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Big Data analytics in Smart Grids for renewable energy networks: Systematic review of information and communication technology tools

Ramón Fernando Colmenares-Quintero1*, Darío Jesús Quiroga-Parra2, Natalia Rojas3, Kim E. Stansfield4 and Juan Carlos Colmenares-Quintero5

Abstract: The industrial and economic development of the industrialized countries, from the nineteenth century, has gone hand in hand with the development of electricity, the internal combustion engine, computers, the Internet, data use, and the intensive use of knowledge focused on science and the technology. Most conventional energy sources have proven to be finite and exhaustible. In turn, the different production activities of goods and services using fossil fuels and conventional energy have significantly increased the pollution of the environment, and with it, contributed to global warming. The objective of this work was to carry out a theoretical approach to data analytics and business intelligence technologies applied to smart electrical-system networks with renewable energies. For this paper, a bibliometric and bibliographic review about Big Data Analytics, ICT tools of industry 4.0 and Business Intelligence was carried out in different databases available in the public domain. The results of the analysis indicate the importance of the use of data analytics and business intelligence in the management of energy

ABOUT THE AUTHOR

Ramón Fernando Colmenares-Quintero is currently the national head of research in engineering and Professor Dr. at UCC with research focus on energy generation, simulation and modeling in the energy sector and vulnerable communities. Darío Jesús Quiroga-Parra is a researcher at UCC. He obtained a PhD in Information and Knowledge Society from Universidad Oberta de Cataluña. His research interests are related to ICT and industry 4.0 topics.

Natalia Rojas has a degree in Civil Engineering and an MSc in Marine Renewables, works for Aquatera bringing knowledge and expertise in energy engineering.

Kim E. Stansfield got a PhD in Composites from Kingston University. He was sustainable energy systems transformation planner at the UK ETI. Joined Warwick WMG in 2016.

Prof. Dr. Juan Carlos Colmenares-Quintero is the leader of the research group CatSEE from the IPC/PAS in Poland. His interests range from materials science/nanotechnology to photocatalysis and water/air purification.

PUBLIC INTEREST STATEMENT

The industrial and economic development of the industrialized countries, from the nineteenth century, has gone hand in hand with the development of electricity, computers, the Internet, and the intensive use of knowledge focused on science and the technology. Also, several production activities of goods and services using conventional energy have significantly increased the pollution of the environment, and with it, contributed to global warming. This study carried out a review of data analytics and business intelligence technologies applied to smart electrical-system networks with renewable energies.
companies. The paper concludes by pointing out how business intelligence and data analytics are being applied in specific examples of energy companies and their growing importance in strategic and operational decision-making.

**Subjects:** Renewable Energy; Systems Engineering; Intelligent Systems

**Keywords:** Big Data analytics; smart grids; renewable energy; business intelligence; sustainable development goals

1. **Introduction**

The use of the energy properties of coal led to the development of the steam engine. At the same time, the development of electric power by Thomas Edison and Nikola Tesla, plus the contributions of George Westinghouse and Samuel Morse, helped in the invention of electric motors and the light bulb. At the same time, the generation of direct current and the alternating current electricity emerged. The first scientist to find evidence and recognize the existence of electricity was Thales of Miletus, who found the so-called seeds of static electricity. His theory was based on observing that rubbing a skin would make two metallic objects attract each other. He was also able to produce electric sparks by rubbing amber.

On the other hand, nowadays, the revolution of information and communication technologies (ICT) has led to a massive increase in the use of data and information in the micro- and macro-production spheres of goods and services, which is changing labor and management working practices and processes. According to Torrent (2004), these spheres have converged into digitalization processes, changes in the demand and consumption patterns and other accelerated globalization activities brought by the emergence of the global, digital internet (Torrent, 2004). So, the presence of ICT in the global Internet network is facilitating the integration of different market factors through the intensive use of knowledge. All this is oriented towards an important part of economic activities becoming more intangible, where high levels of data, information, and knowledge are used in production processes (Vilaseca & Torrent, 2006). Hence, the ICT technology infrastructure has stimulated the global economic structure to evolve towards a new type of configuration based on the critical use of data, information, and knowledge (Quiroga-Parra, 2014).

Consequently, the existence of massive amounts of data, that has to be converted into knowledge, has begun to play a central role in economic, professional, and social activities while helping address emerging new requirements. New technologies for processing big data have been developed such as data analytics, to convert data into information and useful knowledge (Bhattarai et al., 2019). In fact, David’s (1990) economic vision of knowledge and innovation states that a stock of knowledge that is used for production processes through application of these technologies is critical knowledge for business decision-making.

The advance of ICT in the emerging fourth industrial and technological revolution of industry 4.0 generates significant volumes of data during the production processes, which is now being used and processed to become useful knowledge in the operational management of electric power companies.

The relevance of this work relies on exposing how data analytics and business intelligence, based on the information and communications technologies (ICT) have the potential to integrate into conventional electricity networks of renewable energies, and transform them into intelligent system networks, capable of generating new information and knowledge. The latter supports the technical and managerial decision-making process thanks to the application of technologies of industry 4.0 in the electrical business context. Likewise, it promotes positive impacts on productivity increases and cost reduction, where technological innovation is taken as a central driver for organizational processes.
The purpose of this document is to carry out a systematic review of the state of the art of topics related to the analysis of data and business intelligence in order to guide in the process of conversion of electrical networks into “intelligent grid systems”.

