Vaasan yliopisto

UNIVERSITY OF VAASA

Giau Huynh

Business intelligence in the electrical power industry

School of Management
Master's thesis in Strategic
Business Development

Vaasa 2020

UNIVERSITY OF VAASA
School of Management
Author:	Giau Huynh
Title of the Thesis:	Business intelligence in the electrical power industry.
Degree:	Master of Science (M.Sc) in Economics and Business Administration.
Programme:	Strategic Business Development
Supervisor:	Jukka Partanen
Year:	2020 **Pages:** 75

ABSTRACT:
Nowadays, the electrical power industry has gained tremendous interest from both entrepreneurs and researchers due to its essential roles in everyday life. However, the current sources for generating electricity are astonishing decreasing, which leads to more challenges for the power industry. Based on the viewpoint of sustainable development, the solution should maintain three layers of economically, ecologically, and society; simultaneously, support business decision-making, increases organizational productivity and operational energy efficiency. In the smart and innovative technology context, business intelligence solution is considered as a potential option in the data-rich environment, which is still witnessed disjointed theoretical progress. Therefore, this study aimed to conduct a systematic literature review and build a body of knowledge related to business intelligence in the electrical power sector. The author also built an integrative framework displaying linkages between antecedents and outcomes of business intelligence in the electrical power industry. Finally, the paper depicted the underexplored areas of the literature and shed light on the research objectives in terms of theoretical and practical implications.

Contents

Figures

Tables

1. Introduction

In recent years, the electricity market has gained tremendous interest more than ever before due to the essential benefits for everyday life and the fact that the current sources for generating electricity are astonishingly decreasing (oil, gas, and coal could run out in over 53 years, 52 years and 150 years respectively if we carry on as we are, according to CIA World Factbook). Moreover, the contemporary methods of generating electricity are affecting nature (mainly fossil fuels) or bring a high risk for humans and the natural ecosystem (nuclear power). Many countries have invested in smart and clean electricity projects to find solutions for the future. The topic is becoming an important concern of researchers, practitioners, and leaders not only in the electricity field but also in other research dimensions like information system, information technology, data science, business intelligence, just to name a few.

From the viewpoint of sustainable development encompassed three layers of economically, ecologically, and society, the energy industry's objectives, on the one hand, focus on environmental sustainability and society issues, and on the other hand, must have the profitability goal itself. In that context, the development of smart technologies (smart grids, smart meters, and smart sub-stations) and information systems are considered as potential step for the former objectives (for instance, Finland, Sweden, Germany), which, at the same time, has changed the way of operation in electricity market. The latter goal can be obtained by a system that supports business decision-making, increases organizational productivity and operational energy efficiency. Although the technological assets continuously move forward to the next level, the management system's collar still procrastinates in the cycle of traditional resources. Besides, a massive amount of real-time data has not yet been used as it possible to be and often returned in term of daily, monthly, quarterly, yearly reports or analysis paper. Many professionals answer the calls with profound contributions, such as real-time/right-time business intelligence (Popeangă & Lungu, 2012; Liu, 2014); real-time electricity pricing (Allcott, 2011; Krishnamurthy et al., 2018); electricity demand-side management from real-time aspect (Qian et al., 2013); day-ahead energy market

model (Conejo et al., 2005; Bakirtzis et al., 2007); business analytics (Seufert & Schiefer, 2005); analytics (Escobedo et al., 2016); energy informatics (Watson et al., 2010).

However, the energy sector notably still lacks deserved attention where heavy pressure of environmental and societal problems still lay on. The absence of research illustrating the capability of providing measurable, actionable intelligence that bolsters organizational strategic decision making and managing the complexity of operational and production processes in the electricity industry is the primary motivation behind the choice of this thesis research questions. The existing discussion of business intelligence in electrical power sector has generated a set of dispersive and overlapping constructs: business intelligence swinging from stand-alone decision-making support system to a multidimensional business intelligence system (Felden & Buder, 2011; Wang & Chuang, 2015; Park et al., 2015; Lukić et al., 2016; Chongwatpol, 2016); business intelligence at a component-level like data warehouse architecture (Li et al., 2013, Garwin & Marcinkowski, 2017), data visualization (Lea et al., 2018); as a business model in supply chain management or market operator (Lukić et al., 2015; Radenković et al., 2018); and as an energy management system (Al-Ali et al., 2017). The proliferation of the concepts nurtures discrepancies among different components of a process whereas needs to be approached as an entirety for inter-complementary purpose. The electricity industry is not nascent; however, with innovation in technologies, it is expected to witness a pluralism of intelligence-related contributions examining the common issues from a multitude of angles to advance toward maturity. Business intelligence, in that context of the electricity sector, witnesses disjointed theoretical progress. This state of affairs calls for a proper literature review that links the field and builds and body of knowledge to nurture our understanding. Hence, this thesis aims to answer two research questions that investigate, and systematic review of the contributions related to business intelligence in the electrical power sector. In this paper, the research questions are formulated according to the PICOC paradigm of Petticrew and Roberts (2008):

Population (P):

For the purpose of this review, the application area is the antecedents that influence the utilization of business intelligence in the electrical power sector.

Intervention (I):

In this context, the methodology is the process whereby business intelligence concepts ensure optimal use in the data-rich and competitive environment of the electrical power sector.

Comparison (C):

According to the purpose of this review, it is the evaluation measures for business intelligence related business performance toward sustainable development, in comparison with the available or traditional alternatives.

Outcome (O):

In this context, this component represents the added value of business intelligence for the electricity-related companies, the electrical power market operators, as well as electricity end-users.

Context (C):

This element stands for the context in which the comparison takes place. For instance: industry or academia. The review contains (a) the articles involving experiments in academia that are unlikely to replicate the real electricity sector, as well as (b) a wide range of empirical studies in the field of energy efficiency management.

As a result, this paper's research questions disclose as below:

1. *What antecedents and processes influence the use of business intelligence in the electricity sector?*

2. *What are the outcomes of business intelligence and its role in the electricity sector?*

In this paper, the focus is to review business intelligence in the electrical power industry systematically. This study considers BI as an ambitious solution in turning the exponential amount of data into actionable information and generating real-time decisions. In contrast, it makes the difference in the operation process with small time-gap. By following a systematic literature review methodology, the thesis aims to clarify and build a systematic review of business intelligence in the electrical power sector in terms of a framework and body of knowledge which can be a guidance for further research. This study will collect the last two decades contributions of researchers, entrepreneurs and countries following with reviewing and synthesizing the role of BI in the electricity market. The paper also outlines the challenges that emerge during the implementation process and outcomes of BI systems following with directions for future research.

This thesis is organized in five chapters. Firstly, an overview of the contemporary electricity industry encompassing potential tools and possible scenarios in the industry is presented in chapter 2. In section 3, I outline the research design, which based on the protocol engineering the systematic literature review. Chapter 4 presents the results of a literature review with linkages between the antecedents and outcomes of business intelligence in the electrical power industry. Following, an integrative framework is constructed to show the relationship among each element is included in this section as well. Finally, a scrutiny of the body of knowledge is generated to depict the underexplored areas of the literature and shed light on the research objectives in terms of theoretical and practical implications, and then I close the paper with limitation and suggestion for future research.

2. Review of the global contemporary energy/electricity sector

As this section focuses on the development of the energy industry, particularly electricity power, the scope of the review may pay more attention to developed and developing countries that are on top of the electricity domain to clarify the contemporary transformation and future tendency.

2.1. Scenarios of the future electrical power industry

It is an inevitable fact that the world cannot move forward without energy, especially electricity, which is, however, a double-edged sword. Meanwhile, the current sources for generating electricity are astonishingly decreasing as mentioned above. In another aspect, the current methods of generating electricity are affecting the nature (mainly fossil fuels) or bring high-level of risk for human and the natural ecosystem (nuclear power).

A variety of scenarios about the global energy trends have put on the table for consideration. All the scenarios represent the future solutions for the electricity industry to maintain the total amount of generation, simultaneously, reduce the emissions discard to the natural environment, and minimize the total cost at the same time. On the one hand, major transformations are underway for the global energy sector, from the growing of renewable and clean generators to significant investment in high-technology assets such as smart grids, smart metering, smart substation, as well as policy choices made by governments, by which will determine the shape of the energy system in the future.

On the other hand, extreme weather, global climate engagement, and fragmented policy in emission measurement are other concerns that that need to be considered. In Europe, although the EU reduced its use of fossil energy sources and occurring a shift towards increased renewable energy globally, renewable energy is not growing strongly enough to offset the increase in energy consumption. Other countries that are on top of

consuming and producing energy are also having their first achievements in reducing fossil energy and extending renewable energy.

From the viewpoint of a renewable generator, Statkraft (2019)– a Norway company leading in hydropower- proposes a *Low emissions scenario 2019-2050*, which is demonstrated as in Figure 1 and 2:
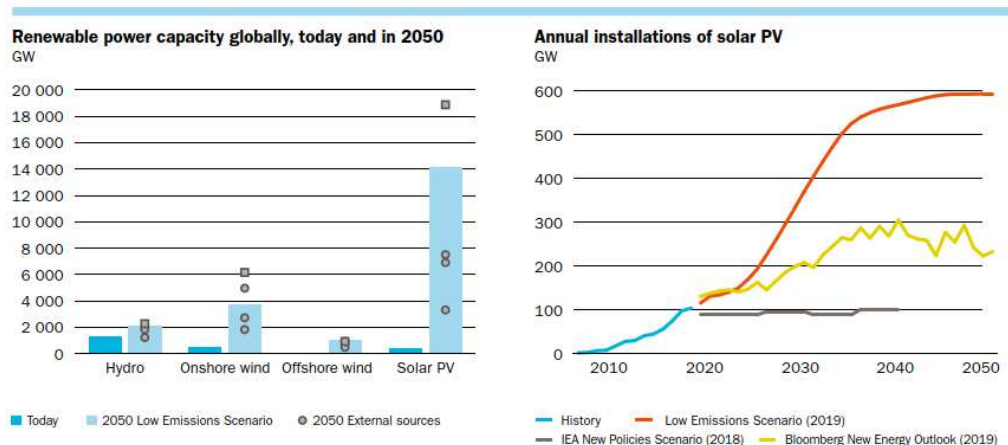
Figure 1. Renewable capacity today and in 2050 for the Low Emissions Scenario and external sources (left). Annual expansion of solar power capacity, per year (right) (Statkraft, 2019).
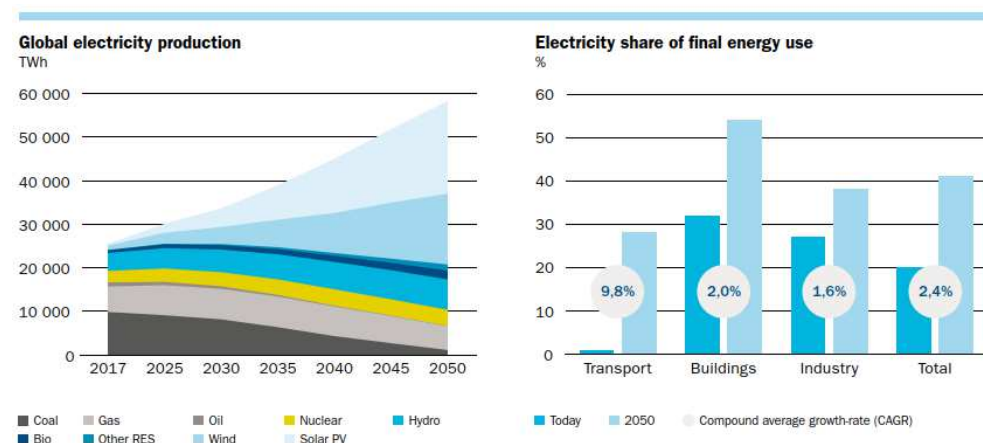
Figure 2. Electricity production to 2050 in TWh (left). The electricity shares of final energy use per sector today and in 2050 and compound average annual growth rate per sector (right) (Statkraft, 2019).

In sum, the global tendency of the energy sector is moving toward sustainable development, at the same time, achieving energy efficiency in the whole process of

generation, transmission, and consumption. In terms of the electricity industry, there are three main streams:

Stream 1: Renewable energy

Energy from renewable sources is an inevitable movement of the energy sector according to the fact that fossil fuel will soon be running out shortly, as mentioned above. In the last few years, the industry had attempted to overcome the barrier of substantial initial investment or relatively high price to expand the scale of renewable energy generators and its production capability. Beside immense support from the national government in terms of energy subsidies, taxes, and policies, gigantic concentration in technology development also tackles the impediment in many means. One significant application in the field is to integrate variable generation into the grid, which interconnected electricity markets and smarter grids with more elastic demand. In the transformation of the energy industry, numerous sources of energy are in consideration, some of them are outweighed other genres, namely:

- Wind power: onshore and offshore wind (policy support: Production Tax Credit – PTC)
- Solar PV (policy support: Investment Tax Credit - ITC)
- Hydropower

In 2020, the competitive market will presumably evolve further to encompass not just renewable versus traditional resources, but also renewables in competition with each other (Deloitte, 2019). Furthermore, fusion of different energy-related sectors, for instance, "heating and power plant" to reduce the total amount of energy needed, will relatively change the face of the traditional energy sector.

- Green model,
- Hybrid model,
- Heating and power plant

In sum, using sustainable sources for electricity generation, on the one hand, facilitate to replace traditional sources of energy that is enormously running out, on the other hand, assist in reducing energy-related greenhouse gas emissions.

Stream 2: Extensive-technology energy industry

As mentioned above, technology is a core property for the future energy industry; simultaneously, it is a glue to integrate with numerous sectors, which can give the energy industry a boost and expedite the progress to achieve sustainable goals. With the same direction in mind, residential energy management, information systems management, and technological elements have made the fusion and are implementing in many ways:

- Smart technology fuse with information systems management: new source of data which for identify customers' behavior, predicting demand, reduce lost during transmission, efficiently deliver sustainable, economical and secure electricity supplies
- Smart building
- Real-time business intelligence –> day ahead market
- Self-supply model

Key technologies at all levels of organizational processes in the electricity sector will impact the entire energy industry, which can mention by smart grids, smart metering, smart substation, etc. Technologies that have been developed are:

- Energy storage
- Microgrids and AI
- Energy blockchain and IoT
- Automation technologies

Stream 3: New national policies and global commitments

The influential role of national policies and global commitments together with critical technological development and the market transition will reinforce each other and permanently move in the same direction.

The new Renewable Energy Directive (REDII) was approved on 3.12.2018. The EU target of the share of renewable energy sources is 32 per cent of energy end consumption by 2030. To support that outcome, the government provides investment support and operating support, such as price subsidies, green certificates, tender schemes, and tax reductions for the production of renewable electricity.

