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Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey

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Synonyms

Colombia Energy Transformation; Energy efficiency; Smart grids; Sustainable Development Goals; Turkey Energy Transformation

Definition

Currently, the United Nation's Sustainable Development Goals (SDGs) established in the Agenda 2030 have stimulated a series of actions by several countries, such as affordable and clean energy (SDG7) and sustainable cities and communities (SDG11). These objectives lead to thinking about the concept of smart grids (SG) so that the communities can become more sustainable in terms of energy and climate change. The paradigm is complex in a world where gas emissions, the greenhouse effect, and energy consumption from processes that include fossil fuels, damage the environment and undermine the conditions of well-being and good living. For this reason, project initiatives are being developed that seek the modernization of electricity generation and distribution systems in communities. One of the strategies is the creation and adaptation of micro-grid architectures that adapt to their operational context. The microgrid concept focuses on the controlled use of electrical energy, with a high degree of autonomy, monitoring, and control supported by information technology (IT), to optimize energy transfer while minimizing risks, and increasing quality, efficiency, and reliability of energy supply.

Introduction

The Sustainable Development Goals (SDGs), which are agreed by the United Nations (UN) (2017), aim to increase the welfare of societies, but at the same time to create strategies in combating important environmental problems such as climate change, global warming, biodiversity loss, and deforestation. The UN declared

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17 SDGs, which are accepted by 193 countries. In 2018, these goals were updated and renewed. Among the SDGs, the purpose of referring to the concept of the smart city through the establishment of sustainable cities can be connected through SDG 11. The main aim of this goal is to make cities and human settlements inclusive, safe, resilient, and sustainable (Oral et al. 2020). According to UN Environment (2020), the concept of sustainable cities is sustainable consumption and production roadmap for cities covering all the sectors and upstream interventions through policy, technology, and financing to reduce and manage pollution and waste. The types of pollution are various, but one of the significant types, also known as air pollution, is based on Greenhouse Gas Emissions (GHGs) emissions from industrial plants in cities. The main sources of GHGs can be grouped under electricity generation, transportation, industrial processes, commercial and residential activities, agriculture, land use, and forestry. For instance, in the United States of America (USA) the contribution of these GHGs by economic sectors in 2018 were noted as Agriculture (10%), Transportation (28%), Electricity Generation (27%), Industry (22%), Commercial and residential (12%). Among them, electricity production generates the second-largest share of GHGs emissions. Approximately 63 % of the country's electricity comes from burning fossil fuels, mostly coal and natural gas (EPA 2020).

A significant route to sustainable development (SD) is the convergence of smart grid technology (SGT), renewable energy infrastructure, and low-carbon emissions in power generation systems. In addition, SG strategies increase the quantity of variable renewable energy generation that can be used in power systems, thus increasing the ability of grid-connected clean energy systems such as solar, wind, and photovoltaic. Secondly, in the power sector, an SGT encourages energy saving. The key benefit of the SGT is that it will increase the efficiency of the usage of power grids and the efficiency of power consumption (Hu et al. 2014). The term "SGTs" is described by Milborrow (2016) as different technologies that might need to be introduced in the future to allow more efficient operation of electricity networks. Improving energy efficiency is one of the major advantages of intelligent grids. SGT optimizes demand and supply management for energy, minimizes the loss of electricity between power plants and customers thereby saving electricity. Related costs of constructing new power plants can also be avoided due to decreased peak demand. Via increased production and use of clean, renewable energy, SGTs also produce lower GHGs as a response to their contribution to climate change (Lee et al. 2012).

The research question of this study can be summarized as: "Which architecture model among SA applications is the most suitable for reducing energy use and carbon emission especially in off-grid communities?"

Consequently, the purpose of this book chapter is to present how lower energy usage and carbon emissions can be achieved based on SA architecture models in Colombia and Turkey to fill the gap in the literature.

The following is the book chapter's organizational structure:

- Section 4 provides a literature review on SGT architecture models, presenting the pros and cons of the systems
- Section 5 provides an overview of the current situation in Turkey and Colombia
- Section 6 presents the likely future applications in Turkey and Colombia
- Section 7 shows Results and Discussion
  - Section 7.1 proposes a data-structure architecture for smart grids
  - Section 7.2 summarises reference models for big data architecture
  - Section 7.3 outlines the challenges in designing big data architectures for smart girds
- Section 8 concluded the study

Smart Grids Architecture Models Available in the Literature

Below is an analysis of the advantages and disadvantages of different architecture models for SGTs, detailing the relevant components and characteristics. The architecture models reviewed in this section are SGAM (Smart grit architecture model), SGM (Smart micro-networks), AMI (Advanced metering infrastructure), ADA (Advanced distribution automation), DER (Distributed energy resources).