Methodologically, bibliometrics was used in digital databases that would facilitate the availability of recent articles on the frontier of knowledge, of greater citations in the different subjects under study, and their technological trends. Through the systematic integration of theoretical knowledge, empirical business technology, and knowledge of adoption of ICT and industry 4.0 in new technologically intelligent systems, the aim is to establish the ability to generate new knowledge that will help guide future projects deploying smart grids.

The second section presents an approach to the state of the art of both the most outstanding renewable energies and Smart Grid networks, as well as the use of ICT as a digital tool for the productive transformation in Smart Grid and Renewable Energies. At the same time, the topic of Big Data Analytics and its application in Smart Grids are explored. Likewise, other important tools of Industry 4.0 are described such as Blockchain and its application in a Smart Grid network and renewable energy subsystems along with its importance in safe electrical transactions. Finally, business intelligence and data analytics are presented as management tools that support the decision-making process.

The third part briefly describes the methodology used in this work, while the remaining parts discuss the topic and the different areas developed. Finally, the conclusions describe the most important aspects of the study topic of this review.

The results exposed the importance of the use of data, data analytics and business intelligence, as well as its application in intelligent electricity networks, in the generation of new knowledge for management decision-making. The paper concludes by pointing out the importance of data analytics as an ICT tool, its application in smart electricity networks, and business intelligence in companies in the sector.

2. An approximation to the state of the question

2.1. Renewable energy

Some of the most important inventions of humanity in recent centuries have been electricity, the internal combustion engine, and the Internet. Electricity is very much the backbone of the production activities of daily goods and services in developed countries or not. However, a good part of the current sources of electricity generation is finite and exhaustible (Okoro, 2006). Thus, the global environmental and warming problems are forcing humanity to review the problem related to conventional polluting energies, either by CO2 or other pollutants (Panwar et al., 2011; Stoppato, 2008).

In fact, the intensification of different economic activities in the world’s economies is growing out of conventional energy consumption. This escalation is having an increasingly negative impact on the global environment. This has driven the need for public policies aimed at encouraging the use of renewable energy (RE), to reduce CO₂ emissions. Empirical evidence from international studies shows that there is a positive, direct, and significant, long-term relationship between the variables of RE and the decrease of greenhouse gas emissions, that is, demonstrates the contribution of this type of energy in helping mitigate the problem of climate change (Reddy et al., 2017).

In the generation of electricity, three main sources are being used: fossil fuels, nuclear resources, and renewable resources.

Renewable resources show advantages, considering that they can be used multiple times and are free of greenhouse gas emissions in the atmosphere. Some of these most used renewable resources are solar, wind, sea wave, biomass, and geothermal energy (Panwar et al., 2011).
2.2. Solar renewable energy

The process of converting solar energy into electricity is carried out using photovoltaic cells, which make use of the photovoltaic (PV) effect. The traditional belief is that energy is produced only by the process of burning fuels. However, the idea of generating electricity using solar energy was born in France with physicist Edmond Becquerel in 1839, when he observed that two brass plates incorporated in a liquid electrolyte and exposed to sunlight produced electricity viz. the photovoltaic phenomenon (Green, 2001; Komp, 2001; Smestad, 2002). Later Charles Fritts in 1883 built the first battery made of cans of Selenium, which only achieved 1% electrical conversion, this being an important step. In the year 1954 in the Bell laboratories a cell with 6% efficiency was achieved (Machado & Miranda, 2016).

The daily amount of energy that the sun sends to the earth could be enough to supply the planet's electricity consumption several times over (Komp, 2001; Machado & Miranda, 2016). It is estimated that the Earth receives the equivalent of $3 \times 10^{24}$ joules per year from the sun, that is $9.5 \times 10^{14}$ TW (terawatts) (Anders. et al., 2010; Grätzel, 2001; Smestad, 2002; Service (2005); Schiermeier et al. (2008). However, the advances in the efficiency of solar panels have not yet achieved high-efficiency technological levels. Some of the additional restrictions of the system are the exposure time of the panels to the sun, the use of batteries and the associated costs which have been decreasing. In fact, solar energy has become an important option, given the multiple advantages and since it can be used in remote places where it is difficult or uneconomic to deploy traditional systems.

In summary, solar energy and ER are considered sources of clean energy, an aspect that mitigates negative environmental impacts, providing sustainability to present and future social needs. It is estimated that by 2030 the consumption of planet earth will be 13 TW and 30 TW by 2050 (Machado & Miranda, 2016; Service, 2005).

2.3. Smart grid networks

Electrical networks are designed, created, and interconnected to provide electricity from a supplier to end-users. The magnitude and complexity of the networks have made administration both complicated and costly. The technological advancement of ICT has facilitated modernizing these electricity networks, where they are known as Smart Grids (Briones et al., 2017; Ko et al., 2020). This intelligent system where ICT, sensors and intelligent control systems are integrated to make it easy to manage and monitor the process of generation, transmission, and distribution of electrical energy. This is defined as: “a modernized network that allows two-way energy flows and uses two-way communication and control capabilities that will lead to a series of new functionalities and applications” (NIST, 2010: 05).