In a close connection with energy industry transformation, electrification transitions in other sectors such as buildings, industry, and transport are also considered as attractive solutions that co-create the sustainable scenario. Some of the achievements can be reviewed as follows:

- Intelligent building:
  - Capital Tower, Singapore
  - Hindmarsh Shire Council Corporate Centre, Australia
  - Duke Energy Center, Charlotte, NC
  - The Crystal, London
  - Burj Khalifa, Dubai
    (Sources from the internet)
- Smart industry – Industry 4.0
  - BJC HealthCare (15 hospitals in Missouri and Illinois) adopts IoT for inventory and supply chain management
  - Bosch Automotive Diesel factory (China): Big Data decision-making
  - Volkswagen Automotive Cloud: Volkswagen joined with Microsoft to develop a cloud network
  - DHL (California): Fetch Autonomous Mobile Robots improve warehouse operations and logistics facilities. (Source:

- Electrification transportation alters the customers' behaviors in consumption
  o Private vehicles: hybrid and electric cars, trucks, bicycles, etc.,
  o Public transportation: electric buses, tram lines, etc.,

The energy industry has changed in the past three decades, mainly in two terms. Firstly, the energy market moved from a closed and mostly controlled by the national state to an open and free competitive market. The EU member states started to reform the previously closed electricity markets during the 1990s. The electricity transmission, however, is still a monopoly and controlled by national authorities. The second movement is to make the energy industry become a sustainable industry by many 10-20-30 years of projects and commitments. In 2006, there was EU directive 2006/32/EC on energy end-use efficiency and energy services. In the year of 2003, the term Smart Gird was ever used for the first time. Smart Grid is made Smart by using protection system of the grid and central control through Supervisory Control and Data Acquisition (SCADA) system, diagnostic monitoring of all transmission equipment, treating all the power system as a complex adaptive power system, Grid Computing, making the power system a self-healing network using distributed computer agent (Amin and Wollenberg, 2005). Then in 2010, the installation of smart electricity meter is required by law in Germany (EnWG § 21c subpar. 1 a, b, c, d). For instance, in October 2014, the 2030 energy framework aims to make the European Union's economy and energy system more competitive, secure, and sustainable (European Commission, 2014). Following is energy savings of 9% and 80% of EU consumers having smart metering systems by the EU regulations in 2016 and 2020, respectively. Asian countries also response to the global tendency, for example in 2019, Energy ministers from across Central Asia today committed their countries to collaborate on meeting the United Nations' seventh Sustainable Development Goal (SDG), which pledges "affordable and clean energy" by 2030 (according to Energy Investment Forum, 2019).

2.2. Potential solutions for the electrical power industry

Business intelligence

Business intelligence has generic concepts and not-well defined terms, which has numerous definitions by professionals in the industry. According to Wayne W. Eckerson (2010), Director of Research and Services for The Data Warehousing Institute (TDWI), "business intelligence is an umbrella term that encompasses a raft of data warehousing, and data integration technologies as well as querying, reporting and analysis tools that fulfil the promise of giving business users self-service access to information."

Generally, BI encompasses a broad concept. Firstly, BI tools derive actionable information from different-sources-of-data (Petrini et al., 2004), as well as discover patterns, relations, and correlations between data. Secondly, business intelligence spans through an array of research areas including Online Analytical Processing (OLAP – Thomsen, 2002), Data Warehousing (DW), Decision Support Systems (DSS), Executive Information Systems (EIS) with a set of methodologies, processes, architectures, technologies, and applications that transform raw data into useful and actionable information for business decision-makers in order to improve business performance (Wixom and Watson, 2010). To put those elements in a relevant linkages framework, Affeldt and Junior propose a BI architecture framework which comprises: Data Warehouses, Data Marts, External Information, Source Systems, OLAP, Data Mining, Balanced Scorecard, OLTP Process – Transactional, Data Warehousing, OLAP Process, Legacy IT (view more from Framework of BI Architecture, Affeldt and Junior, 2013, Figure 3). The framework clarifies the contributions of each technological tool to assist managers in the decision-making process in terms of software (Affeldt and Junior, 2013).
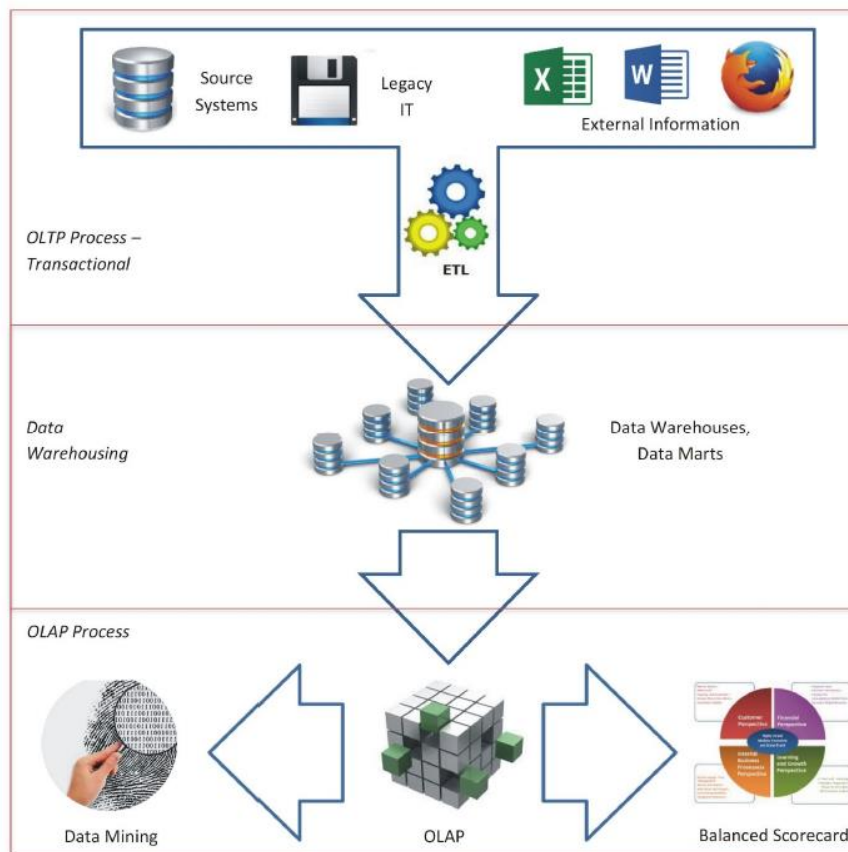
Figure 3. Framework of BI Architecture (elaborated by Affeldt and Junior, 2013, then developed by Gawin and Marcinkowski, 2016).

In those elements, Data Warehouse is the foundation of a BI-related system, particularly in the energy sector. Since energy-related systems require data from numerous sources, in forms of various patterns, simultaneously captured every aspect of the operational process, a data warehouse must have high-level functions. For any data warehouse, the infrastructure that facilitates the retrieval of data from operational databases into the data warehouses is known as the ETL process, which stands for Extraction, Transformation, and Load. Data in the data warehouse captured various aspects of the business by which actionable information can be extracted for supporting the decision-making process. According to Radziszewski (2016), input for data warehouse can be categorized in many ways:

i. Input types:
   o Internal sources: transactional data from information systems – ERP, CRM, data from organization's website
   o External sources: social media, reports, market surveys, external systems and databases

ii. Organization of the input data:
   o Structured data: data that has been organized into a formatted repository like a record or file which includes relational databases and spreadsheets
   o Unstructured data: data that does not reside in a conventional database, and is usually not easily searchable, for instance: videos, photos, audio files, email messages, etc.

iii. Data reliability:
   o Transactional data: data from transactional systems – CRM, ERP
   o Declarative data: data collected from social networking sites, contains information about the intentions in place of actual decisions and transactions

Since the technological and IT infrastructure of the energy industry has developed at rapid speed, new sources for data input have been identified, such as Internet of Thing – IoT, smart technologies as smart metering, smart grids, artificial intelligence – AI, just to name a few.

In recent years, organizational managers have expanded the scope of data sources to every aspect of the business to capture a comprehensive insight and make use of those new data sources; they can be a research market in terms of interviews, scanning, or data collected from publicly available sources like a press, radio, TV channels – open-sourced intelligence OSINT (Gawin and Marcinkowski, 2016)

The main categories of business intelligence technologies are querying, reporting, online analytical processing (OLAP), data mining, business performance management (BPM), and so on (Popeangă and Lungu, 2012).
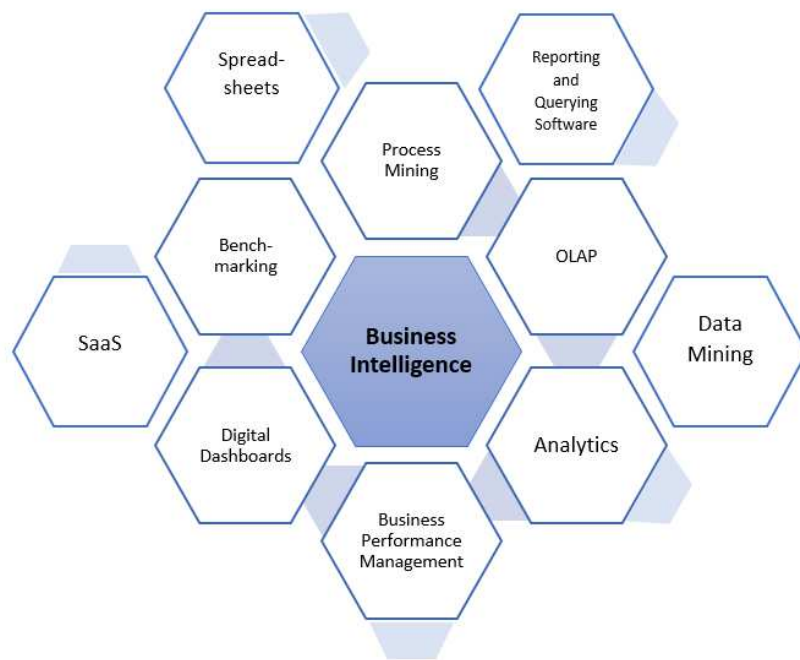
Figure 4. Some of the main functions of BI technologies (Popeangă and Lungu, 2012).

According to Azvine et al. (2005), the contemporary direction of Business intelligence is toward real-time data together with real-time actions in response to analysis results. Especially, enterprise decision-makers demand real-time actionable information from analytic applications using real-time business performance data, and these insights should be accessible to the right people exactly when and where they need them (Azvine et al., 2005). Furthermore, advances in technology, especially the internet and modern ICT technologies, make real-time business intelligence seemingly achievable.

In general, business intelligence has two main streams: one treating business intelligence as a system, another illustrating it as a decisional paradigm (Talaoui, 2015). In the electrical power industry, business intelligence is treated as a system, including decision-making functions either in firms or in the electricity market.

To design a business intelligence system and determine an appropriate implementation of a solution, Lukić and colleagues (2016) have proposed a hybrid methodology for designing business intelligence systems that can build in parallel with the contemporary organizational rules. The primary objective of the mixed methodology is to tackle the

complexities in the processing of utility companies using a comprehensive data warehouse solution. The solution deploys strong points from two methods: the Kimball Lifecycle (Kimball et al., 2008) and ASAP methodology (Hazebrouck and Frerichs, 1999). In 2018, Lukić and colleagues continued introducing a BI solution for the electricity market with necessary data flows and information for forecasting, data analysis, and decision making, aiming to better business performance and more control over the market in the data-rich smart grid condition.

The application of multidimensional BI impacts the following areas: customer behaviour, technical indicators, economic indicators, and management and decision-making (Hoss, 2012; Kaleta & Toczyłowski, 2009).

A survey on recent research in business intelligence, conducted by Aruldoss and coworkers (2014), reveals that business intelligence offers different solutions in which the widely applied solutions are algorithm-based, architecture-based solutions, and model-based solutions. According to the survey, a wide range of business intelligence components encompass:

- Data source and extraction: data collection, data integration, ETL, data pre-processing, data linking
- Data storage: data warehouse, data mart, database
- Feature extraction: feature filtering, rule filtering, context cache
- Knowledge base: new knowledge, technological intelligence, knowledge identification, market intelligence
- Data analysis: factor analysis, dimensional analysis, situation assessment, OLAP, OLTP
- Software agents: business agent, AI agent, management agent, evaluator agent, expert agent, advisor agent
- Reporting: reporting portal, reporting tools, annotation, dashboard
- Information management: information extraction, relation extraction, unstructured information, structure information

- Data mining: stream mining, sales data mining system, mining comparative opinions, parallel data mining
- Business intelligence and integration: CRM, ERP, SOA, business process management

Moreover, business intelligence solutions can be applied to different domains, especially in a data-rich environment, to tackle different kinds of problems (Aruldoss et al., 2014). Some examples of the key solution of business intelligence are BI framework, BI architecture, relation/information extraction techniques, integration of BI with other techniques, BI reference model, BI decision support, data collection techniques, BI with information management, enhanced data mining techniques, and so on.

With the drastic development in technology and dynamic business environment, the corporate decision-making process demands a business intelligence system that includes data warehousing, data integration technologies as well as querying, reporting and analysis tools to generate actionable information at the right time (Eckerson, 2010). Moreover, those insights need to be accessible to the right people exactly when and where they need them (Azvine et al., 2005).

The appearance of smart-grid technologies (Gungor et al., 2011), such as advanced metering and sensor infrastructures (Martac et al., 2016), slowly pushes firms to engage in the business intelligence environment for new requirements in companies' information systems and need for real-time analytics.

In the era of big data, BI opens the door to various opportunities to deal with the massive amount of data not only by integrating platforms to handle more complex, unstructured data with emerging data sources but also by emphasizing the analytical process enabled by big data (Phillips-Wren et al., 2015).

The infrastructure of the competitive electricity market mostly has three elements encompassed generation, transmission, and distribution companies; thus, the business intelligence system also has different objectives depending on one or more end-users it serves. The main functions of the business intelligence system, however, moderately

associated with decision-making processes that provide actionable information derived from the massive amount of data.

Researchers in the domain of the electricity sector approaches the business intelligence field in various angles derived from different kinds of problems. As a result, business intelligence's definition can be varied to some extent, which can be seen below.

Table 1. The definitions of BI constructs according to the literature.