1. **SGAM - SA architecture model** It is an architecture model that is characterized by having a neutral technological position, adaptable to both traditional and unconventional energies. One of its main characteristics is having a set of interoperability layers that, in an articulated way, facilitate the proper functioning of the architecture. It is composed of: a commercial layer where the commercial goals, the regulatory, and policy approaches are outlined; a layer of functions where the use cases and functions for the micro-network are described; an information layer where the structure and modeling of the data are carried out; a communications layer where the protocols and rules for communication are established and finally, a layer of components where the domains are established: Process, field, station, operation, company and marketing and the other domains of Generation, transmission, distribution, distributed energy resources (DER), customer facilities (Trefke et al. 2013).

   SGAM those involved in micro-network creation projects, by providing a comprehensive methodology to achieve a micro-network. In the case of management (Jacobson et al. 2016), it allows information to be shared between projects that implement similar use cases, with different technical solutions that lead to the so-called SGT.
2. **Smart micro-networks (SGM)** are a SA architecture, which is characterized by the interaction of interoperability functions. It is supported in three main layers that interconnect with each other. The first is a process layer in which all business and regulatory or normative processes are managed. The second is the station layer which includes activities, in addition to managing information, functional and non-functional requirements, procedures, records, storage, protocols, infrastructure, equipment, and communications. Finally, there is the operations control layer in which monitoring, follow-up, control, and supervision are carried out, with a special emphasis on the detection of alternative solutions to failures., This is a centralized control system generally accompanied by sensors, added to an automated control system supported on a distributed operating system for the management of SA resources and the management of the electrical network. Another important feature is the implementation of common methodologies that are based on traditional and evolutionary processes. Currently, there is no documented evidence of the application of agile methodologies, which would surely be good practice due to the successful application in other architectures (CENELEC 2014; Zakariazadeh et al. 2014.
3. **Advanced metering infrastructure (AMI)** is an architecture proposed in a disruptive way, in it the paradigm of the layers or levels of its structure is broken and is replaced by the concept of various stages of communication, management, and engineering, where the AMI architecture becomes a system that combines smart meters, data management systems, technological communication networks in a bidirectional way, transforming the concept of architecture and allowing the effective interpretation of supply and demand management information. In some articles or scientific documents identified in the literature review, complex situations of security risk arising from alteration or modification of data are evidenced. However, it is mentioned that the solutions can be achieved through adequate public policies, regulations, and norms. Consequently, a suitable implementation of the AMI architecture is possible due to the strategic and rapid response to the needs of the demand, the monitoring of energy quality, the distribution process, efficiency of use, and the tendency to reduce the environmental impact. In documented cases, it mentions the application of agile methodologies such as Scrum, XP, lean, among others (Rua et al. 2010; Stellman and Greene 2014; Abdulla 2015).

4. **Advanced distribution automation (ADA)** In this architecture, bidirectional smart meters are consolidated and are expected to improve the quality of service, as the automation of energy distribution processes is increased, with an integrated, real-time monitoring system optimizing the efficiency in the delivery of energy, reducing failures and interruptions. The fundamental bases are the sensors, transducers, and intelligent electronic devices (IED) with a large amount of behavioral information being collected via the micro-network. Through the SCADA system (supervision, control, and data acquisition), the micro-network is managed with greater speed, reliability, and efficiency (Hanser 2010; Mohassel et al. 2014). In reports from the Center for Energy Advancement through Technological Innovation (CEATI) (Hanser 2010) (Kolberg and Zühlke 2015), an attempt is made to define and show that for the network to behave intelligently, it must include automated monitoring of the network with sensors to improve reliability, automatic monitoring of equipment to improve maintenance, product monitoring based on supply and demand analysis to improve service quality. ADA architecture documentation mentions that experiments and projects are underway demonstrating its implementation results in the reduction and control of the voltage force, or voltage, and the conservation and management of the flow of electric current or intensity is achieved. The architecture also gives greater accuracy in the detection of faults and their location plus analysis of the structure of the integrated monitoring and supervision system while providing results and reports on the operation of the micro-network.
5. **Distributed Energy resources (DER)** architecture aims to enhance energy resources in a way that optimizes planning the design of the network, for which a distributed electricity generation system is established (DG) (Beck et al. 2015; Bodek 2018). Key in planning is the analysis of geographic areas, the social and economic impact of the region (Highsmith and Cockburn 2001). An interesting characteristic of this architecture is its adaptability to accommodate conventional electrical energy systems with sensors and a system of micro generation with connections and control from alternating current (AC) to direct current (DC) (McGranahan et al. 2005). There is monitoring, control, and supervision system for energy storage (ESS) allowing virtualization of the use of load fluctuations, adapting to variables that influence the balancing of supply and demand (Brown 2008) in micro-grid processes managing: losses in the system, real-time fault detection, average interruption duration index (SAIDI), giving better power distribution, and a favorable cost-benefit ratio.

