazilian electric sector as an object of study. The methodological path of this research is based on a qualitative approach, through in-depth interviews with 12 Cleantech entrepreneurs in the energy area. The content analysis technique was used for data analysis.

The article's contribution to the literature, Felsberger and Reiner (2020) lies in presenting Cleantechs as stakeholders in the introduction of digital technologies for sustainable solutions to solve bottlenecks in the electricity sector, specifically the Brazilian one. The sustainable transformation provided by Cleantechs can bring digital solutions for the creation of a more competitive electric sector, as well as ensuring more predictability for the construction of more solid regulatory frameworks (Scott et al, 2007; Jolly, Spodniak, & Raven, 2016). The managerial contribution lies in understanding the role of Cleantechs for the consolidation of a sustainable digital ecosystem in the electricity sector. Especially for the stakeholders of the ecosystem, knowing which digital solution is linked to the sustainable solution of a bottleneck in the sector, allows a more efficient interaction of investments and efforts for the management of the companies themselves and the ecosystem.

Literature review

Digital Technologies

Digital transformation is conceptualized as a fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity and redefine its value proposition for its stakeholders, understanding that an entity could be an organization, a business network, an industry, or society (Gong, & Ribiere, 2020). Exploring the use of these digital technologies among companies of a specific sector is key, as cooperative actions between small companies can create the conditions for joint confrontation in the market for countries where innovation system is at an early stage of technological development, like Brazil (Da Cunha, Bulgacov, Meza & Balbinot, 2009).

Those digital technologies are mostly framed in the acronym SMACIT (Social, Mobile, Analytics, Cloud, Internet of Things), defined as technologies related to social media, mobile, data analytics, cloud technologies and internet of things (IoT) (Günther, Mehrizi, Huysman & Feldberg, 2017; Sebastian et al., 2017; Vial, 2019). There are more digital technologies than are implied by the acronym SMACIT. There are also technologies like artificial intelligence and big data. In this article, the focus is on artificial intelligence, big data & analytics, IoT and data cloud technologies applied in the electricity sector. In this research, both digital extension technology will be considered, when it does not promote the replacement of existing activities and processes, and transformation, when it promotes replacement to traditional models. (Li, 2007; Lindgardt, Reeves, Stalk, Deimler, 2009; Massa, & Tucci, 2012; Sebastian et al., 2017; Li, 2020).

Artificial intelligence is defined as a set of computational technologies with finite processing capacity, inspired by the human mind for learning and problem solving, aiming to imitate cognitive functions (Schalkoff, 1990; Stone et al., 2016; Stone, 2020; Yigitcanlar, Desouza, Butler & Roozkhosh, 2020). Artificial intelligence contributes to the performance of unexpected tasks and learnings from experience and maintenance of data, promoting automation in services and products (Wang, 2008; Monett, Lewis, & Thórisson, 2020).

Big Data technologies are designed architectures for the acquisition, storage, processing and analysis of an immense volume of data, described through its three key features: volume, velocity and variety; although additional characteristics are commonly associated with this digital technology definition like: value, veracity, variability and visualization (Wang, & Hajli, 2017; Hallikainen, Savimäki, & Laukkanen, 2019).

Data Analytics is described as obtaining learnings that can be hidden in the data (Gandomi, & Haider, 2015). Large volumes of data are analyzed and used for practical applications and business solutions, as the new possibilities presented for marketers of understanding customer behavior and advertising personalized in an individual level, which is possible due to the large amount of data created by user (Hausberg et al., 2019). In addition, Data Analytics also serves to support managers with data reliability and validity based on scheduled or manual analysis (Hallikainen et al., 2019).

The Internet of Things (IoT) can be defined as the dynamic global network infrastructure with self-configuring features supported by standard and introperable configuration protocols, which allows advanced services to interconnect with things, both physical and virtual (Peña-López, 2005; Kranenburg, 2008; Ray, 2018). It allows devices to be connected simultaneously and interact with other sensors to increase the productive efficiency of managers and companies.

Data Cloud is described as the technique that enables access and sharing of data, software and resources between people through the internet, in a ubiquitous and convenient way (Mell, & Grance, 2011; Tan et al., 2018). The data cloud can be offered in a service format and on demand, enabling a minimum interaction effort from the service provider, in which you pay based on your use and storage of information (Sajay, Babu, & Vijayalakshmi, 2019).

The role of Cleantechs for sustainable digital solutions

A startup is an organization created to research a repeatable and scalable business model and can also be defined as a human institution, designed to create new products and services under conditions of extreme uncertainty. Digital technologies play a central role in the business model of startups. They play a central role in creating and reinforcing disruptions that occur at the level of society and industry (Vial, 2019). Within this context, a Cleantech is a startup focused on products, services or processes that add value using renewable resources, or generate less social and environmental impact than conventional offers (Pernick, & Wilder, 2007).

Energy and energy efficiency technologies represent around 70% of all Cleantech financing. The financing includes recycling, renewable energy (wind energy, solar energy, biomass, hydropower and biofuels), information technology, green transportation, electric motors, green chemistry, composite materials and lighting (Cumming, Henriques, & Sadorsky, 2016). They are digital technologies, which through Cleantechs business models generate value for the market and society. Clean solutions related to energy storage, residential, industrial and distributed energy generation, Big Data and Data Analytics solutions for maintaining a wind and solar farms data center, and even commercialization of energy quotas are examples of these digital technologies (Scott et al, 2007; Pinkse, & Groot, 2015; Weiß, Kölmel, & Bulande, 2016). In this way, the digital technologies implemented by Cleantechs can be precursors of a more sustainable business environment in the electricity sector. This can be explained, as technological progress has the potential to reverberate in the three dimensions of sustainability: environmental, social and economic (Triple Bottom Line) (Gibadullin, Pulyaeva, & Yerigin, 2018; Gielen et. al, 2019; Felsberger, & Reiner, 2020).