Author(s)	Business intelligence definition
Lukić et al., 2016	"complexity of the data-warehousing solutions and their high implementation cost … "
Rajan, 2009	BI is a methodological transformation of data from any source system into information suited for result-oriented decision-making
Seufert and Schiefer, 2005	BI's primary goal is to offer support that, through a closed loop, links strategies, design, and execution with business intelligence
Al-Ali et al., 2017	"… business intelligence (BI) platform plays an essential role in energy management decisions for *homeowners* and the utility alike."
Garwin and Marcinkowski, 2017	"… BI solution … support the transformation of data into information for support decision-making … provides real-time energy usage information and advanced analytical capabilities that enable continuous improvements in energy management …"
Flath et al., 2012	"… BI significantly supports decision makers …"
Harison, 2012	"Some scholars refer to BI as a tool (Grave, 2005), while others regard it in the broader context of a technology (Gibson et al., 2004; Hannula &Pirttimaki, 2003)."
Lea et al., 2018	"… visualization prototypes … were built upon a business intelligence platform utilizing OLAP functions."

Park et al., 2015	"Business intelligence is a concept or method to improve business decision making by using fact-based support systems …"
Radenkovic et al., 2018	"BI solutions based on data warehousing technology are becoming a standard in the electricity markets."
Felden and Buder, 2012	"A BI reference model represents all the necessary requirements of regulatory and strategic asset management."
Wang & Chuang, 2016	"The concept of BI is adopted to implement the BSC framework to achieve effective performance measurement and efficient performance management."
Chongwatpol, 2016	"Business intelligence … growing importance in supporting business decisions … to deal with big data … an umbrella term that combines architectures, tools, databases, analytical tools, applications, and methodologies to aid in decision making …"
Lukić et al., 2017	"… benefits of BI include cost reduction, optimization of business process across the supply chain and increase in profit … most frequent application is for speeding up the reporting process, and integrating information from various sources … support for trading on the wholesale electricity market … "
Hou, 2016	"… BI systems can provide real-time information, create rich and precisely targeted analytics, monitor and manage business processes via dashboards that display key performance indicators, and display current or historical data relative to organizational or individual targets on scorecards."
Liu, 2014; Wixom and Watson, 2010	"… Business Intelligence (BI) … is an umbrella term to describe a set of methodologies, processes, architectures, technologies, and applications that transform raw data into meaningful and useful information so as to provide actionable insights for business decision makers."
Escobedo et al., 2016	"It is imperative that companies have an in-depth knowledge about factors such as the customers, competitors, business partners, economic environment, and

	internal operations to make effective and good quality business decisions. Business intelligence enables firms to make these kinds of decisions."
Popeangă and Lungu, 2012	"Real-time business intelligence is the process of delivering information about business operations as they occur, with minimum latency."

Supply chain intelligence system in the energy market.

A study in this stream investigates and evaluates a business intelligence model within the Serbian transmission system and electricity market operator. Lukić and colleagues demonstrate that there are two main elements in the electricity supply chain that have influences on the electricity market: one is the smart grid, the other is a real-time business intelligence system. The former one is considered as a complete information architecture and infrastructure system covered the entire electricity value chain: power generation, transmission, distribution, and electricity networks (Li et al., 2013), which optimizes electricity delivery as well as bidirectional communication between the system operator and grid users. The latter one is expected to integrate various data sources, extract and display KPIs, leverage existing investment, improve scalability and security, and save resources and costs (Lukić et al., 2017). Escobedo et al. (2016) emphasized the crucial role of business intelligence and data analytics in a smart grid environment to make better decisions and reduce the number of accidents and incidents.

It is worth mentioning the research stream that emphasized the crucial role of Key Performance Indicators (KPIs) in the managerial decision-making process within the business intelligence system environment. In the current context, KPIs are widely used in many companies to measure business processes where business goals are translated into KPIs (Lukić et al., 2016; Masayna et al., 2007). In 2014, Personal and colleagues proposed a new approach of BI entirely focused on a metric of key performance indicators (KPIs), outlining proactive performance management through a combination of performance indicators capability and alerts. In the same vein, Martin-Rubio et al.,

(2015) propounded that BI solutions in smart grid companies should encompass selected important KPIs.

Also derived from the idea of monitoring KPIs to capture insights and deliver an analytical solution to power producers, a study in coal-fired power plants is conducted to investigate the behavior of the electricity generation processes and indicate significant factors that affecting combustion efficiency. For a solution, Chongwatpol introduces a business intelligence framework that managing big data and prioritizing the significant plant-wide signals associated with the emission of NOx in the combustion process to improve the performance of the plant (Chongwatpol, 2016).

Within this stream, Wang and Chuang introduce an integrating decision tree with a back-propagation network to conduct business diagnosis and performance simulation in solar companies. In order to improve the performance outcomes, the decision tree rapidly identifies KPIs to fast forecast ROE and EPS as well as the causalities between predictors and outcomes to choose which KPI should be firstly adjusted (Wang and Chuang, 2016).

Energy informatics (EI)

Watson and his colleagues propose a new subfield of Information Systems (IS) in 2010 called energy informatics, which plays a role in reducing energy consumption and CO2 emissions. In 2013, a scope of energy informatics research was stated with two overall goals of energy efficiency and renewable energy supply derived from the development of smart energy-saving systems and smart grids, respectively (Goebel et al., 2013), as in the figure below:
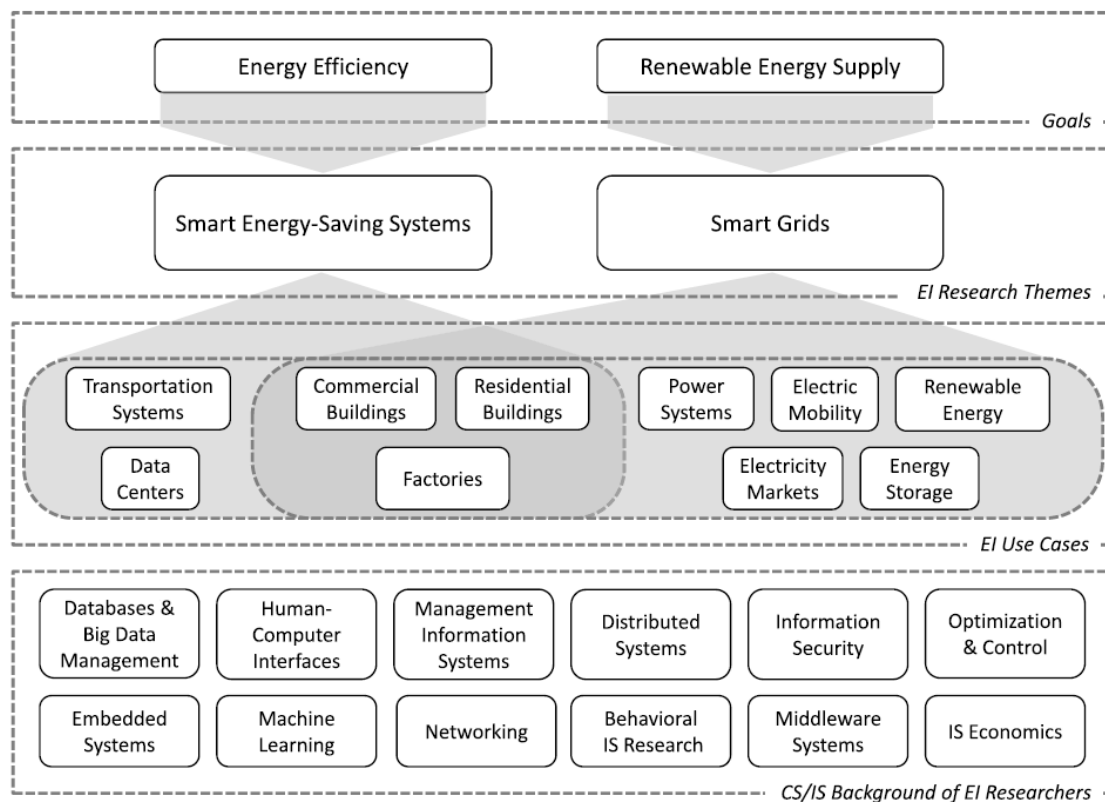
Figure 5. Scope of energy informatics research (Goebel et al., 2013).

Energy informatics encompasses analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems (Watson et al., 2010). With the core idea of using information systems and technology to increase energy efficiency, energy informatics collects the data from smart devices like smart grids, smart metering, to extract information that supports to balance the supply and demand sides with the condition of sustainable requirements. Many researchers have watered the tree of EI, such as commercial and residential buildings, data centers, electric mobility (Kozlovskiy et al., 2016; Khorram et al., 2018), industry 4.0 in corporate energy management (Junker and Domann, 2017), etc.

A framework of energy informatics represents the relationship among different components with the core function of the information system (view more in Figure 9).
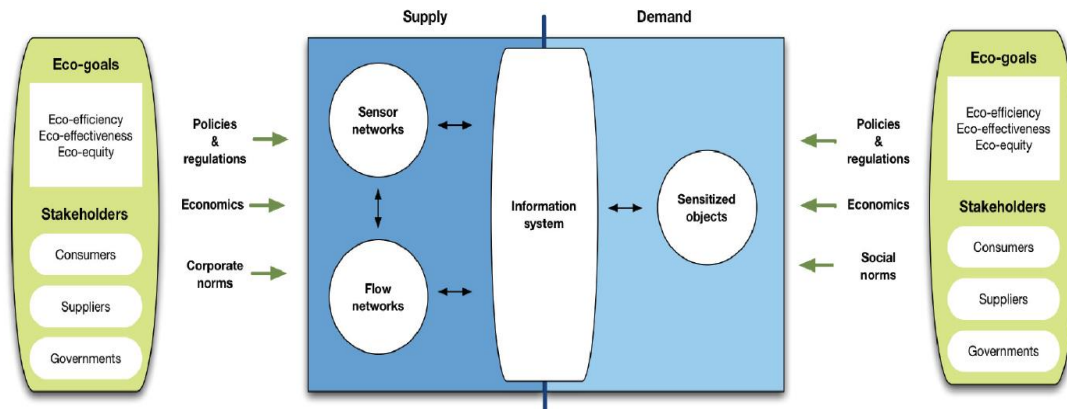
Figure 6. Energy informatics framework (Watson et al., 2010).

In sum, energy informatics focuses on energy efficiency derived from information systems and smart technology with the interdependencies between supply and demand and significant components.

Demand-side management model

The ever-increasing share of renewable energy brings a high level of uncertainty due to the volatile nature of renewable sources like wind, solar, or hydro (Paulus & Borggrefe, 2011). Demand-side management (DSM) is considered as one of the potential solutions for the increasing amount of inflexible production according to Finland's transmission system operator – Fingrid, which is defined as below:

"Demand-side management means transferring electricity consumption from hours of high load and price to a more affordably priced time, or temporarily adjusting consumption for the purpose of power balance management."

By encouraging electrical power users to optimize their energy use, DSM delivers two-fold of potential benefits: (a) customers can reduce their electricity bills by adjusting the timing and amount of electricity use; (b) the energy system can benefit from the shifting of energy consumption from peak hours to non-peak hours. Put differently, DSM can reduce the risk of imbalance of supply and demand of renewable-intensive energy industry, provide a given degree of reliability, and lower the system operation costs

27

(Paulus & Borggrefe, 2011). Palensky and Dietrich (2011) demonstrate DSM as a portfolio of measures improving the energy system at the consumption side, which ranges from improving energy efficiency by using better materials to sophisticated real-time control of distributed energy resources.

Hence, many countries, such as German, Finland, and China, realized the crucial role and utilized DSM in their transformation and restructured progress in the electricity industry (Paulus & Borggrefe, 2011; Bergaentzlé et al., 2014; Hu, Moskovitz & Zhao, 2005).

3. Research design

This paper follows the guidelines for performing systematic literature reviews by Kitchenham (2007). The research methodology is, therefore, structured in five-step as demonstrates in Figure 7.
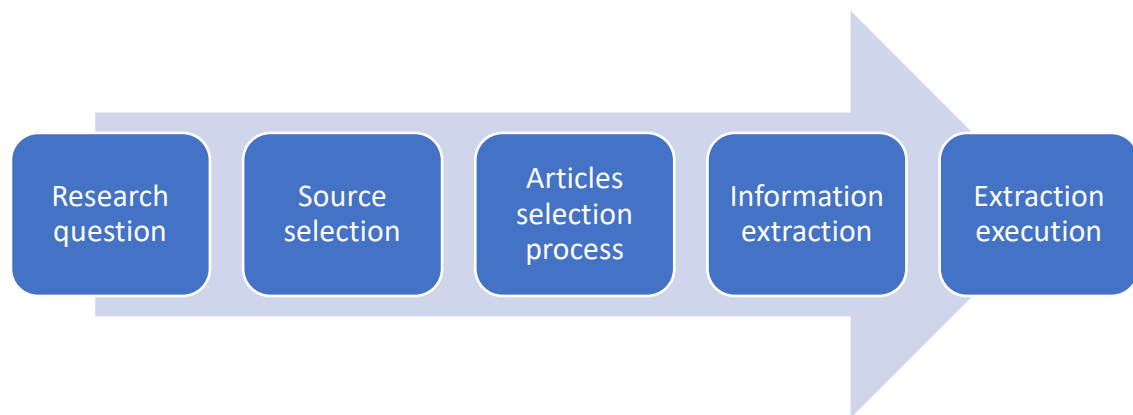
Figure 7. Research methodology's structure.

A systematic literature review is the theoretical foundation of this paper, in which it identifies the selection of articles susceptible to providing compelling insight into business intelligence emerging in the electrical power industry. Since there are no specific guidelines about the threshold number of databases - source selection is based on the author's best knowledge about the relevant and the reputable ranking among

scholars of strategic management, energy management, and information management fields.

3.1. Source selection

The database selection stage in this paper is mostly based on the best of the author's knowledge combining with the interdisciplinary nature of business intelligence literature since there are no guidelines in the field. Therefore, Business Source Premier (EBSCO) and Scopus database are chosen by their influential and reputable scholars of strategic management, operation technology and management, and information system management fields.

Pilot research of keywords was conducted in the databases with two keywords: business intelligence and electricity/energy. The pilot research aims to explore and gather all keywords related to the domain. Then, all the keywords will be collected and filtered regarding the research questions.

3.2. Articles selection process

A systematic search is conducted in Business Source Premier (EBSCO) and Scopus databases with a twofold technique: one involving keywords, and another based on content title. All the search queries that apply to each database are limited to peer-reviewed articles published in top-ranking journals in the last two decades. Inevitably, the search result will also yield the duplicated and poorly ranked journals; therefore, a careful examination is required to extract the acceptable and relevant ones.

3.3. Information extraction

Following the data extraction employed by Hutzschenreuter and Kleindienst (2006), all the articles will be coded and stored in an excel sheet in terms of summarizing the selected sample, the methodology of the study, and the key findings. The process can be seen in Figure 7.