According to Zavoda (2008), a case study is reported where the DER architecture is used to reduce greenhouse gas emissions and while optimizing the use of electrical energy in a shopping center in Sydney Australia. It included integration between renewable energy (solar and thermal) with conventional energy. After implementation, a comparison is made taking into account: (1) cost and emissions solution compensation, (2) the cost of reduced emissions achieved in each investment scenario, and (3) benefits of investment concerning the business in a typical scenario. The results show that energy costs are reduced by 8.5%, carbon dioxide emissions are reduced by 29.6% and it is predicted that by making a greater investment in the construction of a micro-grid with a network architecture of 90% renewable energy can offer a 72% reduction in carbon dioxide emissions and a 47% reduction in energy costs. In the words of the authors: “the study demonstrates effectiveness, efficiency and flexibility of DER architecture for micro-networks in changing market conditions”.

According to a literature survey by Kantarci and Mouftah (2011) of wireless sensor networks (WSNs), they will play a key role in the extension of the smart grid technology toward residential premises and enable various demand and energy management applications. The authors concluded that the packet delivery ratio, delay, and jitter of the wireless sensor home area network (WSHAN) improve as the packet size of the monitoring applications, that also utilize the WSHAN, decreases. Kanchev et al. (2011) proposed a model that aims for a deterministic energy management system for a microgrid, including advanced PV generators with embedded storage units and a gas microturbine. In conclusion, the authors suggested that the hypothetical business cases associated with smart grids and distributed resource integration provide more value to microgrid management.

Pawar and Panduranga (2019) conducted a study about the design and development of a flexible Smart Energy Management System (SEMS) for optimal power negotiation and concluded that the design of a smart energy management system aims to replace the scenario of a complete power outage in a region with partial load shedding in a controlled manner as per the consumer's preference.

Rathor and Saxena (2020) summarized the studies relevant to the energy management system for a SA, that presents an overview and key issues. Hence, this review paper gives a critical analysis of the distributed energy resources behavior and different programs such as demand response, demand-side management, and power quality management implemented in the energy management system. Added to that Xu et al. (2016), Prakesh and Sherine (2017), and Etesami et al. (2018a, b) proposed different approaches and novel models related to deploying efficient, smart energy grid management techniques.

Trefke et al. (2013) investigated the smart grid architecture model (SGAM) used for case management in a European Smart Grid Project. The authors highlighted the importance of determining the Key Performance Indicators (KPIs), which are closely related to having the highest efficient energy production.

Gottschalck et al. (2017) investigated SGAM methodology in a broad sense. In the study, the methodologies used under this model were examined in detail, and the usage of these methodologies was exemplified with case study examples. Uslar et al. (2019a, b) reviewed the studies in the literature under the title of "Applying the SA Architecture Model for Designing and Validating System-of-Systems in the Power and Energy Domain: A European Perspective." The authors provide a comprehensive overview of the state-of-the-art and related work for the theory, distribution, and use of the aforementioned architectural concept in Europe.

A limited number of studies (Pratt et al. 2010; Fu et al. 2012; Darby et al. 2013) have been found on the SA architecture on low carbon emission and energy use. Pratt et al. (2010) reported the reduced CO_2 benefits as the result of deploying SGAM, which are based on a survey of published results and simple analyses. Fu et al. (2012) investigated the potential use of SGAM in China, and Darby et al. (2013) examined the potential carbon impacts of smart grid development in some European countries. Moreover, as for Colombia, Rey et al. (2013) and Roldan et al. (2013) investigated the potential use of SGAM and for Turkey, Colak et al. (2014) presented the SA opportunities and applications relevant to the SGAM approach.

Current Situation for Smart Energy in Turkey and Colombia: Turkey

In Turkey, smart energy investments in the public utility sector are maintained by the government and stakeholders. Smart directives requiring the use of energy are another element that has led to the increase of investments in Turkey's energy sector. For instance, Northeast Group conducted a study in 2016 in Turkey with the eastern and central European countries (Keskin 2021) that focused on SA applications. Approximately $ 25.2 million investment has been made focused on eliminating power outages and reducing the power transmission and distribution losses. According to this report, the government's "intelligent distribution automation systems" in the distributed renewable energy resources will play an enabling role in promoting the use of rechargeable electric vehicles.