The Smart Grid (SG) network makes it possible to integrate electrical resources from different origins such as conventional energy and renewable energy; technological resources such as automated systems, smart consumer devices, electrical energy storage, and data storage. An SG system reduces the obstacles of integrating renewable energy (ER) to national and international electrical systems (Je & Huh, 2019). The SG systems show that they have at least five purposes: first, reduce the energy dependence of non-renewable resources; second, reduce the non-positive impact on the environment of energy pollution; third, increase energy security, by integrating the ER into the system; fourth, improve the operational, energy, cost, and management efficiency of the electrical distribution systems; fifth, increase stability, system reliability, service improvement, and consumer participation.

Thus, an SG can collect significant volumes of data of various kinds. Data that, in turn, make the system complex and merits efficient administration. The technology that facilitates the handling of these sizeable volumes of data is called Big Data (BD). This technology has characteristics such as volume, speed, variety, and value (Zhou et al., 2016).
2.4. Big Data Analytics in Smart Grids

The innovation of products, processes, and procedures is leading to positive impacts on the productivity of companies. Thus, ICT and Big Data are providing relevant opportunities for the electricity sector to place added value in terms of technical, economic, and social gains. However, it is a challenging task. The improvement of the electrical network measurement and communication technologies generates sizeable volumes of heterogeneous Big Data from diverse sources (Zhang et al., 2018), leading to computational complexity necessary for planning, operational integration of data and security of the data (Hossain et al., 2018; Mujeeb et al., 2019). Operational and system planning are challenges for companies trying to make proper use of the volumes of data and its processing for the purpose of managerial decision-making (Bhattarai et al., 2019). BD infrastructure includes a methodological architecture that facilitates the access, processing, storage, management, and analysis of the data, as well as the monitoring and forecasting of the volume of data for decision-making (Mayilvaganan & Sabitha, 2013).

The sources of data collection in an SG system are multiple and heterogeneous, for example, Energy inventory; user operation input; supervisory control and data acquisition (SCADA) social networks; phasor measurement units (PMUs); field sample values; communication & networking; smart meters; traffic data; smart home appliance sensors; weather data; simulation processes; energy consumption; system devices and their status; user interaction; network status; subsystems of renewable energy systems; type of renewable energy system; etc. (Bhattarai et al., 2019).

2.5. ICT tools in smart grid and renewable energies

The emergence of ICT in the so-called third industrial-technological revolution, especially the internet and software, has facilitated the design, structure, and management of the smart grid (Smart Grid). However, the fourth technological and industrial revolution, industry 4.0, has accelerated the massive application of ICT in multiple fields. One of them has been data encryption and with it the emergence of the “Bitcoin” and with it the enabling blockchain technology, among others.

2.5.1. Blockchain in a smart grid network and renewable energy subsystems: Transactions and security

Blockchain technology emerged as the proposal of the technological base for the creation of the Bitcoin cryptocurrency, originally proposed in 2008, Muhammad. et al. (2008). Blockchain is considered a distributed database technology, which is based on a secure list made to prevent forgery of transaction records, with a predetermined time frame. This technology is a relevant innovation for smart grid systems due to it allowing transactions to be executed between trusted individuals, and managing operations through a secure, digital computer network, Muhammad. et al. (2008). The name of Blockchain arises from the essential structure of the data that corresponds to a list of blocks chained together. This blockchain is distributed along with a peer-to-peer digital network, where each of the nodes is always kept updated, with the latest date version. The blocks can contain information about transactions made (Jan. et al., 2018).

The above process is executed through a combination of peer-to-peer computer networks, applying the consensus-building regulations, the use of cryptography and the use of market mechanisms. The system has an accounting book to record the transactions. Blockchain-based distributed accounting books allow collaboration in open environments, the system has been successfully tested in different complex contexts. The applications are multiple from Bitcoin financial transactions, financial transactions in banks, normal commerce, securities transactions, renewable energy power networks, and multiple social business applications (Walport, 2016). In every transition of a good or service, a new block is added to the chain, a signature is made using cryptographic methods. In this way, you can verify if the content and signature match. The system is based on an algorithmic consensus function, called hash, which is based on concepts called “work test” or “stake test” and “an elapsed time test” (Bentov et al., 2016).
As mentioned, each block of the network is related to a hash is related to a hash which is generated from its content and the hash value of the preceding block in the list. Moreover, the hash values uniquely represent the mechanism of transactions within the blocks and the order of each block. The mechanism in question is at the base of the chain, as a control and security element. So, when a hacker tries to alter a transaction, the hash value of its block would automatically be changed. This action would break the chain. Considering that each node can create blocks in a peer-to-peer network, therefore, there must be a consensus on the new version of the blockchain, and this includes the new block created, this being the function of the consensus algorithm (Jan. et al., 2018). So, for example, in a smart grid network, electrical energy transactions in the networks and their system networks show a high level of confidence, security, and certainty of the type of transaction, both internally within the system and externally with customers.

The function of the denominate miners in the blockchain system is to follow a predefined protocol. They work on the designed test, searching with mathematical algorithms for a value for a specific field that meets the condition that it must be smaller than a certain threshold of the protocol. The network is dynamically adjusted according to the default protocol. Specifically, the blockchain chain embodies two important concepts that are fundamental to business processes: A blockchain that corresponds to a data structure, a non-tamper proof format that captures the history and current state of the business-net, and second, the transactions that move the system to a new state.