Cleantechs as a research and market context

The Cleantechs market in the Brazilian panorama is visualized from the country's addition to the 2030 Agenda and Paris Agreement, but also in the commitment to ensure the achievement of sustainability (Di Vaio, Palladino, Hassan & Escobar, 2020). In addition, the Brazilian energy matrix is composed by 83% of renewable sources, 11.8% of which are wind sources and 2.6% solar photovoltaic (ABEEólica, 2022).

The geographic distribution of Cleantechs in Brazil is studied by Associação Brasileira de Startups (ABSTARTUPS) which released a report “Mapeamento das Cleantechs 2021” in the beginning of the year 2022. In this study, companies are concentrated on Southwest (56.9%); Middlewest (5.9%); Northwest (11.8%); North (2.9%) and South (22.5%). The report states that was founded and counted 102 organizations in activities, performing in Brazil’s electricity sector by order 26.5% in clean energy, 19.6% efficiency and 1% storage, totalizing 47.1% in these sectors. Compared to the world, brazilian cleantech organizations are positioned in 11th of 40 countries in Global Ranking and they were leader in Latin America (ABSTARTUPS, 2021).

The inoculated interest from the actual predominance of renewable sources in Brazil, is one of the reasons to receive investments in clean energy and digital technologies, allowing the scalability of the clean technology startup. The majority business model for these organizations are divide by means: a SaaS (i.e. software as a service), hardware, APIs, and selling data (ABSTARTUPS, 2021). Analyzing all cleantech organizations counted by ABSTARTUPS, 36% received some investments and capital, and 44% are in the traction phase.

Energy-focused startups have already received $66.4 million in 2021, according to a survey by the EnergyTech Mining Report District 2021 and will be movement more than $2.5 trillion in 2022 (ABSTARTUPS, 2021). Compilating all these information and data, the panorama of Cleantechs is established to be a research context by the growth themes as renewable energies and digital technologies.

Electric sector challenges and bottlenecks

The electricity sector is divided into five major segments: Generation, Transmission, Distribution, Commercialization and Consumption (La Rovere et al., 2013). The Generation segment is responsible for the production of electricity. The Transmission line is responsible for transporting the generated energy to the Distribution segment, which is responsible for reducing the voltage level of the energy coming from the Transmission sector and supplying this energy to the Consumer segment. The Consumer segment is the end of the chain, which uses the energy generated in the Generation segment. The Commercialization segment permeates the Generation and Consumption segment, being responsible for the purchase and sale of electricity (EPE, 2020).

Through these five segments, the energy flows in a unidirectional manner, originating in the Generation segment and being used in the Consumer segment. However, with the natural evolution of the electric sector, the development of new technologies, the sector modernization processes and the decentralization of generation with the increasing use of distributed generation, the direction of this energy flow has changed. This energy flow becomes bi or multidirectional. This results in a new complexity to the electricity sector and its operation, and challenges to the segments previously mentioned (EPE, 2020).

In the Generation segment, one of the biggest challenges concerns the increasing insertion of renewable energy sources, mainly wind and solar (Goldemberg & Lucon, 2007; Guijo-Rubio et al., 2020). Such sources have the variability of their fuels as characteristics, which are the wind and the solar incidence. Thus, the operation of the electrical system requires operational flexibility, adjusting the balance between generation and energy demand, when there are variations in the supply of energy from renewable sources. In this way, Cleantechs can assist in providing flexibility services in the process of associating renewable sources with storage technologies.

New challenges have emerged for Transmission segment within the generation of decentralization, which has to consider in their planning models the inclusion of new power plants, the consumers producing their own energy (self-produced), distributed generation and storage. Cleantechs play an important role in order to help managers and transmission companies in the optimal expansion solution, since the decentralization of sources avoids investments in transmission lines (Lima and de Oliveira Santos, 2020; Santos et. al, 2021). This also allows for the most appropriate management of the entire integration and operation of the sources and new actors in the network.

The Distribution segment has seen the increasing insertion of distributed generation in its network. The challenge of distributed generation is the predictability of the energy source, which originates mainly from the solar photovoltaic source (Lima and de Oliveira Santos, 2020; Santos et. al, 2021) In addition, its supply of demand and eventual insertion of excess energy in the distribution network are also points of attention (Zareipour, Bhattacharya, & Canizares, 2004). Cleantechs have a relevant role in this segment, optimizing these processes and helping to decentralize generation.

For the Consumer and Commercialization segment, new business models have emerged with the natural evolution of the electricity sector, the insertion of renewable sources and the use of new technologies (Magalhães, 2009; Lima and de Oliveira Santos, 2020; Santos et. al, 2021). In these segments, Cleantechs are essential for overcoming the challenges related to the control and management of energy generated with distributed generation and consumed. They can mitigate the risks of energy purchase and sale operations, due to the variability of renewable sources, which directly impacts the financial valuation of contracts signed bilaterally (Sadorsky, 2009).

As previously presented, these bottlenecks can be solved using digital solutions and technological innovations (Tolmasquim, 2012; Grubler, & Wilson, 2014). The advent of Cleantechs companies with solutions focused on energy and electricity can contribute to meeting challenges related to the five segments of the energy sector. They present solutions that contribute to more sustainable businesses in the electricity sector. Thus, it is established as a central proposition:

*Central **proposition**: Cleantechs solve bottlenecks in the electricity sector through sustainable digital solutions.*

For better visualization, the Table 1 consolidates all challenges and bottlenecks previously described in Brazil's energy sector and its scope of five segments: Generation, Transmission, Distribution, Commercialization and Consume. This compilation is necessary to visualize and understand the main problems faced in the current energy sector and through the insertion of renewable sources. The management of these segments searching a digitization is a main point worked by Cleantechs companies.