3.4. Extraction execution

This stage will be about narrow down the number of articles were collected from the initial stage to phase four, which is indicated in as follow:
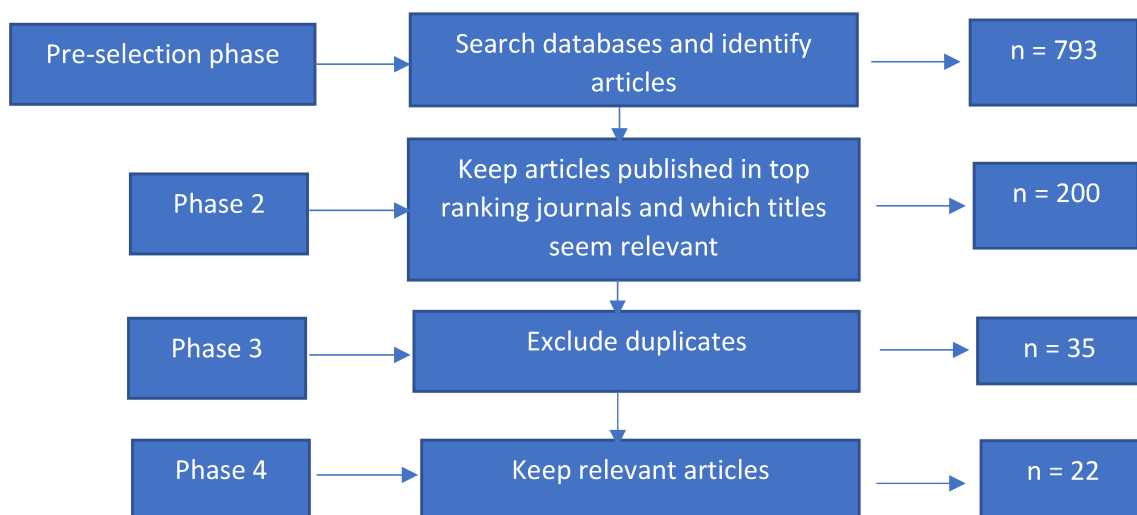
Figure 8. The selection phases of systematic review.

Table 2. List of keywords and journals of the systematic literature review.

KEYWORDS	
("Business Intelligence" OR "Business Analy*t*" OR "Competit* Intelligence" OR "Competit* Analy*t*") AND ("Energy" OR "Electric*" OR "Utilit*")	
Group fields	**Top peer-reviewed Journals (Grade 4*-3/ABS2015)**
Group 1: Information management:	"Information Systems Research" OR "MIS Quarterly" OR "Journal of Management Information Systems" OR "Journal of the Association of Information Systems" OR "Computers in Human Behavior" OR "Decision Support Systems" OR "European Journal of Information Systems" OR "Expert Systems with Applications" OR "Government Information Quarterly" OR " Information and Management" OR "Information and Organization" OR "Information Society" OR "Information Systems Frontiers" OR "Information Systems Journal" OR "Information Technology and People" OR "International Journal of Electronic Commerce" OR "International Journal of Human-Computer Studies" OR "Journal of Computer Mediated Communication" OR "Journal of Information Technology" OR "Journal of Strategic Information Systems" OR "Journal of the American Society for Information Science and Technology (JASIST)"
Group 2: Innovation, general management, ethics and	"Journal of Product Innovation Management" OR "Research Policy" OR "Research Policy" OR "Technovation" OR "Academy of Management Journal" OR "Academy of Management Review" OR "Administrative Science Quarterly" OR "Journal of Management" OR "British Journal of Management" OR "Business Ethics Quarterly" OR "Journal of Management Studies" OR "Academy of Management Perspectives" OR "Business and Society" OR "California Management Review" OR "European Management Review" OR "Harvard Business Review" OR "International Journal of Management Reviews" OR "Journal of Business Ethics" OR "Journal of Business Research" OR "Journal of Management Inquiry" OR "MIT Sloan Management Review"

social responsibility:	
Group 3: Operations and technology management, Operations research and management science:	"Journal of Operations Management" OR "International Journal of Operations and Production Management" OR "Production and Operations Management" OR "Computers in Industry" OR "IEEE Transactions on Engineering Management" OR "International Journal of Production Economics" OR "International Journal of Production Research" OR "Journal of Scheduling" OR "Journal of Supply Chain Management" OR "Manufacturing and Service Operations Management" OR "Production Planning and Control" OR "Supply Chain Management: An International Journal" OR "Management Science" OR "Operations Research" OR "European Journal of Operational Research" OR "IEEE Transactions on Evolutionary Computation" OR "Mathematical Programming" OR "ACM Transactions on Modeling and Computer Simulation" OR "Annals of Operations Research" OR "Computational Optimization and Applications" OR "Computers and Operations Research" OR "Decision Sciences" OR "Evolutionary Computation" OR "Fuzzy Optimization and Decision Making" OR "IEEE Transactions on Cybernetics (formerly "IEEE Transactions on Systems Man and Cybernetics Part C (Applications and Reviews)")" OR "IEEE Transactions on Systems, Man, and Cybernetics: Systems (formerly "IEEE Transactions on Systems, Man and Cybernetics - Part A: Systems and Humans")" OR "IIE Transactions" OR "INFORMS Journal on Computing" OR "International Journal of Forecasting" OR "Journal of Heuristics" OR "Journal of Optimization Theory and Applications" OR "Journal of the Operational Research Society" OR "Mathematics of Operations Research" OR "Naval Research Logistics" OR "Omega: The International Journal of Management Science" OR "OR Spectrum" OR "Reliability Engineering and System Safety" OR "SIAM Journal on Optimization" OR "Transportation Science"
Group 4: Sector studies:	"Journal of Service Research" OR "Energy Journal"

Table 3. Linkages – Exploring Review matrix.

No.	Author(s)	Industry firm characteristic region	Sample size method	Linkage(s)	Key findings
1	Argotte et al., 2009	Electricity market	survey	A-III, B-I, c-IV	BI is considered as solution for electricity market that tackles challenging electricity market issues like prediction, pattern recognition, modeling, and others.
2	Flath et al., (2012)	A German regional utilities companies	data analysis, case study	A-I — B-I, B-I — C-I	Integrating cluster analysis in BI environment and apply to real smart metering data can identify customer segmentation based on timely consumption behavior.
3	Harrison (2012)	Energy sector	Case study and data analyses	B-I	Measurement method for BI system implementations
4	Felden and Buder, 2012	Grid companies	proposed model validated by expert interviews	A-I, B-II, C-I	A reference model with BI architecture integrates the asset management within information systems close the gap between the technical and financial perspectives in grid asset management.

5	Lv et al., 2012	Power grid enterprises in smart power field		B-I, C-I, C-II	A business intelligence system architecture based on cloud computing technology delivers better expansibility, faster processing speed, stronger security and so on for the intelligent power consumption.
6	Popeangă and Lungu, 2012	Utilities industry	Case study	B-V, C-I	The authors emphasized the importance of real-time BI in utilities industry. Real-time BI improves customer experiences and operational efficiencies.
7	Momeni & Mehrafzoon (2013)	Iran's power plant industry	case study	B	Critical competitive intelligence factors in Iran power industry
8	Li et al., 2013	Electricity utilization		A-I, B-I, C-I, B-IV, C-III	An intelligent electricity management system delivers better performance of efficient energy management and monitoring for both corporate decision-makers and electrical power users.
9	Liu, 2014	European electricity retail market		B-I, B-V, C-I, C-II, and C-V	Real-time business intelligence framework and a price-responsive demand modeling method provide insights of pricing differentiation and targeted retailing and develop demand response electricity retail market.
10	Park et al., (2015)	Building energy management	Real-world data analysis	A-II, B-II, B-III, C-I, C-II, and C-III	BI framework that helps buildings' managers easily identify indoor units that consume high levels of energy and provides clues on why this is occurring – improve Energy efficiency

11	Wang & Chuang (2015)	Solar energy	statistical schemes, machine learning techniques	A-I, A-III, B-I, B-II, C-I, and C-II	BI concept is incorporated into the balanced scorecard framework to help solar companies accomplish better performance measurement and management.
12	Lukić et al., (2017)	electric power transmission company Public Enterprise	Case study	A-III, B-I, C-IV	A BI model reaps immediate business value for a smart grid supply chain. Simultaneously, the model shows a more effective management of smart grids and ensure that firms can achieve sustainability while providing high quality service to end users in electricity market.
13	Gawin and Marcinkowski (2016)	Energy efficiency domain		A-II, B-I, B-IV, C-I, and C-III	A literature review on recent works of BI implementation in Energy Efficiency domain, especially focuses on data sources for BI analysis.
14	Escobedo et al., 2016	Operational BI, smart grid	Case study	A-I, B-I, C-II	A framework for the application of Business Intelligence and Data Analytics techniques applied in a smart grid environment aims to have available and timely information to make better decisions, to reduce the number of accidents and incidents.
15	Chongwatpol (2016)	coal-fired power plants in Thailand	Case study	A-I, B-I, B-II, C-I, and C-II	A ten-step business intelligence framework supports power plant management system in a complicated condition of coal-fired power plant.

16	Lukić et al., (2016)	Serbian: energy transmission system and market operator	case study	B-I	A hybrid methodology derives from the Kimball and ASAP methodologies that can be incorporated for BI system operating in data-rich environment.
17	Al-Ali et al., (2017)	Smart homes	Lab prototype mimics small residential area HVAC systems	A-II, B-I, C-III	An Energy Management System (EMS) helps to enhance the performance of energy consumption management and meet customers' electricity demand in smart homes.
18	Gawin & Marcinkowski (2017)	Polish subsidiaries	multiple case studies	B-I, C-III	Multiples Polish subsidiaries obtain positive results in energy management BI solutions focused on data sources to improve energy efficiency
19	Junker & Domann (2017)	corporate energy management		A-I	Operational energy management systems with existing IT-supported that harmonize ISO 50.001 and Industry 4.0 effectively and to optimize the operational energy efficiency.
20	Lea et al., (2018)	RES	Case study (research lab)	A-I, A-II, B-I, B-II, B-III, C-I, C-II, C-III	BI concepts are utilized as the foundation of a map that helps understand the positive impact of RES biofuel from microalgae.

21	Radenkovic et al., (2018)	Serbian electricity market operator		B-I, C-IV	BI systems solution for the electricity market in a data-rich smart grid environment, aiming to provide necessary data flows and information that support processes of forecasting, data analysis and decision making for better business results and more control over the market.
22	Yiying Zhang et al., (2019)	Intelligent community		B-I, C-III	A business intelligence architecture based on cloud computing, a multivariable, multidimensional intelligent electricity energy analysis model and a parallel algorithm that is proposed for the intelligent community and smart industrial park to improve the energy efficiency and functional applications.

A-I: Suppliers' factors   B-I: Business intelligence   C-I: Decision-making

A-II: Customers' factors   B-II: System operator   C-II: Operational and tactical

A-III: Market's factors   B-III: Generator   C-III: Sustainable development

B-IV: Decision support system   C-IV: Market intelligence

4. The results of the literature review

The results of the literature review in the electrical power industry, researchers approach the challenges in a variety of ways and simultaneously fuse with various domains stimulated by management information systems (MIS) (Klonowski, 2004). Leading positions in the field that can be mentioned are automated technologies, workflow and organizational process improvement (Jeston and Nelis, 2013), acquiring knowledge about systems and devices, mining data, and forecasting solutions (Lech, 2007; Gawin and Marcinkowski, 2017). In a competitive electricity market environment, the electrical power industry generally has four elements, including electricity generators, transmission system operators, distribution system operators, and retail business which share a mutual interrelationship.

The paper is limited in those articles that utilized business intelligence as a tool or a system or in combination with other devices that facilitate companies for achieving organizational and global goals in a competitive environment.

4.1. Antecedents of BI domain in the electrical power industry

Although data warehouse, data mining or information system appeared decades ago, the concept of BI in the electricity sector only emerged in the last ten years. That is because the antecedents of the BI domain in the electrical power industry have only burgeoned in recent years, including smart technologies, IT and computing science.

4.1.1. Supplier side factors
4.1.1.1. Technological development and IT sophistication

The development of technologies and IT sophistication in the electrical power industry influence on the emerging of BI was subject to multiple studies. Most of the researches

aim to turn a massive amount of data or real-time data into actionable information for better business outcomes and sustainable development. A high-volume data with high data creation rate and an increased variety of data (different formats, different rates, and various types) depend on the source (Gartner, 2014)- called Big Data - was utilized to describe the data derived from the electrical power sector with the assistance of smart technologies (Radenkovic et al., 2018; Lukić et al., 2017; Chongwatpol, 2016). Simultaneously, the availability of real-time data proliferates when there are increasing applications of sensors, wireless transmission, network communication, cloud computing technologies, and smart mobile devices (Zhou et al., 2016). Undoubtedly, big data and real-time data bring difficulties to the traditional information management system (Zhou et al., 2016) and affect all parts of the electricity supply chain, as well as leading to changes in market structure, business models and services (Radenkovic et al., 2018; Lukić et al., 2017).

While some researchers consider data warehouse as the most powerful technologies for storing, integrating, and analyzing complex data sets (Li et al., 2013; Lukić et al., 2016; Gawin and Marcinkowski, 2016); others attempted to capture business insights in terms of data mining (Flath et al., 2012), business diagnosis and performance simulation (Wang and Chuang, 2015), data analytics and BI (Escobedo et al., 2016) within the BI infrastructure or framework. Researches in this stream emphasized the importance to find a solution which collects, correlates and analyzes data from multiple sources, for various tasks, namely processes optimization, planning, prediction, diagnosis, decision-making, and re-evaluate the situations to determine whether further actions are required (Khanna et al., 2015, Hoss, 2012).

In addition, the very sophisticated, non-linear dynamic processes derived from complicated operating conditions and uncertainty variables, make it difficult to understand the energy consumption behaviour and to effectively control the operational parameters. Two studies in this stream reveal the complicated operational processes in the coal-fired power plants (Chongwatpol, 2016) and in algae-based biofuels production (Lea et al., 2018).

Further, a larger share of renewable energy means a more considerable influence of weather patterns in generation stage, follows with changes in plant location and production structure, consequently, makes the electrical power systems of industrialized economies to become one of the most complex systems.

4.1.1.2. Managerial decision-making roles

Nowadays, many electricity-related companies demand in developing the decision-making processes by capturing actionable information and insights from the exponential amount of data in the smart technology's environment. This tendency stems from various challenges that the electricity sector is facing, such as energy efficiency and environmental issues (Zhou et al., 2015), renewable energy management (Altin et al., 2010; Crăciun et al., 2012), system stability and reliability (Amin et al., 2008), and consumer engagement and service improvement (Aalami et al., 2010).

According to a study of Felden and Buder (2012), many empirical studies reveal that information supply and consolidation are error-prone and long-term processes due to the missing of automation in extraction, transformation, and loading. This makes a call for a framework that considers the coupling of financial and technical key figures, the coupling of strategic and operative key statistics, as well as the integration into the information system (Felden and Buder, 2012).