The blockchain system also contains smart contracts which are important and necessary for the negotiation processes (Szabo, 1997). In fact, all negotiation processes are subject to rules, including fines for noncompliance. Every contract has a code that is implemented with a specific type of transaction. The process is like other blockchain transactions. The use of blockchain and code in contracts generates trust between the parties. Smart contracts can be used in business collaborations and business processes between organizations. In fact, the implementation of the smart contract code in the blockchain is immutable. Once this is implemented, the contract guarantees a way to execute code directly on the blockchain network. The process is like the conditional transfer of money if a certain condition is met. Every blockchain system, public or private, works based on rules to follow in a blockchain network, which are specified in the called “white paper” for each system.

The transaction speed is varied and depends on each system. As an example, Jan. et al. (2018: 4) says that: “The performance in the Ethereum blockchain is currently limited to approximately 15 transaction inclusions per second (tps). In comparison, the transaction volumes for the VISA payment network are 2,000 tps, on average, with a proven capacity of up to 50,000 tps. However, the experimental Belly Red Locking Chain, which particularly serves private blockchain or consortiums, has achieved more than 400,000 tps in a laboratory test”. Even so, academics are not in full agreement of the total benefits of this technology and suggest further research.

2.5.2. Business intelligence and data analytics
The need for energy companies, to properly manage the different resources, has made data and information a fundamental raw material in decision-making. This therefore leads to the need to collect, store, organize, process, analyse and correlate data from multiple sources, to convert them into new knowledge or business intelligence (Nonaka & Takeuchi, 1999). The resulting information is essential for decision-making and planning, predicting, optimizing processes, and reevaluating them, and to take the necessary actions (Manju. et al., 2015). Thus, the combination of software program optimization and intelligent network management, coupled with the application of ICT computing intelligence is proving to be a good tool for these purposes (Morais et al., 2009). So, business intelligence (BI) and data analytics (AD) are shown to be two of the most relevant solutions to the management of Big Data (BI&DA). These two techniques can transform raw data collected from sources of different kinds into useful information. BI&DA also includes practices and methodologies focused on the energy business. With these, high impact applications
Table 1. Methodological process of integration of technologies and knowledge

| Methodology                                      | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 |
|--------------------------------------------------|--------|--------|--------|--------|--------|
| Literature analysis                              | Analysis of ICT technologies and industry 4.0 | Analysis of electrical networks of Renewable Energies in a generation, transmission, distribution, storage and commercialization, and Smart Grid | Analysis of empirical business cases of electricity grids | Big data analytic integration with Smart Grid. Obtaining technological innovation and new knowledge |

such as planning and decision-making, cybersecurity and market intelligence in the electricity sector can be achieved (Briones et al., 2016).

Business intelligence and data analysis or big data analytics (BI&DA), is a unified term that consists of data analysis. This concept was introduced in companies as an analytical component around the year 2009–2010. Recently, it has been used as an analytical technique for complex applications of significant data volumes, which require advanced data storage, in terabyte and exabyte values, which include data from technological sensors and social networks (Chen et al., 2012; Colmenares-Quintero et al., 2021).

In fact, BI&DA (Obeidat, 2015) are a set of technologies that provides access to business intelligence for decision-making. The use of this tool is relevant and useful in quality decision-making when you have a comprehensive knowledge of the competition, customers, internal operations, business partners and the economic environment (Yeoh & Koronios, 2010).

The BI architecture process for a company has four phases: Data source; data integration; data marts and data presentation (Briones et al., 2016). In the first phase, the data sources play an important role since they affect their integration process. The data sources of a company are multiple and can come from structured or unstructured information. These can come from internal data or external data. The internal data can be historical and operational. External sources can be the Internet, market companies, competitors, consultants, suppliers, etc. Different data sources can be related or from different structures. In general, the data can come from several platforms. The organization and preparation of data can be a job that requires important planning and organization, by experts in the field.

Phase two of data integration, this is the process of extracting, transforming, and loading large volumes of data, plays an important role in the activity of finding, correcting the quality problems of the data found, before loading them effectively and efficiently to the data warehouse. Phase three, commonly known as data marts or metadata, enters the business intelligence phase, and where one of the most relevant components is storage or Warehousing. This process supports integration, cleaning, aggregation, and consultation tasks, also allows the physical propagation of data, when handling business records, for the previous tasks. This phase is made up of several thematic areas, which are organized to be able to provide statistical support for decision-making, according to the needs of a specific area of the company. The data pantry is organized to meet the specific needs (Watson & Wixom, 2007).

Phase four corresponds to the presentation of the data. The rapid visualization of the information product of the data processing, in turn, facilitates the dynamic exploitation of the results, through the analysis of patterns and atypical behaviors of the data. The BI essentially includes two types of tools: a) analytical processing and b) advanced analysis. The first group corresponds to the analysis in the
spreadsheets, application software, specialized business portals and online analytical processing, easy access and visual panels, these enable those responsible for BI to track in an ad hoc manner those key indicators that allow relevant staff to make timely decisions. The second group includes data mining, forecasting or predictive analysis, text analysis, and artificial intelligence algorithms. The latter is used to predict certainty measures on specific events (Briones et al., 2016; Zeyar, 2013).