Table 1.
Compilated views of the bottlenecks in energy sector

Segment	Bottlenecks	Reference
Generation	Insertion of clean energies in matrix (wind and solar); Large data sets of forecast weather; conditions in power plant; parameters in energy systems; high cost to produce a large plant	Guijo-Rubio et al., 2020; Goldemberg, & Lucon, 2007).
Transmission	Security, efficiency in transmission and investments in planning projects to add strategically transmission lines according to the demand and growth of renewable sources.	Lima and de Oliveira Santos, 2020; Santos et. al, 2021; de Noronha et. al., 2022;
Distribution	Long distances among substations, grids and consumers, creating barriers for the flow as increases losses without utilization the new digital technologies and resources to management.	Lima and de Oliveira Santos, 2020; Santos et. al, 2021; de Noronha et. al., 2022; Zareipour, Bhattacharya, & Canizares, 2004
Commercialization	Lack regulatory frameworks for renewable sources according to new technologies; Relationship between buyers and sellers; Growth of prosumers (i.e. produce and consume their own energy)	Magalhães, 2009; Lima and de Oliveira Santos, 2020; Santos et. al, 2021
Consumer	Privacy and security based on large datasets of consumers and their relationship with the regulatory and laws. Monitoring of energy produced by prosumers.	Lima and de Oliveira Santos, 2020; Sadorsky, 2009; Santos et. al, 2021;

Metodologia

The methodological path of this research is based on a qualitative approach, through in-depth interviews with 12 Cleantech entrepreneurs in the electricity sector. The interviews were triangulated with observations, field notes and documents / websites of the electricity sector and the organizations that the interviewees represented. In-depth interviews were conducted fouding managers, co-founders and CEOs of the companies interviewed. The selection criteria was defined based on the study "Mapping the Startup Cleantech Ecosystem in Brazil" (FGV, 2019), conducted with the objective of understanding the ecosystem of startups in the clean technology segment and analyzing its impact on the Brazilian electricity sector. To complement the case unit’s selection, Partner and Head of Growth at the Distrito exported a report of the self-declared Cleantechs in the Distrito’s startups database (https://distrito.me/), an innovation platform for startups, corporations and investors. Table 2 consolidates the descriptive data of each interviewee represented by his Cleantech, which will be used in the content analysis section to title the interviewees. For the security of interviewees and companies, the name of each Cleantech was identified by letters and the interviewees by numbers, to remain anonymous.

Table 2.
Interviewees

Interviewee	Cleantech	Interviewee's Position	Interview Date	Interview Time
1	A	Brand communications & Sustainability Manager	September 9, 2020	31': 39"
2	B	Chief Financial Officer	September 10, 2020	20': 08"
3	B	Relationship with Investors	September 10, 2020	20': 08"
4	C	Product Owner Smart Cities and Energy	September 11, 2020	32': 39"
5	D	Chief Executive Officer	September 16, 2020	42': 33"
6	E	Chief Operating Officer	September 16, 2020	23': 45"
7	F	Co-Founder and Chief Executive Officer	September 17, 2020	25': 57"
8	G	Founder	September 23, 2020	28': 05"
9	H	Founding Research Student	September 24, 2020	25': 47"
10	I	Founder and Chief Executive Officer	September 24, 2020	16': 03"
11	J	VP Sales & Operations	September 24, 2020	32': 57"
12	K	Partner and Founder	August 15, 2020	36': 21”

For the interviews' collection, a research script was used (Appendix A), with 7 questions that unfolded in questions about what the main digital solutions are used by Cleantech entrepreneurs and how these solutions contribute to solving the main bottlenecks in the electricity sector in a sustainable manner. Observation notes were made within the organizations interviewed and from secondary data and supported the inferences about the knowledge that managers have of digital solutions. The documents and websites were the secondary data of the research and were initially used to create selection criteria for the analyzed Cleantechs, as well as to define the theoretical framework of technologies used in the energy sector to be explored in the interviews. The sites also showed the value proposition of startups, as well as giving a prior understanding of the technologies employed by them.

Content Analysis method was selected as the main technique for data analysis, making it possible to systematize and categorize the content collected from the semi-structured interviews (Yin, 2015). The interviews were transcribed and to identify the digital solutions used by Cleantechs, as well as their contributions to the sustainable transformation of the Brazilian energy sector, the categorization methodology was used to verify the repetition and relevance of each category in a thematic way (Shenton, 2004).

The work is divided into deductive and inductive categories in order to identify the intensity of each existing technology and dimension of sustainability and to organize findings not presented on the literature (Neale, 2016). The inductive categories are derived from the theoretical framework of international *marketing* dynamic capabilities from existing literature working as an investigative axis. Deductive categories, on the other hand, emerge from the findings not mentioned in text and which obtained a certain degree of saturation at the time of analysis, both in the theoretical framework on digital transformation and on sustainability (Table 3, Table 4 and Table 5).

In addition to categories, they were separated into categorical blocks, considering theoretical lenses. The block of inductive categories consists based in two theoretical lenses: Digital Transformation (Artificial Intelligence, Big Data & Analytics, Internet of Things, and Data Cloud) and Triple Bottom Line (Environmental, Economy and Social). The block of deductive categories are of the emerging and mediating technologies of the digital transformation process: Blockchain, 5G, Technological Innovation Capacity and governance.

To identify the degrees of analysis saturation, repetition, relevance, connection between themes and even systematization of the material, the Atlas TI software was used to support transcriptions (Friese, 2019). With this software it is possible to code and categorize by themes attributed by the authors, in which is carried out by the elaboration of the theoretical referential. After the transcriptions and categorization, it is counted and assigned relevance degree numbers to highlight which category is most evident during the interviews and how the categorical terms are presented by the interviewees. In the last phase, the researcher begins to make inferences about the numerical results.

However, it is important to highlight the limitations of the software to relate some topics covered during the interviews. After counting the words of the software, findings were manually organized, using field notes, to bring greater coherence and cohesion to the identified categories. In addition, this analytical process to codify, category and count, were final represented by Degree of Relevance (R).