From a different angle, Popeangă and Lungu (2012) emphasized the important role of making real-time business decisions where companies confront competitive pressures. They demonstrated that a true BI solution must have the ability to integrate data from a variety of sources, compile and filter that data, simultaneously analyze and exhibit the data in a clear way for supporting rapid and confident decisions.

4.1.1.3. Operation complexity

Two studies in this stream reveal the complexity of electricity generation companies. One in the coal-fired power plant and the other in transmission services operators (TSOs). It seems that the complexity of an organization in the electrical power industry mainly derives from, firstly, its underlying core technologies, and secondly, its complex environment (Dooley, 2002). Put differently, operation complexity is influenced by environmental and organizational complexity which makes organization structures itself and behaves in a particular manner as an attempt to fit with its environment. Thus, many power producers search for ways to develop smarter energy capabilities as the traditional descriptive statistics, conventional regression analysis.

4.1.1.4. Real-time management

The scheduled analytics reports, pre-configured KPIs, or fixed dashboards are not enough to satisfy enterprise decision-makers in the ever-increasing competition and rapidly changing customer needs and technologies (Azvine, 2005). Meanwhile, the emerging of smart-grid technologies (Gungor et al., 2011), which is anticipated to become a tendency for the future energy industry, has changed the organizational information systems and, inevitably, required for real-time analytics (Lukić et al., 2016). With a plethora amount of data from various sources and formats, as well as the requirement of low latency in accessing, analyzing, and reporting, more firms require a real-time business intelligence system.

Put differently, decision-makers demand actionable information from analytic applications using real-time business performance data, these insights can, simultaneously, be accessed by the right people exactly when and where they need them (Azvine et al., 2005). Nonetheless, Colin demonstrates that some situations require a close to real-time action while other business situations and events have a degree of latency that is acceptable, for instance, few minutes or hours, which can be achieved by automating the decision-making process (Colin, 2004). Otherwise, Janina

demonstrates that the term right-time is more suitable than real-time as all the real-time BI systems have some latency and the goal is to minimize the time from the event initiation to the moment an action is taken to respond to that event (Janina, 2012). However, in general, most researchers prefer to use the term real-time to exhibit that meaning.

It is also worth to mention that the utility industry by itself operates in an environment where decisions are time-sensitive (Popeangă & Lungu, 2012). Noticeably, electricity differs from other energy products (such as gas and oil), which is nearly impossible to be stored economically with current technology, whereas its demand-supply needs to be constantly in balance (Liu, 2014). According to Hackathorn, the value of real-time BI lies in its capability of reducing three genres of latency: data latency (the duration from the business events to when the operational data is captured); analysis latency (the time to analyze the data and when the findings are ready for use); and decision latency (the time to act upon the data) (Hackathorn, 2004).

With that respect, Fischer and colleagues design a real-time business intelligence solution for real-time forecasting, aggregation, and querying data that based on the plex-offers data-warehouse schema that balance supply and demand within the Mirabel smart grid project (Fischer et al., 2012; Siksnys et al., 2012).

Furthermore, a study attempts to comprehend customer consumption behaviour and residential demand-response to the electricity market found that there are not only challenges such as physical constraints, regulatory policies, the transition to a low carbon society, etc., but also the challenges of handling massive volumes of real-time smart meter data, given the complex nature of electricity market. Based on the above characteristics, Liu emphasizes that real-time business intelligence architecture is critical in terms of reducing data latency, analysis latency, and decision latency, simultaneously, increase the capability of companies in maintaining sustainable and profitable growth (Liu, 2014).

Besides, Yiying Zhang (2019) emphasized the vital role of real-time business intelligence in the utility industry adopting a smart grid, where decisions are time-sensitive and proposed the Oracle Business Intelligence solution for utilities at a low level of data latency.

4.1.2. Customer side factors

Although electrical power customers have an indirect relationship in the transformation of the industry, not mentioning the ever-increasing loading demand, the influences on the performance outcomes of the energy efficiency domain are still visible in the electricity value chain.

In recent years, smart meters are being installed in homes and other premises in many regions of the world (Alahakoon & Yu, 2013), which increases the role of electrical power users in managing energy more efficiently and effectively. Together with the extension of the competitive energy market in many countries, it is more flexible for electrical power consumers in choosing and varying their electricity suppliers due to different factors, including the origin of energy or how eco-effectiveness of the electricity, or the quality of services.

In this context, derive from emerging demands of residential, commercial, and industrial customers toward the level of efficiency and effectiveness of energy, many electricity suppliers realize this is time to diversify their sources for electricity other than significantly rely on fossil fuel as they used to. Accordingly, suppliers offer power derived from various kinds of sources or a combination of them to meet the new demands of customers. The result of that movement leads to sophisticated, non-linear dynamic processes, where complicated operating conditions with different kinds of new variables affecting the performance outcomes.

Meanwhile, more electricity suppliers attempt to increase public awareness and brand recognition to attract more customers, for example, by assessing the eco- and cost-

efficiency of renewable energy in algae-based biofuel (Lea et al., 2018). Lea proposes a data visualization within the business intelligence framework to access the biofuel commercialization potential by providing a comprehensive list of financial and non-financial key performance indicators depicting the intangible environmental benefits of alternative fuel such as thermal and wind-powered energy (Lea et al., 2018).

On the other hand, the smart meter also delivers new insight for electrical power companies to identify detailed customer clusters (Flath et al., 2012); customer behaviour (Quilumba et al., 2014); customer segmentation (Kwac et al., 2013); customer consumption pattern (Zhou et al., 2017). Those can improve the accuracy of load forecasting, modify organizational strategy based on customer segmentation and so forth.

In 2015, based on the business intelligence framework, an energy-saving decision-making framework is proposed to gain insight into energy consumption from commercial and residential buildings (Park et al., 2015). The research used real-world data to validate the framework and receive positive feedback from domain experts.

Realizing the importance of data accuracy and data origin, Garwin and Marcinkowski (2016) investigate data sources for the BI system and the use of business intelligence systems to reveal information depicting the power consumption in buildings – along with optimizing and forecasting changes of the consumption.

4.1.3. Market and supply chain factors
4.1.3.1. Market dynamism and competitive pressures

In the last few decades, many countries had been reformed to bring deregulation and competition to the energy market, especially in the electricity sector (Priddle, 2001). Moreover, the electric power sector attempts to improve efficiency, save cost to lower energy prices, appropriate power pricing mechanism, extend renewable energy, promote electric power development, push ahead with a fully integrated smart grid

construction, and establish an intelligent power market system while maintaining security of supply, environmental and social goals (Liang et al., 2006).

In sum, energy liberalization brings more competitors to the constantly dynamic energy market environment, which makes electricity suppliers, as well as transmission and distribution companies, require more business insights from the market as well as customers' behavior to gain competitive advantages. In order to capture a more granular understanding of the market and to act competitively, researchers proposed various solutions to support the decision support system: analyze the dynamic price change in smart grids by modelling and simulating the wholesale electricity market (Sueyoshi & Tadiparthi, 2008), analyzing the behavior of competitors in the market (Sancho et al., 2008), integrating information system in smart grids (Ipakchi, 2007) and so forth.

On the other hand, customer service and customer relationship management are becoming more critical for electricity utilities serving in the deregulated electricity market (Werner & Hemansson, 2002), which can be obtained by deploying the enormous amounts of information stored in a data warehouse.

4.1.3.2. The balance in supply-demand of electricity

A smart grid supply chain requires necessary data flows and information essential for the decision-making process to reap immediate business value from the enormous amounts of disparate data in emerging smart grids (Lukić et al., 2017). Research in this area also realized that to succeed in a dynamic business environment, electricity market operators need to expand the access to the operational data, and acquire intelligence from that data (Plenninger et al., 2014). Based on those demands, together with the introduction of smart grid technologies, operator companies desire to improve their information systems and requirements for real-time analytics (Gungor et al., 2011). Accordingly, business intelligence and knowledge management infrastructure are

considered as a necessity for large energy systems adopted smart grid technologies (Arends & Hendriks, 2014; Popovic et al., 2015a; Venkat & Saadat, 2009).

It is also expected that the future intelligent business systems for the smart grid supply chain need to be based on big data technologies due to the quantity of data in the smart grid as well as the need for real-time analytics in the electricity market (Diamantoulakis et al., 2015).

4.1.3.3. Latency

Suppose generator companies consider real-time decisions as competitive advantages. In that case, the real-time manner is a prerequisite in managing the electricity system, by which the transmission and distribution system operators need to maintain the safety and reliability of the entire electricity network. So as to the retail electricity market, Liu (2014), on the other hand, explores some aspects of BI to address the analysis latency issue focusing on retail pricing.

4.2. Outcomes of BI in the electrical power industry

4.2.1. Operational and tactical outcomes

Actionable information and insights derived from the data-rich environment of smart technologies have facilitated business intelligence systems in electrical power companies to obtain various achievements.

First and foremost, BI solutions facilitate to alleviate the pressure of high cost in the electrical power business, for example, by identifying and quantifying the economic and technical risks in German transmission service operation (Felden and Buder, 2012). Even though the design reference model has not yet been implemented, it is based on practical knowledge and experience and validated by domain experts.

The complexity of the production process of electrical power derived from renewable sources such as solar, wind, hydro, geothermal, and biomass makes it fail to replace fossil fuels and satisfy growing energy demands. Lea et al., (2018) believe that data visualization based on the business intelligence concept is a promising solution to monitor, analyze, and manage various means to produce biofuel and fine-tuning those means for commercially and affordably production. Also inspired by the business intelligence concept, a study within solar companies develops a balanced-scorecard-based framework to identify KPIs, as well as performance appraisal and scenario simulation, which significantly influences performance outcomes (Wang & Chuang, 2016).

In coal-fired power plants, the complexity and non-linear of combustion processes may be tackled by a BI system that can monitor KPIs, capture insights about the behaviour of electricity generation processes, and indicate variables affecting combustion efficiency (Chongwatpol, 2016).

Garwin and Marcinkowski present that business intelligence solutions, especially when investigating data sources, can result in positive outcomes of firms through multiple case studies among Polish subsidiaries of Sweden, France, and UK-based companies. The proposed determinants and benchmarking scenarios strive to increase the capability of detecting excessive power consumption and lowering costs of retail facility operation and enhancing budget control as well (Garwin & Marcinkowski, 2017).

In sum, business intelligence adds value and brings better organizational outcomes in at least two interrelated ways: (1) to better manage and control the vast and sophisticated operation, and generation processes of electrical power companies, which in turn saving costs and increase profit; and (2) to generate organizational insight and significantly support decision-making process with low latency.

4.2.2. Market intelligence outcomes

BI allows companies to use the information at their disposal for supporting their processes and decisions by combining the organizational and technical aspects of information (Farrokhi and Pokoradi, 2012). There is evidence in a selected group of US residential consumers that hourly real-time pricing increases the capability of consumer surplus by 10$ per household per year (Hunt Allcott, 2011).

An extensive energy system that was adopting smart-grid technologies data is recognized as a potential solution in this highly complex environment (Arends and Hendriks, 2014), with the assistant of BI and knowledge management infrastructure.

4.2.3. Decision-making outcomes

The significant focus of the business intelligence field on the decision-making process as the primary antecedent of organizational factors in the electricity industry has delivered not only competitive added-value for the firms themselves but also poor-quality data that impairs the outcomes. Put differently, the quality of data is considered to have a substantial influence on the quality of a BI solution, especially the decision-making process (Garwin & Marcinkowski, 2017). When feeding inaccurate data can lead to wasting much time searching, generating extra work, and lost potential of information (Jylhä & Suvanto, 2015).

At the organizational layer, the application of multidimensional Business Intelligence impacts the functions of management and decision-making including making market-related decisions, production planning, contract management, risk management, forecasting, generating fundamental analyses and documents related to the mandatory reporting (Hoss, 2012; Kaleta and Toczyłowski, 2009). Besides, other areas that involve in the influenced circle can be mentioned are:

• *Customer behavior* – manufacturers and suppliers of energy analyze the behavior of consumers in order to develop marketing campaigns, and commercial offers targeted precisely at specific consumer sub-groups;

• Technical indicators – oversight of the provider's technical infrastructure through confronting data originating from the operation of the hardware, the automation systems, operation control systems or weather services;

• Economic indicators – developed using both internal and external data (the latter being Energy Exchange Office, Power Exchange Market, Electricity Trading Platform).

4.2.4. Sustainable development outcomes

One of the primarily driven factors behind the current direction of development in the electrical power sector is to make the industry more sustainable in the future. Sustainable development goals influence organizational structure and financial strategies due to external factors such as government policies, price cap, the proportion of renewable energy in the generation, as well as the company's reputation.

At the organizational layer, companies also have their own sustainability goals to operate effectively in terms of eco-friendly and cost-efficiency. Gawin and Marcinkowski (2017) conducted a study among Polish subsidiaries of Sweden, France, and UK-based companies along with a domestic Polish that has been conducted to examine whether data sources for business intelligence solutions have influences on energy efficiency-oriented decision-making process. The findings of the research suggest that organizations following the application of multidimensional benchmarking enables managers to handle excessive power consumption and keep costs down.

On the other hand, energy efficiency in a residential-user layer such as smart home, smart building, which emerge along with smart technologies like smart meter, smart grid, and sensor and wireless technologies. Two studies in this stream attempt to reduce electricity load while remaining users' satisfaction by Energy Management System for

smart homes (Al-Ali et al., 2017) and Energy-saving business intelligence framework for HVAC usage logs (Park et al., 2015). The former study enables consumers to be aware of their consumption behavior and providing close interaction with electrical devices, whereas easy to adjust and optimize their power consumption, put differently, helps increase energy efficiency. Attempting to detect excessive and inappropriate energy use in commercial and residential buildings, the research of Park and colleagues proposes a business intelligence framework for building managers to discover opportunities of saving energy system, ultimately, enhances energy efficiency.

4.3. A synthesis – Integrative framework

This study aims to provide a theoretical foundation for the reader to understand the roles and linkages of BI specific in the electrical power industry where the proliferation of BI concept emerges in the whole production process not to mention the managerial level. An author described BI as a tree metaphor with its root in strategic management, its branches in marketing, and its leaves in information management (Talauoi, 2015). Therefore, such a fragmented and multidisciplinary concept called for a synthesis, followed with an integrative framework for comprehensive understanding. The systematic literature review of the BI concept in electrical power industry uncovered shared patterns along which three components were discerned: antecedents (A), business intelligence domain (B), and outcomes (C). Different from other industries, the product of the electrical power industry is unable to economically store with the current technologies, which makes every decisions and actions very time-sensitive. This implies that organizations should constantly capture insights and generate actionable information from a massive amount of data at a low latency manner to enhance better performances and obtain sustainable development.