The first group of analytical-processing software application companies Gartner (February 2019) classifies as leaders, visionaries, challengers, and niche players, in what Gartner calls the magic quadrant set out in a Cartesian plane. The leaders of these quadrants are: In the leading quadrant are Microsoft with Power BI, Tableau, Qlik, and ThoughtSpot. In the visionary quadrant, there is Salesforce, Sisense, TIBCO Software, SAS, and SAP software. In challengers is MicroStrategy, and, in niche players, eleven software application companies are shown, including Looker, Dome, Good Data and Yellowfin.

Since BI&DA is a unified term of technologies, for the specific case of Smart Grid, Zeyar (2013) and Briones et al. (2016) suggest that BI&DA technology must use other technologies to manage the system and subsystem of an electricity network for this. According to these authors, technologies can be used in the previous phase: frequent pattern mining, classification, association of rule mining, clustering or grouping, regressions, and detection of outliers. In the external user access process, the sub-processes include the BI&DA generation, BI&DA transmission, BI&DA distribution, and BI&DA end uses. A Smart Grid network continuously uses BI&DA to create centralized statistical data. However, there are data from other sources such as sensors, power system machinery and smart meters.

A BI&DA center will typically have the following parts and artefacts in its infrastructure: the definition of the project, the business architecture, ICT architecture, mapping of the business process, ICT applications, data quality, BI&DA techniques, interface and applications, results, and improvements (Briones et al., 2016). The emergence and rise of renewable energies suggest that a current smart-grid network must have a mixed system of traditional and renewable energies, where BI&DA has the capacity to manage the process dynamically. This may contain hydro, thermal, nuclear, solar and wind power generation plants, which supply electric power to factories, cities, offices, houses, and electric vehicles.

3. Materials and methods
For the theoretical approach, the bibliometric technique was used in different international public domain databases and the VOSviewer software was also implemented.

The bibliometric analysis was carried out by topic independently since the research contains topics such as conventional energy, renewable energy, renewable solar energy, Smart Grid networks, data analysis, ICT, blockchain technologies, business intelligence, and big data analysis. In each context, the most cited articles and the most recent articles that facilitate a solid literature review about renewable energies, Smart Grid, and ICT as a digital technological tool that supports industry 4.0 technologies such as big data analytics were selected.

In the second part of the research, word maps and author maps on each subject under study were relevant in the process of selecting articles and authors. The methodology sought to access articles located on the frontier of knowledge in the subjects of study.

The detailed theoretical analysis of the literature and the different empirical cases in renewable energy electrical networks, as well as the analysis and application of ICT that technically support the multiple technologies of industry 4.0 such as big data analytics allowed us to establish the status of both application and integration of the technology into renewable energy electrical grids.
Table 1. Methodological steps the team has used to understand the integration of electricity grid technologies with some of the technologies of Industry 4.0. Step one corresponds to the study of the literature on the subjects under study. Step two exposes ICT as the basis of a new digital technology based on the Internet, and the technological basis of Industry 4.0. Step three corresponds to the study of electrical networks based on smart grids. Step four corresponds to the study and analysis of three empirical cases of application of the above technologies in electrical networks. The final phase facilitates the integration of these technologies with some of the technologies of Industry 4.0.

Table 2. Technological components, process performed and knowledge generated of three case studies

| Technological structure and characteristics | Study cases |
|--------------------------------------------|-------------|
|                                            | Case Study 1: BI&DA for Health & Safety | Case Study 2: BI&DA for Photovoltaic system | Case Study 3: Bitlumens Blockchain IoT |
| ICT                                        | x           | X           | x              |
| Big Data                                   | x           | X           | x              |
| Block blockchain                           | -           | -           | x              |
| IoT                                        | -           | X           | x              |
| Business intelligence                      | x           | X           | x              |
| Data received                              | x           | X           | x              |
| Storage data                               | x           | X           | x              |
| Processing data                            | x           | X           | x              |
| Analytical data                            | x           | X           | x              |
| Monitoring Data                            | x           | X           | x              |
| RE system                                  | x           | X           | x              |
| Smart grid system                          | x           | X           | x              |
| Security system                            | x           | X           | -              |
| Photovoltaic system- Solar energy          | -           | X           | x              |
| Electric system                            | x           | -           | -              |
| Verification of generated information      | x           | X           | x              |
| Forecast                                   | x           | X           | x              |
| Alerts                                     | x           | X           | x              |
| Analysis data                              | x           | X           | x              |
| Solar panel analysis                       | -           | X           | x              |
| Efficiency verification                    | x           | X           | x              |
| Meteorological information                 | -           | X           | x              |
| Demand                                     | -           | X           | x              |
| Capacity                                   | x           | X           | x              |
| Industrial area                            | x           | -           | x              |
| Commercial                                 | -           | -           | x              |
| Financial                                  | -           | -           | x              |
| Social economics                           | -           | -           | x              |

Table 1 shows in detail the methodological steps the team has used to understand the integration of electricity grid technologies with some of the technologies of Industry 4.0. Step one corresponds to the study of the literature on the subjects under study. Step two exposes ICT as the basis of a new digital technology based on the Internet, and the technological basis of Industry 4.0. Step three corresponds to the study of electrical networks based on smart grids. Step four corresponds to the study and analysis of three empirical cases of application of the above technologies in electrical networks. The final phase facilitates the
integration of the processes of the previous phases, that is, the integration of academic-theoretical concepts with the empirical experiences of three electricity companies.