Table 3.
Inductive Digital Transformation Categories

Inductive Category		Degree of Relevance (R)
Block Digital Transformation	Artificial Intelligence	8
	Big Data & Analytics	33
	Internet of Things	21
	Data Cloud	7
Block Cleantechs and digital solutions – Triple Bottom Line	Environmental	25
	Economy	21
	Social	23

Table 4.
Deductive categories

Deductive category		Degree of Relevance (R)
Block Enabling Tecnology	Blockchain	4
	5 G	15
	Technological Innovation Capacity	41
	Governance	8

Results and Discussions

Each Cleantech investigated has a predominant technology with socioeconomic and environmental impact that collaborates with the solution of some of the bottlenecks presented by the literature. As a way of mapping and presenting how sustainable digital solutions can contribute to certain bottlenecks and challenges in the electricity sector, Table 5 summarizes the selected cases and their relationship with sustainable transformation, showing the fulfillment of the central proposition of the work.

Table 5.
Cleantechs Digital Solutions solving the Bottlenecks from Energy Sector

Cleantech	Predominant Technologies	Social Economic and Environmental Impact	Cleantech Solution	Bottlenecks from Energy Sector
A	Big Data & Analytics IoT	Economic Environmental	Development and implementation of solar electricity systems and shared distribution through credit packages	Transmission Distribution Consumption Generation
B	Big Data & Analytics 5G	Environmental Economic	Development of renewable energy projects, energy commercialization, civil construction and asset management and structured products	Generation Commercialization Consumption

	Artificial Intelligence			
C	IoT Big Data & Analytics 5G	Economic Social	Planning, installation and management of solar plants and energy supply aimed at retail networks, industries, homes, and the public distribution electrical system	Consumption Transmission Distribution Generation
D	IoT Artificial Intelligence 5G	Environmental Economic Social	Digital energy bill management through tariff studies, energy efficiency, consumption monitoring or purchase of energy in the free market	Consumption Commercialization
E	IoT Big Data & Analytics	Social Environmental	Supply of photovoltaic panels to capture solar energy and chargers for electric vehicles	Consumption Generation Transmission
F	Big Data & Analytics IoT 5G	Environmental Economic	Management and monitoring of water and energy distribution focused on automatic leak detection in the distribution network	Distribution Generation Consumption
G	Big Data & Analytics IoT Artificial Intelligence	Economic Environmental	Resale of solar energy and installation of photovoltaic solar panels	Generation Consumption Commercialization
H	Big Data & Analytics IoT Data Cloud Blockchain	Economic Environmental	Smart meters for energy management	Consumption Distribution
I	IoT	Environmental Economic Social	Technological platform for financing solar energy uniting investors, integrators and customers	Generation Commercializatio
J	Big Data & Analytics IoT Data Cloud	Environmental Social	Clean energy subscription for residential consumers	Consumption Generatio
K	Big Data & Analytics IoT 5G	Economic	Shared generation of renewable energy through the electricity grid	Consumption Generation Distribution

Based on the information previously collected by Table 3, Table 4 and Table 5, and in order to present the relation and behavior of each technology investigated with the triple bottom line, a graph was constructed with the aid of the Power BI software, according to Figure 1.

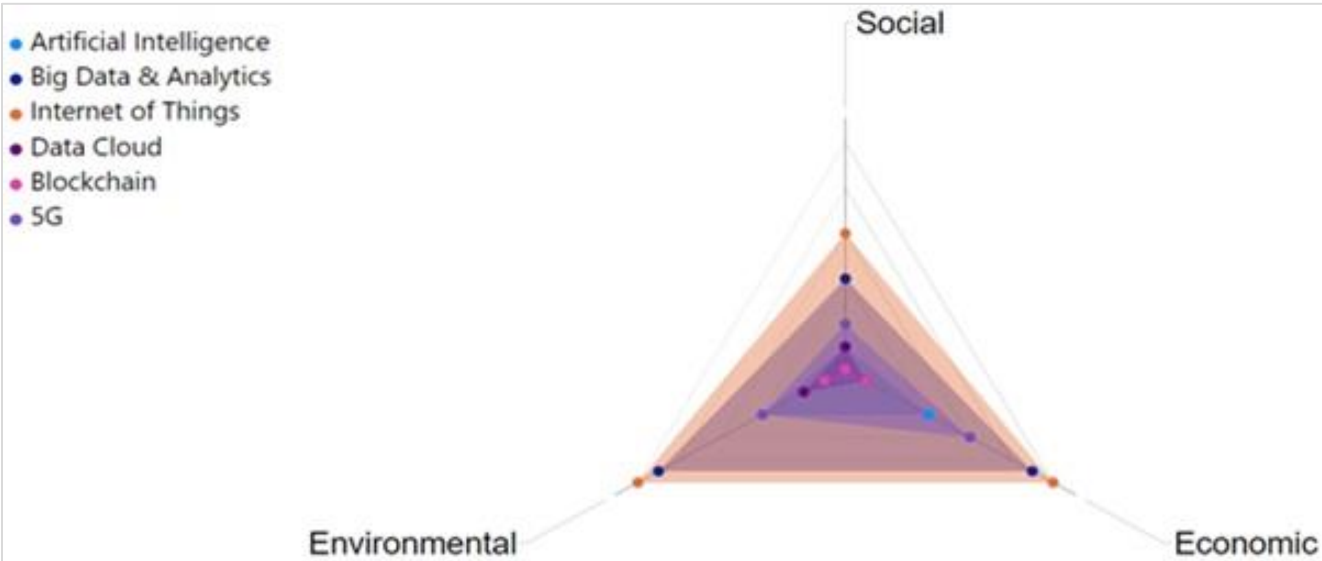

Figure 1. Relation and behavior of each technology with the sustainability triple bottom line

Analyzing the results generated by the cleantech interviewed, it is possible to state that the mentioned technologies are complementary for their use is scaled up and effective, for example: Cleantech B use the Artificial Intelligence algorithms, linked to the use of a 5G connection and using Big Data collection. The scalability of this organization can be altered intensely because of how the complementation of one technology and another works. Through this, data volumes can be utilized in a more agile manner through 5G, but also generating more assertive results and predictions from the initial argument about Artificial Intelligence.