The BI domain is influenced, firstly, by internal factors such as core technologies (Lv et al., 2012), IT sophistication (Junker & Domann, 2017), the complexity of the operation and complicated production processes (Chongwatpol, 2016). A further influence on the

BI domain might be attributed to the uncertainty conditions. This may include the uncertainty of independent variables of resources such as sunlight, wind, rain, tides, waves, temperature and geothermal heat in generating renewable energy (Wang and Chuang, 2015; Lea et al., 2018), different coal characteristics, different levels of equipment and sub-process in a coal-fired power plant (Chongwatpol, 2016). Because of those factors mentioned above, the top managerial teams and power plant management teams require intense support in the decision-making process at real-time fashion (Popeangă and Lungu, 2012; Liu, 2014; Escobedo et al., 2016) and a comprehensive management system to manage and enhance organizational performances. Furthermore, the fact that electrical power is nearly impossible to be stored as mentioned above, whereas the electricity system is required to maintain a continuous supply-demand balance. This means that reliability and security in electrical power need an appropriate market system in trading electricity among domestic generators, transmissions, and distributors as well as cross-border suppliers.

Meanwhile, environmental scanning is pictured as the first link between a firm and its business environment (Talaoui, 2015), whereby a firm can understand the business phenomena and deliberately confront with changes. In recent years, the deregulated transformation makes the electricity market more dynamic and brings more competitive pressures to electricity-related companies. Meanwhile, environmentally sustainable goals have changed the structure of resources in generating electricity continuously from fossil fuel to renewable sources. In contrast, the uncertainty of the transformation threatens the balance of supply-demand of power. Therefore, this state of the affair makes a call for a national- and international-wide trading system that can deploy the massive amount of data of the electrical power industry at a low level of latency or in a real-time manner (Liu, 2014; Popeangă and Lungu, 2012). Once detected, grid operators and electrical power suppliers initially entail day-ahead energy market model (Conejo et al., 2005; Bakirtzis et al., 2007), and then real-time electricity price (Allcott, 2011; Qian et al., 2013; Krishnamurthy et al., 2018).

At the outer layer, customers play an essential role in constructing organizational business strategy. Customers' factors affect the BI domain in terms of the patterns of customers' using, customers' segmentation (Flath et al., 2012), electricity pricing strategy and service quality, and the sustainability of the electricity (Yiying Zhang et al., 2019). In order to apprehend customer-related insight, two fundamental elements are required: one is customers' data, and the second one is an analytic tool to turn the data into actionable information and business insights. After all, the data collected in the electrical power industry both internally and externally is a prerequisite step in a more complex journey.

Since most companies collect their databases in one way or another, effectively extracting and utilizing actionable information from the considerable amount of data arises as to the ultimate challenge. As the electrical power industry is very time-sensitive, therefore, the extent of latency to what actionable information and business insights are delivered decides the organizational outcomes as well as the effectiveness of the System Operators in the electricity wholesale and retail markets (Liu, 2014).

With the advent of the internet, the traditional information management system of the electrical power industry faced the challenge of information overload (Chen et al., 2002). The abundance of data went beyond the capability of executives' attention and called for an intelligent information management system (Christen et al., 2009). Thus, a computerized decision support system (DSS) emerged to support executives in making decisions. Later an executive information system (EIS) was designed, relied on data warehouses and user interface to retrieve information related to internal operations and business environment (Leidner & Elam, 1993). An EIS was able to integrate various technologies for data acquisition, information extraction, and knowledge creation (Lönnqvist & Pirttimäki, 2006).

Thus far, different separate tools may require strenuous efforts of executive teams to link the information from various instruments, integrate them to make decisions and

bring to actions. Hence, such a more complex system called BI system emerged popularly at managerial level (Watson & Wixom, 2007). As from the advent of smart technologies and the deregulation of the electricity market, BI system extends to different parts of the electrical power industry: (a) to the production stages of companies, (b) to the Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in managing the security of the power system in real-time and co-ordinate the supply of and demand for electricity with the requirements of safety and reliability, and (c) to the electrical power users in managing the consumption of electricity. Moreover, real-time BI can boost the agility of a firm to increase the responsiveness toward the ever-changing customers' needs and market situations.

A BI system encompasses a sum of various applications (Gawin and Marcinkowski, 2016). At the outset, both structured and unstructured data are extracted from different kinds of source systems, as well as IT legacy and external information, then went through an Online transaction processing (OLTP) to prepare and load into the data warehouse, for a later clustering into Data Marts. This process is called a transactional stage and usually performed through the ETL process, which stands for Extraction, Transformation, and Load. The primary purpose of a data warehouse is data analysis for supporting the management's decision-making process. Next, data mining techniques uncover the linkages among data and visualize the reports, graphs and the present status of metrics and key performance indicators (KPIs) through data visualization tools such as balance scorecard and dashboard (Gawin and Marcinkowski, 2016).

Primarily derived from Information Systems which have visible impacts on many levels, BI system is designed as an integrated-function system of various essential systems include Enterprise Resource Planning (ERP) solutions, Customer Relationship Management (CRM), billing, call center, Global Information Systems (GIS), Supply Chain Management (SCM), Decision Support Systems (DSS), passporting/stocktaking/security solutions, etc. (Kaleta and Toczyłowski, 2009).

As a result, a multidimensional BI system influences four primary areas in the domain of energy efficiency (Hoss, 2012; Kaleta and Toczyłowski, 2009) including:

(a) customer behaviour – generators, TSOs, and DSOs comprehend the behaviour of consumers to develop marketing strategies, commercial offers and specific services targeted precisely toward different customer segmentation,

(b) technical indicators – enhance the operation of the hardware, the automation systems, operation control systems and weather services,

(c) economic indicators – development in electricity exchange agency/market, electricity trading platform, maintain a continuous balance between electricity supply from power stations and demand from consumers,

(d) management and decision-making – increase market-related decisions' quality, production planning, contract management, risk management, forecasting, analysis extension.

Last but not least, BI system domain was found related to certain outcomes: (a) of decision-making process such as decision quality (Garwin and Marcinkowski, 2017), reduce decision latency (Liu, 2014), enable the capability of real-time response management (Popeangă and Lungu, 2012), and extend analysis results in terms of forecasting customers' demand of electricity (Flath et al., 2012), business diagnosis and performance simulation for solar companies (Wang and Chuang, 2015), (b) related to operational processes like increase organizational profit (Flath et al., 2012; Lea et al., 2018), saving costs (Garwin and Marcinkowski, 2017), enhance productivity rate in coal-fired power plants (Chongwatpol, 2016), (c) of sustainable development areas including increase shares of renewable electrical power(), in energy management (Park et al., 2015, Garwin and Marcinkowski, 2017), smart homes and smart buildings (Al-Ali et al., 2017), and (d) under the umbrella of market intelligence encompassing remained safety and reliability of the power system in real-time (Lukić et al., 2017), enhance supply chain management (Popeangă and Lungu, 2012), development of an intelligent real-time market system (Liu, 2014).

In sum, the antecedents mentioned above exert a moderately influential role in the relation between the business intelligence domain and the outcomes, which in turn reveal a bidirectional connection with the BI domain. This simplistic view of BI focusing in the electrical power industry might fall short of considering all the BI involvement available in the literature. Nonetheless, to the best of the author's knowledge, this paper aims to represent the basis upon which synthesis is drawn to declare the linkages of the three components and role of BI domain in the electricity industry.

Therefore, the interrelationships among antecedents (A), BI domain (B), and outcomes (C) are depicted in the form of an integrative framework in Figure (9). The framework shows three groups of antecedents: suppliers' factors, customers' factors, and market's factors; four BI concepts: decision support system, business intelligence system, real-time business intelligence system, and executive information system; and four sets of outcomes: decision-making, operational process, sustainable development, and market intelligence.

There are five influential interrelationships displayed in the framework (Figure 9): (1) antecedents influence on BI domain; (2) BI domain influence on outcomes; (3) moderating role of BI domain on the association between BI domain and outcomes; (4) bidirectional relation of outcomes toward BI domain; and (5) cross-outcomes relation.
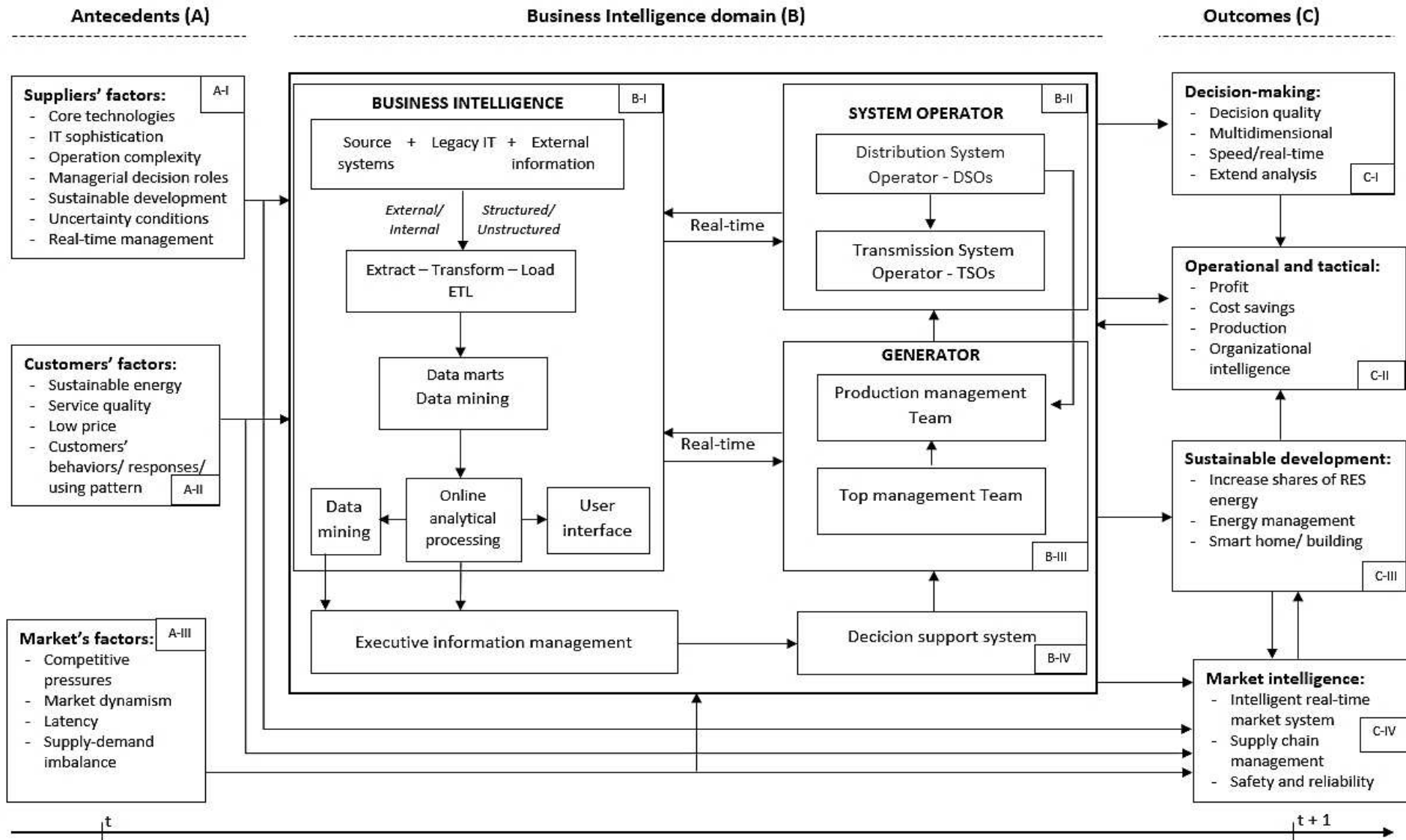
Figure 9. An integrative framework.

5. Discussion

The first research question presented at the beginning of this paper discovered the antecedents influencing BI domain by which it uncovered three groups of antecedents: suppliers' factors, customers' factors, and the electricity markets factors. Only in one decade, BI burgeoned in various parts of the electrical power system (2009-2019). BI related researches span from the electricity market system, through the electricity generations, to electricity transmission and distribution system, simultaneously in energy efficiency domain. Scholars contributed a considerable number of articles partly prescriptive, partly explorative, revealing discrepancies between theory and practice. However, ten years of research seemed fragmented and scattered, where no reply was found for integration research of BI among numerous stages of the industrial system. On the other hand, it is needless to mention the competitive intelligence (CI) – was coined after BI - which was seldom considered by BI researchers in the electrical power industry; thus, only one study engaged into the unresolved dichotomy and attempted to explore critical factors of CI in the power plant industry (Momeni and Mehrafzoon, 2013).

To this point, one might conclude that the taxonomy of antecedents was completely answered. However, the extent to which each factor influences the BI domain and the ramifications associated with each aspect is still under the unexplored area. Although such an inquiry was not among the research questions, it is also worth to highlight the ambiguity for future research. Moreover, analogous to the blind men and the elephant (Godfrey Saxe, 1816-1887), researchers within the literature all contributed valid prescriptive BI processes for the intelligence practice. Still, none strived to nurture an overarching movement that integrates all the scattered notions, and empirically evaluate its effectiveness.

Furthermore, the review of the literature found many studies combined BI with other tools to enhance the outcomes while others built an application within the BI

environment. Unfortunately, no study empirically measured the effectiveness of BI nor linked any added value to the use of BI in the electrical power industry. Not to mention the significant contributions of BI in improving the quality and speed of decisions and by which delivered better outcomes, it is too impulsive to conclude the specific position of BI in the electrical power industry.

Besides, the relevant literature delivered four outcomes to the BI in the electrical power industry: decision-making, operational and tactical, sustainable development, and market intelligence. Hence, the second research question was answered in the available literature. Nonetheless, scholars within the literature all provided ambiguity of the better outcomes, and none seems capable in fostering an empirical study to measure the outcomes associated with BI. This might be an apparent consequence of the scattered researches of BI around different areas of the electrical power industry, makes it a risky and challenging attempt. Similarly, researchers in the energy management domain or sustainable development were rendered by the uncertainty conditions of externally varied variables in delivering an appropriate estimation. Thus, an integrative approach still awaits adaptation, yet with today available evidence, no reply was found for the BI's performance indicators in the electrical power industry.

The literature review also revealed a variety of research methods that were adopted to investigate the issues related to the BI domain, ranging from bibliometric studies to surveys, and case studies. Most of the studies were conceptual papers or settled for laboratory experiments, except one paper had empirically tested (Gawin and Marcinkowski, 2017). Furthermore, longitudinal studies were absent in the scope of the literature review despite mentioning in numerous scholars' future research directions. Overall, aside from the mainstream that deployed BI applications to turn raw big real-time data into actionable information offered by many authors (Flath et al., 2012; Felden and Buder, 2011). Data warehousing applications, key performance indicators, benchmarking and balanced scorecard together with IoT and cloud computing are the other branches of the BI domain tree in the electricity industry.