4. Results
Below are three case studies of application of ICT in Renewable Energy.

4.1. BI&DA system in an electric energy company
A real case of BI&DA data analytics was developed and applied in the Mexican Electric Company, in its Integral System of Occupational Health and Safety (SISST) group. Structurally, the system is composed of the company's business architecture, plus ICT technology architecture. The first includes the strategic plan of the company plus the business process (BP) mapping. The technological architecture includes the definition of the data set and data flow; communication definition; information system management; information systems application management; business management; handling units; security system.

The SISST industrial safety system has three sections: infrastructure security and health protection; accidents; and security management, in accordance with Jacome Grajales et al. (2011).

In summary, the main function of the system architecture can be described as system process functions of data collection, preparation, and analysis. This was structured as the BI & DA-SISST information system (Briones et al., 2016).

4.2. BI&DA for a photovoltaic system
Briones et al. (2017) present a case of BI&DA application for a photovoltaic system. This was carried out, with the objective of enabling reliable and timely decision-making by obtaining real-time information on the solar RE generation processes and the analysis of historical data, to be sure timely and flexible information and data were made available through the control panels. This was seen as key enabler that improved the integration of RE in a Smart Grid network. The case study illustrated the construction of the relevant “Big Data" infrastructure necessary to collect the data, store it, process it, analyze it and monitor it in a photovoltaic system.

The study also presents the architecture of the system in question connected to the network, as well as the variables that make it easier to measure network operational performance. The “Big Data” system is composed of logical layers. The flow of information is given as follows: acquisition of data, sending of data, data reception, processing, verification of alerts, storage, notification of alerts, and analytical processing. The application case shows two types of analysis: generation of and analysis of forecasts and operational control panel analysis. The latter explains the performance of the operating processes of the photovoltaic system and is essentially a descriptive analysis.

The system has the ability to show elements such as efficiency of the photovoltaic system, the capacity of the power generated by the photovoltaic array, ability to monitor meteorological information such as the temperature of the medium, modules, and radiation. It also has the ability to monitor the reduction of electricity demand, this is the typical way in which photovoltaic generation can respond to energy demand patterns arising from factories, offices, buildings and houses (see Briones et al., 2017).

4.3. Blockchain technology and Internet of Things in solar energy systems
The advance and accelerated development of ICT in the last decade is facilitating its application in multiple industrial, financial, commercial, economic, and social domains. The emergence of blockchain in 2008 and “internet of things (IoT)”, are accelerating the development of renewable energy. They are also providing the integration of RE subsystems to the macro systems of a “smart-grid” network. They have done this by speeding up the data collection and administration process, with the assistance of BI&DA technology.
Multiple examples are appearing in different countries. However, it is relevant to cite the case study of Bitlumens, who are deploying electricity with solar panels in remote locations in developing countries, with a priority of meeting the needs of female heads of households. Bitlumens is specifically using blockchain technology and the IoT, to collect information and data energy consumption data in rural areas of Latin America and Africa. Thus, solar energy is allowing families to access the Internet, television, and power up to six light bulbs per home, recharge electrical appliances and supply water to crops. The Bitlumen system has capability to: have a centralized service to store the user's identification, with a fingerprint identification system, an intelligent contract to create the Token with the Ethereum technique, an energy consumption billing system contract and decentralized files with hash techniques (see Bitlumens, 2018).

The first part of Table 2 lists the technological components and characteristics identified in the three case studies. In the second part of the table, the system processes and activities performed in the three case studies are listed for comparison.

Finally, the types of business intelligence and new knowledge resulting from the BI&DA analysis are listed versus the three case studies.

In summary, each of the three cases illustrates how the following ICT technologies have been integrated into the Smart grid electrical network: in case number 1, three ICT technologies are integrated. Case number 2 integrates four technologies, and finally case 3 integrates five ICT technologies. The three systems present similar processes for handling Big data analytics, in correlation with Business intelligence. Finally, the three case study systems have the ability to generate managerial information, with the potential to be transformed into new business knowledge and technological information for both technical and administrative decision-making.

5. Discussion
The accelerated dynamics of the development of ICT in recent decades and the high availability of data in the production processes of goods and services are changing the conventional working practices and processes of companies or organizations and the way of they are managed both strategically and operationally. So, Big Data technology encompassing the analysis and transformation of data into useful knowledge with the help of different ICT technologies has become a priority development area for companies in general. For organisations concerned with generation and supply of electricity, this process is of great relevance.

As a result, data analytics of Big Data has emerged as an activity and profession of growing future importance in the economic activities that are focused on the intensive use of knowledge. Business intelligence tools, especially those contributing to data processing and provision of explicit information that can be transformed into new knowledge in the management of energy companies, are especially important in the development and operation of so-called smart grids (Smart Grid). Other important ICT technologies such as blockchain are also becoming critical to the future of these companies, in the current digital era.

The present work runs within the research project “Enhancing Aquatic Renewable Energy (ARE): Technology design and adaptation program for Colombia”, attempts to analyse which technologies and skills are key to the successful development of smart-grids integrating conventional and renewable energy generating systems. The limitations are given, based on the limited availability of statistical data in specialized databases on the subjects that help address the objectives of this empirical study.

It is important to enhance future research in this conceptual line for renewable energy development and deployment in the Latin American region, by answering questions such as: How can data analytics and ICT tools, including blockchain, contribute to accelerating the advancement of RE in Colombia and Latin America?
6. Conclusions
Given the significant volume of data generated in the processes of generation and distribution of electricity by companies, the transformation by data analytics of this information into useful knowledge for the real-time management decision-making processes is becoming a priority. Different ICT technologies are contributing to this.