The recurrent use of these technologies increases the way the electricity sector behaves, from the generation of energy to its destination in consumption. There are cleantech that use data monitoring systems in the generation plant and other cleantech that use Artificial Intelligence to validate models used in the transmission and distribution of energy. On the other hand, there are Cleantech that use the same idea of Artificial Intelligence, but linked to 5G, further improving their service and impacting on the environmental, social and economic tripod.

Regarding the secondary objective, to present how digital solutions contribute to solving the main bottlenecks in the electricity sector in a sustainable way, in Figure 1 it is possible to observe that, despite the technologies present a relationship with practically all three dimensions of the sustainability tripod, most of them are oriented more sharply towards the economic dimension, followed by the environmental dimension. This behavior can be explained by the attendance and supply of services that provide a reduction in energy consumption, as well as greater efficiency, which directly influence the billing and, in the same way, the use of natural resources, also collaborating with the reduction of emissions of greenhouse gases.

Through Figure 1 it was also possible to observe that in addition to the technologies of the inductive category, as shown in Table 3, there was also the appearance of the deductive category: Blockchain and 5G. According to the correlations drawn, these technologies were more oriented to the economic dimension. This orientation can be explained by the fact that these technologies save the use of physical resources, for example, when they spend the use of paper for the signing of contracts, which generates both an economic and an environmental benefit. Another point to be highlighted, concerns these technologies acting to improve the processing capacity of the systems, assisting in the integration of physical systems and making transmission infrastructures unnecessary. This directly influences the investments of companies.

The economic impact, in addition to being predominant in the interviews (R=21), has its relevance highlighted in the current context imposed by the pandemic of COVID-19, since the Brazilian economy expects a contraction of 5.8% in 2020 according to projections of the Monetary Fund International (IMF), in addition to the unemployment rate in Brazil continuing to increase and in the quarter between May and July it was 13.8% (Istoé Dinheiro, 2020). An example of such an impact is the fact that during the preparation of this article the largest beverage company in Brazil closed a partnership with the startup Lemon Energy to allow bars and restaurants to buy renewable energy produced by mini producers, in Generation systems Distributed (GD). By 2023 the company expects more than 50 thousand establishments to join the initiative, generating savings of approximately R$ 150 million to its customers with a reduction in electricity costs (E-Investidor, 2020).

Environmental issues are cited (R= 25) from the decrease in CO_2 emissions being cited as the main benefit of startup's solutions, but in more than one interview there was concern about what will be done with solar panels, which last between 25 and 30 years, with 80% of its original capacity.

Additionally, new proposals were raised in order to explore the field of digital, sustainable technologies and the challenges of the electricity sector. These propositions are presented according to the interviewees' reports and the connection between the theoretical tools of the article.

Proposition Development

Big Data and Data Analytics technology was the most relevant category (R= 33), especially for the collection and ingestion of data for the creation of bases for the management of renewable energy generation. The reports demonstrate that the *Cleantechs Big Data and Data Analytics* solutions interviewed aim to solve the bottlenecks in the Generation, Consumption and Commercialization segments by managing large databases of the generating and consumer units. These technologies allow data management for the operation of the interconnected systems, generating predictability in relation to energy demand. These bases also serve to understand people's consumption, which can mitigate peak demand, in addition to allowing energy trading companies to optimize energy supply contracts for consumer units.

In addition, *Big Data and Data Analytics* enable other technologies such as internet of things, artificial intelligence, data cloud and machine learning that are concepts investigated at work (Wang, & Hajli, 2017). Technology is also cited in a context of data capture via the internet of things (Hallikainen et al., 2019; Rangel-Martinez, Nigam and Ricardez-Sandoval, 2021). Big Data supports data storage and the creation of large information bases for energy management. The *Big Data* reports from interviewee are concomitant with the data cloud and the internet of things.

> *We need to understand the consumption patterns of a mass of people in order to be assertive in marketing actions. [...] We have to cross a lot of data to arrive at a list of consumers who spend R$ 200 or more, understand? It is a special interest of ours, we would not be able to do these segmentations without analyzing a series of data sources, so that we can filter and prioritize who will receive our advertising*. Interviewee 11

Big Data and Data Analytics assist in predicting consumer behavior based on the construction of consumer behavior databases. *Cleantechs* offer devices with sensors and digital services with communication capabilities that reveal individual consumer preferences, through applications that favor economic efficiency and the use of renewable energy sources from solar and wind microgeneration, once again favoring bottlenecks generation, commercialization and consumption. Based on this premise, **Proposition 1** of the paper is:

Proposition 1: *The digital technologies of Big Data and Data Analytics introduced by Cleantechs promote solutions for consumption, generation and commercialization bottlenecks in the electric sector*.

As an extension of *Big Data and Data Analytics* technology, the *5G* category (R = 15) emerged in the interviewees' reports because it made possible a substantial gain in speed in the huge data storage, managing to solve bottlenecks in data processing and analytics. That technology act as propelling mechanisms to resolve the needs and challenges of the energy sector and can mainly speed up the tasks arising from generation, transmission, distribution, commercialization and consumption (Jolly, Spodniak, & Raven, 2016).