To best describe the areas depicting BI in the electrical power industry, a framework is built (Figure 10) encompassing BI applications, antecedents of BI, BI process, and outcomes of BI. The framework displays (a) two components of antecedents: internal and external; (b) BI applications with six elements including data source, ETL (extract-transform-load), data warehouse, OLAP (online analytical processing), data mining, and user interface (data visualization); (c) five phases of BI process: data acquisition, data transformation, information storage, knowledge creation, and knowledge dissemination; and (d) outcomes of BI encompassing improve decision making process, energy efficiency, enhance operational performance, and market intelligence.
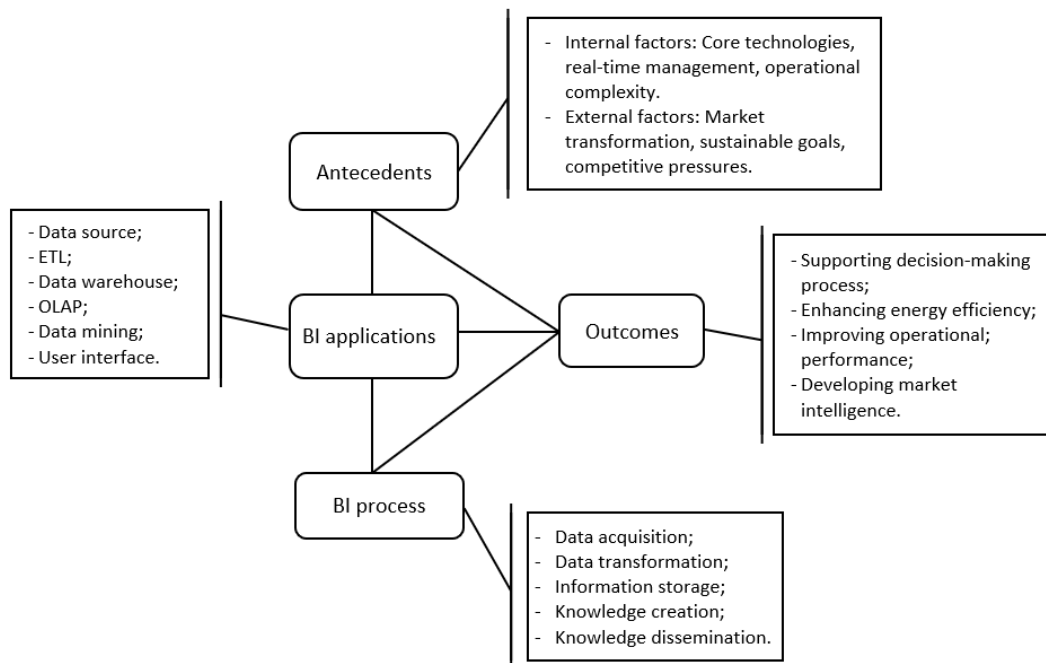
Figure 10. The covered area of the literature.

5.1. Theoretical implications

Since the survey of Argotte et al. (2009) in the electricity market (EM), a plethora of studies attempted to discover to role and influence of BI domain toward the entire electricity system. One might think that the blooming of BI in the electrical power

industry derived from the field of information system where each participant receives an exponential amount of data in real-time respect. However, the impact of the BI domain toward the electricity system goes beyond the contributions of it in the management information system field. Remarkably, the relation between BI applications and organizational strategies, such as customer segmentation (Flath et al., 2012) and product customization (Lea et al., 2018). Moreover, most studies adopted Affeldt and Junior's BI architecture framework (2013) – depicting the flow of data from internal and external sources to actionable information displays in the user interface – in various directions based on their functional objectives might influence the role of BI in an electrical power related organization.

Although BI has been utilized at the managerial level for a long time to support top executive teams in making decisions, none of the studies evaluated the extent to what BI influence organizational performance and outcomes at any specific layer. Except one study emphasized the necessity for establishing a strong relationship between BI and energy market or the electrical power industry due to the ineffectiveness of traditional tools in managing the enormous and increasing data volumes (Argotte et al., 2009). While other studies recommended BI as a potential solution to extract valuable knowledge from a massive amount of real-time data, some also integrated BI with additional tools to enhance the outcomes (Lv et al., 2012; Felden and Buder, 2012). On the other hand, a few studies developed tools or integrated solutions within the BI environment, i.e. integrating cluster analysis in the BI environment to identify detailed customer clusters (Flath et al., 2012). Not to mention the legitimation role BI can play to facilitate the information system management and support the decision-making process. Until integrative research is conducted, any conclusion of the BI role in the electrical power industry is no more than an impulsive consumption. Also, one may confuse about whether BI is a stand-alone solution or a supported application for other solutions. The rationale of this ambiguity may lay at the purpose of each solution.

Although it is beyond the scope of this paper, it is worth to highlight the importance to have an integrative perspective and strategic functions for future research toward BI in the power industry, where scholars seemed to approach from one side of an inter-connective system. One may realize the absence of longitudinal studies in this research domain, which might hinder scholars from taping into cognitive changes prior and after installing an intelligence culture.

5.2. Practical implications

Top executive teams in the electrical power industries must be cognizant of the role they ought to play, should they adopt new technologies and seek actionable intelligence. Across the studies this review examined, some traditional operation companies realized the ever-increasing complication of the production processes and attempted to seek solutions in the intelligence domain, a potential option is BI solution. On the other hand, firms in the data-rich environment, where smart technologies were adopted, basically emphasized the action of extracting, loading, and transforming raw data into actionable information. Put differently, the demand to have an intelligence solution for each participant in the electrical power industry was visible, by which massive amount of raw data can be turned into actionable information in a real-time manner, simultaneously, support decision-making process and organizational management.

Otherwise, the electrical power industry has three separate elements, including generations, transmissions and distributions, where the extent to which BI's influence is varied. For instance, in power generation companies, BI acts as a tool integrated to the operation and production systems to deliver better production-related decisions at the right time manner or in real-time fashion (Chongwatpol, 2016). Meanwhile, the transmission system operators (TSOs) require real-time bidirectional interactions among various generators and distributors to manage the security of the power system in real-time, simultaneously, maintain a continuous balance between electricity supply from power stations and demand from consumers. At the same time, TSOs need a self-heal system to minimize the probability of grid instability and failure.

To design an organizational BI solution, Lukić et al. (2016)'s work proposed a hybrid methodology to build a multi-dimensional data-warehousing and BI system for TSOs operating in a data-rich environment. Following, many scholars proposed BI as a potential solution for grid companies or TSOs such as strategic asset management (Felden and Buder, 2011), BI system solution (Radenković et al., 2018), supply chain intelligence (Lukić et al., 2017). In term of distribution system operators (DSOs), new roles emerged including peak load management, network congestion management, provide reactive power support, procure voltage support and technical validation for power market. One may wonder whether the position of BI is similar to other components of the electricity system, however, none of the studies, until now, has a claim or implied any conclusion about the position of BI whether in any components or in the entire industry.

Top executive teams need to consider the value intelligence can bring to their organization in terms of operational outcomes and the quality of the decision-making process in comparison to their investments. Therefore, empirical tested and longitudinal studies might deliver methods which can help to measure the effectiveness of a solution. On the other hand, managers must be active in installing an intelligence culture across their organizations, from top to bottom layers, where intelligence is participative, not selective, where decision-making is a comprehensive and integrative process of the whole entity not only for top executive teams.

Furthermore, as mentioned above, a measurement method is needed to evaluate the degree of effectiveness or the influence on what the solution delivers, which is still underexplored.

5.3. Research limitations

Following the guidelines for performing systematic literature reviews by Kitchenham (2007), this paper narrows its scope of selection to articles published in top-tier journals, intending to collect significant contributions in the field. Two reputable databases, EBSCO and Scopus, were chosen with the aim to eliminate the limitations of articles selection. However, the keywords strings of this study cannot avoid some failures in retrieving all the related articles in the field, which might cause a degree of deficiency, not mention those publications that not yet available when the database search took place. Focusing on the BI domain does not mean ignoring other effective tools; otherwise, those can be integrated with BI for better outcomes as aforementioned.

References

Aalami, H. A., Moghaddam, M. P., & Yousefi, G. R. (2010). Modeling and prioritizing demand response programs in power markets. *Electric Power Systems Research*, *80*(4), 426-435.

Affeldt F.S., Junior S. (2013). Information architecture analysis using business intelligence tools based on the information needs of executives. *JISTEM-Journal of Information Systems and Technology Management*, 10(2), 251-270.

Al-Ali, A. R., Zualkernan, I. A., Rashid, M., Gupta, R., & Alikarar, M. (2017). A smart home energy management system using IoT and big data analytics approach. *IEEE Transactions on Consumer Electronics*, *63*(4), 426-434.

Alahakoon, D., & Yu, X. (2015). Smart electricity meter data intelligence for future energy systems: A survey. *IEEE Transactions on Industrial Informatics*, *12*(1), 425-436.

Alhyasat, E.B., Al-Dalahmeh, M., 2013. Data warehouse success and strategic oriented business intelligence. A theoretical framework. J. Manag. Res. 5 (3),169-184

Allcott, H. (2011). Rethinking real-time electricity pricing. *Resource and energy economics*, *33*(4), 820-842.

Altin, M., Göksu, Ö., Teodorescu, R., Rodriguez, P., Jensen, B. B., & Helle, L. (2010, May). Overview of recent grid codes for wind power integration. In *2010 12th International Conference on Optimization of Electrical and Electronic Equipment* (pp. 1152-1160). IEEE.

Akhavan-Hejazi, H., & Mohsenian-Rad, H. (2018). Power systems big data analytics: An assessment of paradigm shift barriers and prospects. *Energy Reports*, *4*, 91-100.

Amin, M. (2008, July). Challenges in reliability, security, efficiency, and resilience of energy infrastructure: Toward smart self-healing electric power grid. In *2008*

IEEE Power and energy society general meeting-conversion and delivery of electrical energy in the 21st century (pp. 1-5). IEEE.

Amin, S. M., & Wollenberg, B. F. (2005). Toward a smart grid: power delivery for the 21st century. *IEEE power and energy magazine*, *3*(5), 34-41.

Argotte, L., Mejia-Lavalle, M., & Sosa, R. (2009, November). Business intelligence and energy markets: a survey. In *2009 15th International Conference on Intelligent System Applications to Power Systems* (pp. 1-6). IEEE.

Arends, M., & Hendriks, P. H. (2014). Smart grids, smart network companies. *Utilities Policy*, *28*, 1-11.

Aruldoss, M., Travis, M. L., & Venkatesan, V. P. (2014). A survey on recent research in business intelligence. *Journal of Enterprise Information Management*.

Avci, M., Erkoc, M., Rahmani, A., & Asfour, S. (2013). Model predictive HVAC load control in buildings using real-time electricity pricing. *Energy and Buildings*, *60*, 199-209.

Azvine, B., Cui, Z., & Nauck, D. D. (2005). Towards real-time business intelligence. *BT Technology Journal*, *23*(3), 214-225.

Bakirtzis, A. G., Ziogos, N. P., Tellidou, A. C., & Bakirtzis, G. A. (2007). Electricity producer offering strategies in day-ahead energy market with step-wise offers. *IEEE Transactions on Power Systems*, *22*(4), 1804-1818.

Bergaentzlé, C., Clastres, C., & Khalfallah, H. (2014). Demand-side management and European environmental and energy goals: An optimal complementary approach. *Energy Policy*, *67*, 858-869.

Chaudhuri, S., Dayal, U., & Narasayya, V. (2011). An overview of business intelligence technology. *Communications of the ACM*, *54*(8), 88-98.

Chen, H., Chau, M., & Zeng, D. (2002). CI Spider: a tool for competitive intelligence on the Web. *Decision Support Systems*, *34*, 1–17.

Chongwatpol, J. (2016). Managing big data in coal-fired power plants: a business intelligence framework. *Industrial Management & Data Systems*.

Christen, M., Boulding, W., & Staelin, R. (2009). Optimal market intelligence strategy when management attention is scarce. *Management Science*, *55*(4), 526–538.

Conejo, A. J., Plazas, M. A., Espinola, R., & Molina, A. B. (2005). Day-ahead electricity price forecasting using the wavelet transform and ARIMA models. *IEEE transactions on power systems*, *20*(2), 1035-1042.

Crăciun, B. I., Kerekes, T., Séra, D., & Teodorescu, R. (2012, May). Overview of recent grid codes for PV power integration. In *2012 13th International Conference on Optimization of Electrical and Electronic Equipment (OPTIM)* (pp. 959-965). IEEE.

De Mauro, A., Greco, M., & Grimaldi, M. (2015, February). What is big data? A consensual definition and a review of key research topics. In *AIP conference proceedings* (Vol. 1644, No. 1, pp. 97-104). American Institute of Physics.

Demand side management definition. https://www.fingrid.fi/en/electricity-market/market-integration/the-future-of-the-electricity-markets/demand-side-management/

Diamantoulakis, P., Kapinas, V., & Karagiannidisa, G. (2015). Big data analytics for dynamic energy management in smart grids. Big Data Research, 2(3), 94– 101.

Eckerson, W. W. (2010). *Performance dashboards: measuring, monitoring, and managing your business*. John Wiley & Sons.

Escobedo, G., Jacome, N., & Arroyo, G. (2016). Business Intelligence and Data Analytics (BI&DA) to Support the operation of Smart Grid. In *Proceedings of the*

International Conference on Internet of Things and Big Data (IoTBD 2016), 489-496.

Felden, C., & Buder, J. J. (2012). Integrated information supply for decision support in grid companies. *Business & Information Systems Engineering*, *4*(1), 15-29.

Flath, C., Nicolay, D., Conte, T., van Dinther, C., & Filipova-Neumann, L. (2012). Cluster analysis of smart metering data. *Business & Information Systems Engineering*, *4*(1), 31-39. Farhangi, H. (2009). The path of the smart grid. *IEEE power and energy magazine*, *8*(1), 18-28.

Fischer, U., Kaulakienė, D., Khalefa, M. E., Lehner, W., Pedersen, T. B., Šikšnys, L., & Thomsen, C. (2012, August). Real-time business intelligence in the MIRABEL smart grid system. In *International Workshop on Business Intelligence for the Real-Time Enterprise* (pp. 1-22). Springer, Berlin, Heidelberg.

Gartner, I. T. (2014). Glossary: big data. *Gartner Inc. Available (accessed on 13.7. 2017): https://research. gartner. com/definition-whatis-bigdata*, 1-8163325102.