The use of technologies such as data analytics and business intelligence in smart electricity networks contributes significantly to the generation of new useful knowledge for business managers.

In business intelligence processes, there are several important software categories, where “BI” software is one of the most used in the analysis processes of important volumes of data.

The relationship of BI&DA technologies and their use in the case study companies for analysis of Big Data demonstrates that it is being successfully applied in electric power companies.

The blockchain technology is also being applied in the BIG Data processes of renewable energy systems in several important international companies, generating high levels of reliability and security in the processes of generation, storage, distribution, and control of the RE.

This technology has been shown to be a technically reliable tool in the operation of Smart Grid systems of electricity companies, in the industrial, commercial, financial, BIG Data collection and data management processes.

The limitations of the work occurred in the difficulty of being able to use empirical data necessitating the need to consider international literature.

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Author details
Ramón Fernando Colmenares-Quintero1
E-mail: ramon.colmenaresq@campusucc.edu.co
ORCID ID: http://orcid.org/0000-0003-1166-1982
Natalia Rojas1
Kim E. Stansfield4
Juan Carlos Colmenares-Quintero5
ORCID ID: http://orcid.org/0000-0003-3701-6340
1 Universidad Cooperativa De Colombia, Medellin, Colombia.
2 Faculty of Economic, Administrative and Accounting Sciences, Universidad Cooperativa De Colombia, Cali, Colombia.
3 Project Management, Aquatera Ltd, Old Academy Business Centre, Stromness, Orkney, UK.
4 Independent Sustainability Consultant, Worcester, UK.
5 Research Group CatSEE, Institute of Physical Chemistry, Polish Academy of Sciences, Warsaw, Poland.

References
Anders, H., Gerrit, B., Licheng, S., Lars, K., & Pettersson, H. (2010). Dye-sensitized solar cells. Chemical Reviews, 110(11), 6595–6663. https://doi.org/10.1021/cr900356p
Bentov, I., Gabizon, A., & Mizrahi, A. 2016. Cryptocurrencies without proof of work. International Conference on Financial Cryptography and Data Security, 142–157. Springer. https://doi.org/10.1007/978-3-662-53357-4_10
Bhattarai, B. P., Paudyal, S., Yusheng, L., Manish, M., Kwok, C., Reinaldo, T., Rob, H., Kurt, M., Rui, Z., Power, Z., Milos, M., Song, Z., & Zhang, X. (2019). Big Data Analytics in Smart Grids: State-of-the-art, challenges, opportunities, and future directions. IET Research Journals, 2(2), 1–15. https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/iet-rsj.2018.0261
Bitlumens (2018). White paper. https://bitlumens.com/assets/bitlumensdata/White_Paper_June_2018.pdf
Briones, E., Flavio, G., & Arroyo-Figueroa, G. (2017). Big Data & Analytics to support the renewable energy integration of smart grids - case study: power solar generation. Proceedings of the 2nd International Conference on Internet of Things, Big Data and Security, Rome, Italy (IoTBDS 2017), 267–275.
Briones, E., Guillermo, F., & Gustavo, A. F. (2016). Business Intelligence and Data Analytics (BI&DA) to support the operation of smart grid - Business Intelligence and Data Analytics (BI&DA) for Smart Grid. Proceedings of the International Conference on Internet of Things and Big Data (IoTBDS 2016), 489–496.
Chen, H., Roger, C., & Storey, V. (2012). Business intelligence and analytics from Big Data to big impact. MIS Quarterly, 36(4), 1165–1188.
Colmenares-Quintero, R. F., Maestre-Gongora, G., Pacheco-Moreno, L. J., Rojas, N., Stansfield, K. E., & Colmenares-Quintero, J. C. (2021). Analysis of the
energy service in non-interconnected zones of Colombia using business intelligence. Cogent Engineering, 8(1), 1–21. https://doi.org/10.1080/23311916.2021.1935410

Quiroga-Parrá, D., Hernandez, B., Torrent, J., and Ramirez, J. (2016). La innovación de productos en las empresas, caso empresa América Latina. Revista Cuadernos Del CENDES, 87, 63–85. http://ve.scielo.org/sclielo.php?script=sci_arttext&pid=S1012-25082014000300004

David, P. (1990). The dynamo and the computer: A historical perspective on the modern productivity paradox. American Economic Review Papers and Proceedings, 80(2), 355–361. https://www.jstor.org/stable/2006600?seq=1

Grätzl, M. (2001). Photoelectrochemical cells. Nature, 414, 338–344. https://doi.org/10.1038/35106407

Green, M. A. (2001). Crystalline solar cells on photovoltaic cells. In Advanced Materials, 13 (pp. 1019–1020). Wiley.

Hossain, E., Imtaj Khan, I., Un-Noor, F., Skander, S., & Sunny, M. H. S. (2018). Application of Big Data and machine learning in smart grid, and associated security concerns: A review. IEEE Access, 6(2019), 13960–13988. https://doi.org/10.1109/ACCESS.2018.2894819

Jaccor Grajales, N., Escobedo Briones, G., & Guadarrama Villa, E. (2011). Inteligencia de Negocios en el área de seguridad de la CFE. In Congreso Internacional sobre Innovación y Desarrollo Tecnológico (pp. 677–685).