The *Cleantechs* interviewed identified that the *5G* technological solution also contributes to the rapid response of data between consumers and power generators. The speed of 5G operated by the systems developed at Cleantechs can provide rapid response, solving problems situated at peak demand or need for flexibility in the system due to the variability provided by renewable sources. Through this, 5G intensifies the speed of data transmission, delivering fast response in the system. Thus, it is justified to quickly track data from future hybrid plants, which still lack a regulatory framework for their development, in order to encourage the complementarity of sources and reduce the impacts of variability of renewable generation in the electrical system.

> *We used Vacon inverters, today we use Huawei. To give you an idea, Huawei has a solution where you can make a communication of the plant all in 5G now. So, I think there's a big big data there, right? The idea is for you to set up a private 5G network where your communication is all transmitted, where you have analytics all the time in a much shorter time. [...] After you have the chain, you get it coupled and today you have this quick communication in the generation.* Interviewee 2

In this way, *5G* is a mediator and can be a technology that will collaborate with the rapid digital and technological response to all challenges in the sector. It is proposed that:

Proposition 2: *The 5G digital technology operated by Cleantechs has the potential to assist other technological solutions to solve the bottlenecks of all axes in the electric sector (generation, transmission, distribution, commercialization and consumption).*

The second most relevant category is the IoT solution (R=21), which has proven to be substantial for the development of Cleantech's business models. The IoT allows creating integration in energy systems and enables easier and more agile data management, cybersecurity, and production efficiency. Through IoT, Cleantech organizations solve relationship problems between energy systems, which makes the management of consumer data, paired transmission and distribution more effective. (Ray, 2018). The integration of physical and digital systems allows an optimized operation of the Brazilian national interconnected system. The *IoT* collaborates directly to address bottlenecks in the consumption, transmission and distribution segments, corroborating the system's planning by bringing the challenge of distributed generation and the predictability of energy sources.

The *Cleantechs* also presented their solutions in the sense of saving energy and water through the optimization of processes resulting from the use of technology to map problems in the system that are interconnected (Interviewee 7).

> *Our IoT is a kind of bionic ear that captures faults and sends it to our artificial intelligence and classifies that point as a potential problem in the system [...] so the program monitors the identified problem*. Interviewee 7

In addition, the use of sensors and *IoT* software, which connect homes and the electricity network, allow a more accurate and dynamic view of consumption and expenditure, allowing greater predictability of demand for generators, avoiding waste and increasing chain efficiency productive. In this perspective, we propose:

Proposition 3: *The digital IOT technology introduced by Cleantechs promotes solutions for consumption, distribution and generation bottlenecks in the electricity sector*

The use of the *Data Cloud* (R= 7) proved to be an integrative and complementary technique to the *IoT*, reducing the cost of processes that demand excessive digital spaces and interaction with providers. The investigated companies' solutions are automated through data clouds.

Interviewed 9 and 11 state that the data cloud is combined with the techniques of *Big Data and Data Analytic*s, providing communication between systems at scale and collaborating with the challenges in the segments of distribution, consumption and transmission, making it possible to create better planning for the self -production and distributed generation. The solutions mentioned by the interviewees allow working with algorithms to optimize predictions instantly, which reduces consumption and generates savings for the power grid. This category had low relevance in the research.

> *You have database services in the cloud and services based on in-memory databases, that's why we can make a button press on the application and it doesn't take 3-4 seconds to turn on the light. We did a local thing and also asked this question: cloud is a faster communication*. Interviewee 9

In addition to the operational efficiency gain resulting from the speed provided by cloud navigation, another economic advantage for companies that use cloud services is to reduce the high costs with maintenance and consumption of electricity, as it is an on-demand service, in which it is used as needed, as well as electricity consumption itself. Like the 5G technology, the data cloud technology is a mediator that collaborates with the use of other technologies but focusing on solving bottlenecks linked to all the axes of the sector. We propose:

Proposition 4: *The digital data cloud technology operated by Cleantechs has the potential to help other technological solutions to solve the bottlenecks of all the axes of the electric sector (generation, transmission, distribution, commercialization and consumption).*

Artificial intelligence (R= 8) technology presented itself as a relevant digital solution to collaborate with the sector's environmental impact, providing automation and savings so that consumers can use their energy in a rational way (Stone et al., 2016; Stone, 2020). This technology corroborates directly with the challenges of the consumer segment, collaborating with intelligent energy management based on the provision of services that optimize energy efficiency avoiding waste of energy.

The Interviewee 5 showed that *Cleantech* **D** carries out the process of digital energy management of small and medium-sized companies through *Artificial Intelligence* technology, guiding consumers in their daily expenses and corroborating the sector's energy efficiency process. The solution also allows customers to calculate the ideal cost of implementing a photovoltaic system, monitor and pay electricity bills more easily, in addition to performing other automated analyzes to generate greater efficiency in energy consumption.

> *Consumption reduction is reduction of environmental impact, so my product can work in 3 hours and not in 24 hours and it is much easier. This opens the door to energy efficiency, which is where we also want to operate, be it a timer, an LED lamp, air conditioning automation and they have a series of strategies [...] **D** is an artificial intelligence that reads data from your it counts and guides you in the best paths of economy, which are sustainable, in some way*. Interviewee 5

The evidence presented shows that Cleantechs digital solutions are in line with research by Wang (2008) and Monett, Lewis, & Thórisson (2020), showing that *Artificial Intelligence* can contribute to automation and improve the energy efficiency processes mentioned by (Fitzgerald, 2010). Digital solutions that aim at large-scale energy efficiency collaborate with the optimization of energy expenditure and consumption, avoiding waste and mitigating impacts of peak energy consumption in the national energy matrix. Interviewee 5 also appropriated artificial intelligence solutions to make his business model viable.

Also, according to Interviewee 5, the use of Artificial Intelligence in the distribution sectors is more recurrent due to the greater presence of management in the energy generated and that must be managed by companies. Artificial Intelligence models can facilitate the process of solving bottlenecks in the excess of energy generated and consumed in a specific period of time, in addition to monitoring other movements of energy generation and consumption. Through this, it is feasible to attribute the use of artificial intelligence to the Distribution sectors. Technologies such as IoT, 5G, and others, are mediators and facilitators of processes in general, improving the connection, capture, and sending of data.