Gawin, B., & Marcinkowski, B. (2016). Towards a proficient business intelligence for energy efficiency domain–prerequisites and data sources. ICTM 2016, 73-83.

Gawin, B., & Marcinkowski, B. (2017). Business intelligence in facility management: Determinants and benchmarking scenarios for improving energy efficiency. *Information Systems Management*, *34*(4), 347-358.

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2011). Smart grid technologies: Communication technologies and standards. *IEEE transactions on Industrial informatics*, *7*(4), 529-539.

Guo, Z., Zhou, K., Zhang, X., Yang, S., & Shao, Z. (2018). Data mining-based framework for exploring household electricity consumption patterns: A case study in China context. Journal of Cleaner Production, 195, 773-785.

Hackathorn, R. 2004. The BI Watch: Real-Time to Real Value, *DM Review* 14(1), pp. 24-43.

Harison, E. (2012). Critical success factors of business intelligence system implementations: evidence from the energy sector. *International Journal of Enterprise Information Systems (IJEIS)*, *8*(2), 1-13.

Hazebrouck, P., & Frerichs, P. (1999). Use and enhancement of accelerated SAP: an example. In *1º International Workshop on Enterprise Management Resource and Planning Systems EMRPS, Venice, Italy* (pp. 153-171).

Hong, Y. Y., & Wu, C. P. (2012). Day-ahead electricity price forecasting using a hybrid principal component analysis network. *Energies*, *5*(11), 4711-4725.

Hoss, F. (2012). Energy Efficiency & Demand Response-How to Tackle Big Data. *Electric Light and Power*, *90*(5), 40.

Howard, P., T Agami Reddy PhD, P. E., & Srinivas Katipamula PhD, P. E. (2016). Automated data mining methods for identifying energy efficiency opportunities using whole-building electricity data. *ASHRAE Transactions*, *122*, 422.

Hu, Z., Moskovitz, D., & Zhao, J. (2005). Demand-Side Management in China's Restructured Power Industry: How Regulation and Policy Can Deliver Demand-Side Management Benefits to a Growing Economy and a Changing Power System.

Inmon, W. H. (2005). *Building the data warehouse*. John wiley & sons.

Ipakchi, A. (2007). Implementing the smart grid: Enterprise Information Integration, Grid-Interop Forum 2007. USA:Albuquerque.

Ismail, Z., & Jamaluddin, F. A. (2008). A backpropagation method for forecasting electricity load demand. *Journal of applied sciences*, *8*(13), 2428-2434.

Jacobsen, H. A., del Razo, V., Doblander, C., Rivera, J., Ilg, J., ... & Appelrath, H. J. (2014). Energy informatics. *Business & Information Systems Engineering*, *6*(1), 25-31.

Junker, H., & Domann, C. (2017). Towards industry 4.0 in corporate energy management. *WIT Transactions on Ecology and the Environment*, *214*, 49-56.

Jylhä, T., & Suvanto, M. E. (2015). Impacts of poor quality of information in the facility management field. Facilities, 33 (5/6), 302–319. doi:10.1108/F-07-2013-0057

Kaleta M., Toczyłowski E. (2009). Rola informatyki w zwiększaniu efektywności rynku energii. Rynek Energii, 1, 66-73

Kholeif, S., E Khedr, A., & Tamer Shaker, M. (2019). A Proposed Framework for Reducing Electricity Consumption in Smart Homes using Big Data Analytics.

Khorram, M., Abrishambaf, O., Faria, P., & Vale, Z. (2018). Office building participation in demand response programs supported by intelligent lighting management. *Energy Informatics*, *1*(1), 1-14.

Kozlovskiy, I., Sodenkamp, M., Hopf, K., & Staake, T. (2016). Energy informatics for environmental, economic and societal sustainability: a case of the large-scale detection of households with old heating systems.

Krishnamurthy, C. K. B., Vesterberg, M., Böök, H., Lindfors, A. V., & Svento, R. (2018). Real-time pricing revisited: Demand flexibility in the presence of micro-generation. *Energy policy*, *123*, 642-658.

Kwac, J., Tan, C. W., Sintov, N., Flora, J., & Rajagopal, R. (2013, October). Utility customer segmentation based on smart meter data: Empirical study. In *2013 IEEE international conference on smart grid communications (SmartGridComm),* 720-725.

Lea, B. R., Yu, W. B., & Min, H. (2018). Data visualization for assessing the biofuel commercialization potential within the business intelligence framework. *Journal of Cleaner Production*, *188*, 921-941.

Leidner, D., & Elam, J. (1993). Executive information systems: their impact on executive decision making. *Journal of Management Information Systems*, *10*, 139–155.

Liang, J., & Liang, Y. (2017). Analysis and modeling for China's electricity demand forecasting based on a new mathematical hybrid method. *Information*, *8*(1), 33.

Liang, Z., Yang, K., Sun, Y., Yuan, J., Zhang, H., & Zhang, Z. (2006). Decision support for choice optimal power generation projects: Fuzzy comprehensive evaluation model based on the electricity market. *Energy Policy*, *34*(17), 3359-3364.

Liu, H. (2014). On advancing business intelligence in the electricity retail market.

Li, Y., Wang, L., Ji, L., & Liao, C. (2013, March). A data warehouse architecture supporting energy management of intelligent electricity system. In *Proceedings of the 2nd International Conference on Computer Science and Electronics Engineering*. Atlantis Press.

Lukić, J., Radenković, M., Despotović-Zrakić, M., Labus, A., & Bogdanović, Z. (2016). A hybrid approach to building a multi-dimensional business intelligence system for electricity grid operators. *Utilities Policy*, *41*, 95-106.

Lukić, J., Radenković, M., Despotović-Zrakić, M., Labus, A., & Bogdanović, Z. (2017). Supply chain intelligence for electricity markets: A smart grid perspective. *Information Systems Frontiers*, *19*(1), 91-107.

Lv, H., Xie, Y., Wang, F., & Cheng, Y. (2012, August). Research on intelligent power consumption business intelligence system based on cloud computing. In *2012 International Conference on Computer Science and Service System* (pp. 1541-1546). IEEE.

Lönnqvist, A., Pirttimäki, V. (2006). Measurement of Business Intelligence. *Forthcoming in Information Systems Management, Winter iss*.

Mamounakis, I., Efthymiopoulos, N., Vergados, D. J., Tsaousoglou, G., Makris, P., & Varvarigos, E. M. (2019). A pricing scheme for electric utility's participation in day-ahead and real-time flexibility energy markets. *Journal of Modern Power Systems and Clean Energy*, *7*(5), 1294-1306.

Mancarella, P., & Chicco, G. (2013). Real-time demand response from energy shifting in distributed multi-generation. *IEEE Transactions on Smart Grid*, *4*(4), 1928-1938.

Manju Khanna, N. K. Srinath, and J. K. Mendiratta, "Data Mining in Smart Grids-A Review", Vol. 5, No. 3, pp: 709-712, 2015.

Martínez-Álvarez, F., Troncoso, A., Asencio-Cortés, G., & Riquelme, J. C. (2015). A survey on data mining techniques applied to electricity-related time series forecasting. *Energies*, *8*(11), 13162-13193.

Martín-Rubio, I., Florence-Sandoval, A. E., Jiménez-Trillo, J., & Andina, D. (2015, June). From smart grids to business intelligence, a challenge for bioinspired systems. In *International Work-Conference on the Interplay Between Natural and Artificial Computation* (pp. 439-450). Springer, Cham.

Masayna, V., Koronios, A., Gao, J., Gendron, M., 2007. Data quality and KPIs: a link to Be established (Research-in-Progress). In: Proceedings of the 2nd world Congress on Engineering Asset Management (EAM) and the 4th International Conference on Condition Monitoring, pp. 1377e1386

McKane, A. (2009). Automated demand response: The missing link in the electricity value chain.

McLoughlin, F., Duffy, A., & Conlon, M. (2015). A clustering approach to domestic electricity load profile characterisation using smart metering data. *Applied energy*, *141*, 190-199.

Molderink, A., Bakker, V., Bosman, M. G., Hurink, J. L., & Smit, G. J. (2010). Management and control of domestic smart grid technology. *IEEE transactions on Smart Grid*, *1*(2), 109-119.

Momeni, A., & Mehrafzoon, M. (2013). Critical factors of competitive intelligence in the power plant industry: the case study of MAPNA Group. *Journal of Intelligence Studies in Business*, *3*(1).

Palensky, P., & Dietrich, D. (2011). Demand side management: Demand response, intelligent energy systems, and smart loads. *IEEE transactions on industrial informatics*, *7*(3), 381-388.

Park, J., Cho, S., Lee, S. K., Kang, S., Kim, Y. S., Kim, J. Y., & Choi, D. S. (2015). Energy-saving decision-making framework for HVAC with usage logs. *Energy and Buildings*, *108*, 346-357.

Paulus, M., & Borggrefe, F. (2011). The potential of demand-side management in energy-intensive industries for electricity markets in Germany. *Applied Energy*, *88*(2), 432-441.

Personal, E., Guerrero, J. I., Garcia, A., Pena, M., & Leon, C. (2014). Key performance indicators: A useful tool to assess Smart Grid goals. *Energy*, *76*, 976-988.

Peters, M., Ketter, W., Saar-Tsechansky, M., & Collins, J. (2013). A reinforcement learning approach to autonomous decision-making in smart electricity markets. *Machine learning*, *92*(1), 5-39.

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. *Renewable and Sustainable Energy Reviews*, *33*, 74-86.

Phillips, C., Elmore, R., Melius, J., Gagnon, P., & Margolis, R. (2019). A data mining approach to estimating rooftop photovoltaic potential in the US. *Journal of Applied Statistics*, *46*(3), 385-394.

Phillips-Wren, G., Iyer, L.S., Kulkarni, U. and Ariyachandra, T. (2015), "Business analytics in the context of big data: a roadmap for research", Communications of the Association for Information Systems, Vol. 37 No. 1, pp. 448-472.

Popeangă, J., & Lungu, I. (2012). Real-time business intelligence for the utilities industry. *Database systems journal*, *3*(4), 15-24.

Popovic, T., Kezunovic, M., & Krstajic, B. (2015a). Smart grid data analytics for digital protective relay event recordings. Information Systems Frontiers., 17(3), 591–600.

Priddle, R. (2001). Competition in electricity markets. International energy agency, OECD/IEA.

Qian, L. P., Zhang, Y. J. A., Huang, J., & Wu, Y. (2013). Demand response management via real-time electricity price control in smart grids. *IEEE Journal on Selected areas in Communications*, *31*(7), 1268-1280.

Quilumba, F. L., Lee, W. J., Huang, H., Wang, D. Y., & Szabados, R. L. (2014). Using smart meter data to improve the accuracy of intraday load forecasting considering customer behavior similarities. *IEEE Transactions on Smart Grid*, *6*(2), 911-918.

Radenković, M., Lukić, J., Despotović-Zrakić, M., Labus, A., & Bogdanović, Z. (2018). Harnessing business intelligence in smart grids: A case of the electricity market. *Computers in Industry*, *96*, 40-53.

Radziszewski, P. (2016). *Business Intelligence: moda, wybawienie czy problem dla firm?*. Wydawnictwo Poltex.

Ranjan, J., 2009. Business intelligence: concepts, components, techniques and benefits. J. Theor. Appl. Inf. Technol. 9 (1), 60e70.

Sancho, J., Sánchez-Soriano, J., Chazarra, J. A., & Aparicio, J. (2008). Design and implementation of a decision support system for competitive electricity markets. Decision Support Systems, 44(4), 765–784.

Satre-Meloy, A., Diakonova, M., & Grünewald, P. (2019). Daily life and demand: an analysis of intra-day variations in residential electricity consumption with time-use data. *Energy Efficiency*, 1-26.

Seufert, A., Schiefer, J., 2005. Enhanced business intelligence e supporting business processes with real-time business analytics. In: 16th International Workshop on Database and Expert Systems Applications DEXA'05, pp. 919e925.

Siksnys, L., Thomsen, C., & Pedersen, T. B. (2012, September). Mirabel dw: Managing complex energy data in a smart grid. In *International Conference on Data Warehousing and Knowledge Discovery* (pp. 443-457). Springer, Berlin, Heidelberg.

Singh, S., & Yassine, A. (2018). Big data mining of energy time series for behavioral analytics and energy consumption forecasting. *Energies*, *11*(2), 452.

Sueyoshi, T., & Tadiparthi, G. R. (2008). An agent-based decision support system for wholesale electricity market. Decision Support Systems, 44(2), 425–446.

Turban, E., Sharda, R., & Delen, D. (2010). Decision support and business intelligence systems (required). *Google Scholar*.

Vardakas, J. S., Zorba, N., & Verikoukis, C. V. (2015). Performance evaluation of power demand scheduling scenarios in a smart grid environment. *Applied Energy*, *142*, 164-178.

Venkat, P., Saadat, M. (2009). Smart Grid: Leveraging Intelligent Communications to Transform the Power Infrastructure, White Paper, Cisco Systems, Inc.

Wang, C. H., & Chuang, J. J. (2016). Integrating decision tree with back propagation network to conduct business diagnosis and performance simulation for solar companies. *Decision Support Systems*, *81*, 12-19.

Watson, R. T., Boudreau, M. C., & Chen, A. J. (2010). Information systems and environmentally sustainable development: energy informatics and new directions for the IS community. *MIS quarterly*, 23-38.

Werner, M., Hermansson, U. (2002). Integrated Utility Data Warehousing - A Prerequisite To Keep Up With Competition On Electricity Markets, in: IEEE Conference Publications, (CP488), (pp. 130–135).

Wikipedia. Renewable energy. https://en.wikipedia.org/wiki/Renewable_energy

Wixom, B., & Watson, H. (2010). The BI-based organization. *International Journal of Business Intelligence Research (IJBIR)*, *1*(1), 13-28.

Xu, L. (2005). Data modeling and processing in deregulated power system.

Yang, H., Li, P., He, Z., Guo, X., Fong, S., & Chen, H. (2016). A decision support system using combined-classifier for high-speed data stream in smart grid. *Enterprise Information Systems*, *10*(9), 947-958.

Zhou, K., Yang, C., & Shen, J. (2017). Discovering residential electricity consumption patterns through smart-meter data mining: A case study from China. *Utilities Policy*, *44*, 73-84.

Zhou, K., Yang, S., Shen, C., Ding, S., & Sun, C. (2015). Energy conservation and emission reduction of China's electric power industry. *Renewable and Sustainable Energy Reviews*, *45*, 10-19.

Zhou, K., Yang, C., & Shen, J. (2017). Discovering residential electricity consumption patterns through smart-meter data mining: A case study from China. *Utilities Policy*, 44, 73-84.