Jan., M., Ingo., W., Wil., V. D. A., Vom Brocke, J., Cristina, C., Florian, D., & Zhu, L. (2018). Blockchain systems for business process management – challenges and opportunities. ACM Transactions on Management Information Systems, 9(1), 1–15. https://doi.org/10.1145/3183367

Je, S.-M., & Huh, J. -H. (2019). Estimation of future power consumption level in smart grid: Application of fuzzy logic and genetic algorithm on big data platform

Ko, J.-S., Huh, J.-H., & J-Ch, K. (2020). Overview of maximum power point tracking methods for PV system in micro grid. Electronics, 2020(9), 816. https://doi.org/10.3390/electronics9050816

Komp, R. J. (2001). Practical photovoltaics: Electricity from solar cells (3a ed.). atec publications.

Machado, C. T., & Miranda, F. S. (2016). Energia solar fotovoltaica: Una Breve Revisão. Rev. Virtual Quim., 7 (1), 126–143. DOI: 10.5935/1849-6835.20150008

Manju., K., Sriatham, N. K., & Mandiratta, K. J. (2019). Data Mining in Smart Grids:A Review. International Journal of Advanced Research in Computer Science and Software Engineering, 5(3), 709–712. http://ijcrsee.com/Before_August_2017/docs/papers/Volume_5/3_March2015/VS13-0242.pdf

Mayilvaganan, M., & Sabitho, M. (2013). A cloud-based architecture for Big-Data Analytics in Smart Grid: A proposal. IEEE International Conference on computational intelligence and computing research. https://bitcoin.org/bitcoin.pdf

Morais, J., Pires, Cordoso, C., & Klautau, A. (2009). An overview of data mining techniques applied to power systems. In J. Ponce & A. Karahoc B. (Eds.), Data mining and knowledge discovery in real life applications. I-Tech Education and Publishing.

Muhammad., O., Max., N., Ronny., R., Vebol., R., North., & Satoshi, N. (2008). Bitcoin: A peer-to-peer electronic cash system. /bitcoin.org/bitcoin.pdf.

Mujeeb, S., Javid, N., Akbar, M., Khalid, R., Naezer, O., & Khan, M. (2019). Big Data Analytics for price and load forecasting in smart grids. BWCCA. LNDECT, 25, 77–87. https://link.springer.com/chapter/10.1007/978-3-030-02613-4_7

NIST. (2010). Framework and roadmap for smart grid interoperability standards N.S. P. 1108., Release 1.0, January.

Nonaka, I., & Takeuchi, H. (1999). La organización creadora de conocimiento: Cómo las compañías japonesas crean la dinámica de la innovación. Oxford.

Okoro, O. I. (2006). Modueme TC. Solar energy: A necessary investment in a developing economy. International Journal of Sustainable Energy, 25(1), 23–31. https://doi.org/10.1080/14786450600539147

Pawar, N. L., Koushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews, 15, 1513–1524. https://doi.org/10.1016/j.rser.2011.10.037

Reddy, P. S., Avik, S., & Dogan, E. (2017). The significance of renewable energy uses for economic output and environmental protection: Evidence from the Next 11 developing economies. Environmental Science and Pollution Research, 24(15), 13546–13560. https://doi.org/10.1007/s11356-017-8985-6

Schiermeier, Q., Tollefson, J., Scully, T., Witze, A., & Morton, O. (2008). Electricity without carbon. Nature, 454(7206), 816–823. https://doi.org/10.1038/454816a

Service, R. F. (2003). Is it time to shoot the sun? Science, 309(5734), 548–551. https://doi.org/10.1126/science.309.5734.548

Smestad, G. P. (2002). optoelectronics of solar cells (1a ed.). SPIE.

Stoppato, A. (2008). Life cycle assessment of photovoltaic electricity generation. Energy, 33, 224–232.

Szabo, N. (1997). Formalizing and securing relationships on public networks. In First Monday (Vol. 2).

Torrent, J. (2004). Innovació tecnològica, creixement econòmic i economia del coneixement. Consell de Treball Econòmic i Social de Catalunya (CTESC), Generalitat de Catalunya.

Vilaseca, J., & Torrent, J. (2006). TIC, conocimiento y crecimiento económico. Un análisis empírico, agregado e internacional sobre las fuentes de la productividad. Economía Industrial, 360, 41–60.

Walport, M. (2016). Distributed ledger technology: Beyond blockchain. UK Government Office for Science, Tech. Rep 19.

Watson, H., & Wixom, B. (2007). The current state of business intelligence. Computer, 40(9), 96–99. https://doi.org/10.1109/MC.2007.331

Yeoh, W., & Koronios, A. (2010). Critical success factors for business intelligence systems. Journal of Computer Information Systems, 50. 23–32.

Zeyar, A. (2013). Database systems for the smart grid, book smart grids: Opportunities, developments, and trends 151-168. Springer Verlag.

Zhang, Y., Huang, T., & Bompard, E. F. (2018). Big data analytics in smart grids: A review. Energy Informatics, 1(8), 1–24. https://doi.org/10.1186/s42162-018-0007-5

Zhou, K., Chao., F., & Yang, S. (2016). Big data-driven smart energy management: From big data to big insights. Renewable and Sustainable Energy Reviews, 56, 215–225. https://doi.org/10.1016/j.rser.2015.11.050