The difference for other sectors to use a wider mix of technologies is the way it is operationalized. The generation sector deals with more time data capture and data forwarding. The use of predictive models and use of 5G connections is appropriate. Sectors such as Distribution and Transmission use smaller technology mixes, such as IoT and Artificial Intelligence. The more delimited use by these sectors is visualized by the segmentation and function it presents, demonstrating the importance of monitoring (transmission) and prediction of consumption by consumers (distribution).

With the increasing expansion of distributed generation, which is used entirely from the solar source, there are major challenges with regard to the management of this source of variable energy generation, associated with consumption and the sale of any excess energy. Such challenges can be solved with the application of *Artificial Intelligence.* This solution impacts the transmission axis in the same way, where once there is a greater application of distributed generation, investments in new transmission lines are avoided, as well as investments in the construction of large centralized energy generators. In addition, when it comes to centralized generation, *Artificial Intelligence* solutions are increasingly used in generation forecasting models, especially for renewable and variable sources, solar and wind. This allows the operation of the electrical system to rely on this type of source and also allows such energy to be traded on the energy market. In this way, bottlenecks in both the commercialization and generation spheres are solved by the application of artificial intelligence. It is assumed that these technologies can resolve the mentioned bottlenecks by suggesting **Proposition 5**.

Proposition 5: *The Digital Artificial Intelligence technology introduced by Cleantechs promotes solutions for consumption, generation, commercialization, and transmission bottlenecks in the electricity sector.*

Blockchain technology has emerged in research as a solution that can be further explored by Cleantechs. The technology works as an open, transparent and decentralized database based on a sequential structure linked in block and chain with time recording (Swan, 2015; Wu, & Tran, 2018). The digital solution uses consensus algorithms, in the distributed node model, for adding and updating data that protect transmissions and access through encryption (Yan, Zhao, Wen & Chen., 2017; Wu, & Tran, 2018).

The *Blockchain* (R=4) can be used for the commercialization of energy, especially for the signing of contracts between the parties, for the certification of energy efficiency and even for the registration of processes by Cleantechs, stimulating the consumption of renewable energy sources through compensation processes. This technology collaborates directly with the bottlenecks of commercialization and energy consumption. *Blockchain* can reduce transaction costs and increase transparency, which were benefits cited in many of the interviews in the context of using data cloud and 5G. However, the technology had little relevance due to the low supply of services in the Brazilian market.

> *I see that there is the question of 5G network, IoT, industry 4.0 that is talked about a lot and even blockchain, that start talking and everyone wants to implement. But I see few pilot projects like that, in fact taking place. It is nice that at least now it is having more discussion and openness, but if it can really evolve into pilot projects that start to have results, it starts to see where it is with problems and that is where we can move forward.* Interviewee 9

Considering the entire context of decarbonization of the global energy matrix and an increasingly leading role for the consumer, *Blockchain* technology proves to be of great importance in terms of tracing the origin of the energy that reaches the end of the chain. The technology is able to safely and efficiently identify that the energy consumed has a renewable origin, thus increasing the commercial value of this energy. Both commercialization and consumption benefit from the use of *Blockchain* technology by allowing the record of the exact volume generated, traded and consumed. Still in the context of the decarbonization of the energy matrix, there is an expansion of electric mobility in the world. *Blockchain* technology can assist in the management of electric vehicle recharges, that is, in the optimization of consumption and, at the same time, in the identification of the energy source, as well as it can assist in transactions and payments platforms.

Based on the evidence presented, *Blockchain* technology can be instrumental in resolving energy consumption and commercialization bottlenecks. Based on this assumption it is proposed that:

Proposition 6: *Digital Blockchain technology operated by Cleantechs, promotes solutions to the bottlenecks of commercialization and consumption in the electricity sector.*

The Figure 2 presents a summary of the propositions.

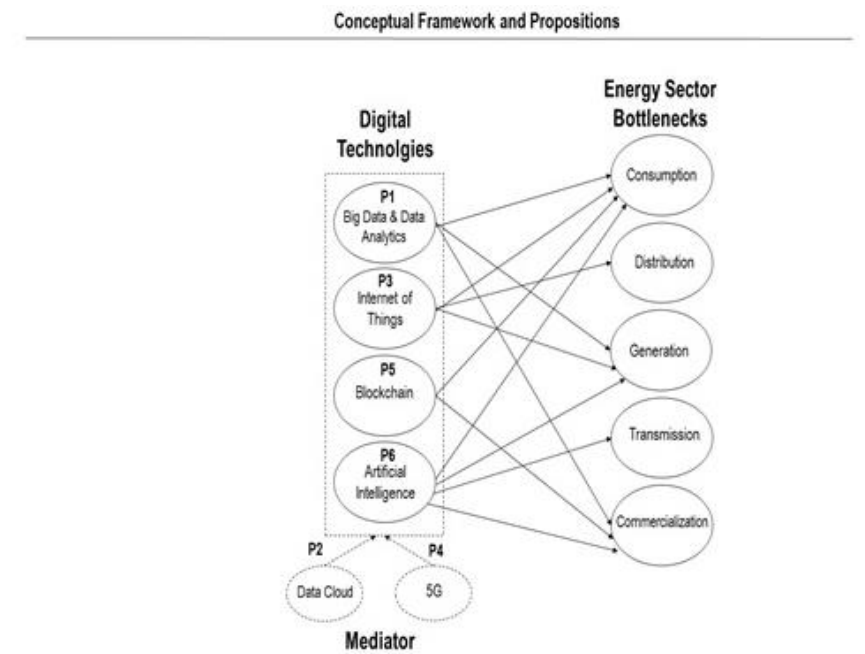

Figure 2. Digital solutions contribution to solving the electricity sector's main bottlenecks in a sustainable way

Table 6 presents how Cleantechs use their technologies to mitigate bottleneck generation in the energy sector. Its breakdown demonstrates each Cleantech organization and its competency for bottleneck resolution, but also the exposition of a related proposition for future research.

Table 6.
Cleantechs and how they address the bottlenecks using new technologies.

Cleantech interviewed	How the cleantech address the bottlenecks	Proposition related for future studies
A	The use of 5g unlocks the communication, generating speed in the transmission of the plant's consumption generation data.	Proposition 1 and 3

B	Prediction of generation plant weather data, as well as assisting in renewable energy projects and area monitoring.	Proposition 1, 2 and 5
C	Improves the process of planning, installation and management of solar plants and energy supply for households and industries through automation and database	Proposition 1, 2 and 3
D	It speeds up the calculation of the cost of implementing an energy system, as well as monitoring and paying costs more easily.	Proposition 2, 3 and 5
E	Supply of structure to generate energy recharges in a customized way by the monitored profile	Proposition 1 and 3
F	It improves the task of finding water and energy leakage points, making the reduction of impacts more efficient and faster.	Proposition 1, 2 and 3
G	Facilitates access to solar plants, monitoring the consumption profile and suggesting projects to supply the client's demand	Proposition 1, 3 and 5
H	Reducing consumption by using Data Cloud and optimizing algorithm prediction in other sectors.	Proposition 1,3, 4 and 6
I	Real-time monitoring of the plant's power generation data to ensure savings and reduce costs.	Proposition 3
J	Predict the customer's consumption profile quickly through communicating sensors that capture volumes of data	Proposition 1, 3 and 4
K	Enable a predictability in monthly costs and visualize the control of consumption	Proposition 1, 2 and 3

Final Considerations

The objectives established for the study were achieved, empirically presenting the possibilities of exploring the digital technologies that are operated by Cleantechs in order to solve the sector's bottlenecks. In addition to the emergence of new technologies such as 5G and Blockchain with regard to the main objective of the work.

The central proposition was also met, as in addition to detailing the technologies that the Cleantechs investigated operate, their social, economic and environmental approach was presented based on the established framework. It is worth mentioning that this approach allows us to assess how sustainable each technology can be through what each startup does, emphasizing Big Data & Analytics solutions and the Internet of Things sequence, which are related to the environmental dimension of the triple bottom line.

Considering that Cleantechs in the electric sector have a sustainable approach in their digital solutions, it is essential to consider that this type of company is associated with sustainable development and the sustainable development objectives (SDGs) established by the UN (Gomes, & Ferreira, 2018). In this sense, three practical contributions highlighted in this research and visualizing the SDGs stand out. The first is access to clean and affordable energy, with the advent of Cleantechs captive consumers can have access to clean energy without depending on energy distributors and generators. The second contribution lies in infrastructure and innovation, the innovation provided by this company format can solve infrastructure problems in the energy sector in a decentralized manner, collaborating from the distributed generation and commercialization of energy. The last contribution, on the other hand, is linked to sustainable production and consumption, enabling access to clean energy and in a decentralized manner, energy matrices may depend to a small extent on polluting and fossil fuel sources.

As a suggestion for future studies, Cleantechs in the energy sector can be explored as Energytechs since the cut and characteristics linked to technology and digitalization are focused specifically on products with the purpose of solving issues in the sector itself. It was noticed that these companies materialize their solutions in digital competencies subsidized by peculiar capabilities that need to be investigated. It is suggested to use the theoretical lenses of capacities and competences to observe how Energytechs operate digital capabilities depending on their resources and their organizational structure.

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Appendix

Appendix A. Questions assigned to the Cleantechs interviewed.

BLOCK	**DIGITAL TRANSFORMATION**			
Categories	Artificial Intelligence	Big Data & Analytics	Internet of Things (IoT)	Data Cloud
Questions	How does Cleantechs use Artificial Intelligence to achieve digital transformation using a huge volume of data collected from organizations' processes?	Big Data is a context present in all of these organizations. How can big data models and analytics facilitate a digital transformation in clean energy startups?	Agility and faster models based on IoT technology bring a new experience in variable processes in Cleantechs companies. Can the IoT connect with digital transformation using its network infrastructure to promote new renewable energy access?	The Data Cloud concept is a importante way to share a variable volumes of date with a minimal interaction. How can the Data Cloud help and facilitate achieving more agility in process renewable energy services?
References	Schalkoff, 1990; Stone et al., 2016; Yigitcanlar et al., 2020; Stone, 2020; Wang, 2008; Monett, Lewis, & Thórisson, 2020	Wang, & Hajli, 2017; Hallikainen, Savimäki, & Laukkanen, 2019; Gandomi, & Haider, 2015; Hausberg et al., 2019	Kranenburg, 2008; Ray, 2018; Peña-López, 2005	Mell, & Grance, 2011; Tan et al., 2018; Sajay, Babu, & Vijayalakshmi, 2019
Block	**CLEANTECHS AND DIGITAL SOLUTIONS: TRIPLE BOTTOM LINE**			
Categories	Environmental	Economy		Social
Question	Can cleantechs reduce environmental impacts and extend CO_2 reductions by optimizing through the use of technologies attributed to the scope of renewable energies?	How can cleantechs contribute to the generation of economic impacts by manipulating the internal and external processes of companies through the use of technology?		How cleantechs can mirror social impacts in the community using new technologies (5G, Data Cloud, IoT, Artificial Intelligence and Big Data & Analytics)
Reference	Gibadullin et al., 2018; Gielen et. al, 2019; Felsberger, & Reiner, 2020	Gibadullin et al., 2018; Gielen et. al, 2019; Felsberger, & Reiner, 2020		Gibadullin et al., 2018; Gielen et. al, 2019; Felsberger, & Reiner, 2020