Smart Meter Systems

According to the 2009/72 / EC Electricity Directive, smart meter usage of countries in the European Union (EU) region requires a transition to 80% by 2020. In line with this directive, Turkey has committed to increasing investment in smart metering infrastructure to greatly reduce energy losses. A 2017 Frost & Sullivan report forecast that Turkey would need to install 3.6 million smart meters per annual installation of smart meters to meet the 2020 EC directive. According to this report, Turkey already surpassed this target in 2016 installing 4.6 million smart meter units (Nhede 2017).

However, in Turkey, the lack of standardization and public awareness of smart meter technologies impedes their successful use. As a result, in the first phase, intelligent systems are introduced in Turkey through pilot projects. A research analyst at Frost & Sullivan says: “The legislation provides the necessary infrastructure for the transition from old meters to electronic meters. Since the Turkish authorities do not have sufficient technical expertise in smart electricity, international companies are setting an example in this regard.”

An Example

Enerjisa (Electricity Distribution Company of Sabanci Holding) serving 20 million consumers is Turkey’s largest energy distribution service company and is deemed to provide a “public service.” The European Bank for Reconstruction and Development (EBRD) forecast that $100 million needed to be invested in Turkey for intelligent-energy infrastructure, and Enerjisa has invested $ 28.6 million. According to The Financial Times, this investment by the private energy sector in Turkey aims to provide the advanced work of the three leading energy companies in the country. According to Power grid International, since 2016 to achieve clean energy in Turkey there has been a significant increase in investment in digital technologies, and this has led to Turkey’s first digital power plant being established.

Energy Diversity

Today, 33% of Turkey’s energy comes from natural gas. According to (Daily Sabah 2020) Energy, the Turkish government aims to generate 30% of its energy from renewable sources, including solar (solar) and wind, by 2023. Although the government does not fully plan to use solar and wind resources as the main source of energy production, it aims to meet a significant proportion of the country’s energy demand from natural gas for a long time.

In April 2017, Wärtsilä, independent energy producer Yeşilyurt Enerji Elektrik Üretim A.Ş. signed an agreement to modernize a 73 MW natural gas facility. Within the scope of developments in the Solar PV (photovoltaic) industry, ET Energy is carrying out its 19 MW solar project in Kahramanmaraş, located in the south of Turkey. In October 2017, it was announced that the project will have an annual power generation capacity of 37,000MWh. According to PV Tech, this project will act as a supplement to the base-load energy generation to meet the country’s peak demand.

A Turkish roadmap report, ‘Turkey Smart Grid 2023 Vision and Strategy Determining Project, Short and Mid-Term’, prepared for Electricity Distribution Services Association (Elder 2020) by AF MERCADOS EMI, collated information in 2014 from projects focused on research and development aimed at electrical energy infrastructures with advanced measurement, implementation of pilot plans with smart meters and communication controllers. The report developed a plan based on this information to focus technical efforts on the following topics:

- Advanced network monitoring, control, and management systems
- IT infrastructure and data analytics
- Enterprise application integration
- Distributed energy integration and storage
- Smart grid company vision and strategy
- Geographical Information Systems (GIS) and asset management
- Electric vehicles
- Customers and smart meter infrastructure
- Communication infrastructure
- Cyber security

To concentrate this work and research effort, it has been proposed to group these into 3 categories: (Elder 2020)

1. Smart Network Management: This category is aimed at the activities of distribution companies including among others administration, management, model design, and business processes, that are subject to advanced supervision of the network through an automated SCADA (Supervision, Control, and Data Acquisition) control system. This allows the activities to be both coordinated, examined, and evaluated in an automated way for the different operating scenarios and situations that may arise with the proper functioning between the power generation station(s) and the distribution feeders.
2. Smart Embedded System: This category is defined for components that are built or designed for the integration of low or medium voltage of electric current, and has a fundamental objective to achieve decreased carbon emissions. In the document, they are discussed at different scales and focus on electrical energy already in the distribution phase, i.e., associated with customer energy access, for example, energy storage in batteries, power plants, electric vehicles, etc.
3. Smart Markets and Customers: This category relates to elements that have to do directly with the consumption of electricity, for example, smart meters, management indicators such as balances in supply and demand, energy trading, and consumption functions, communications, the use of information and communication technologies, the physical and logical security of devices. The highest investment costs that are incurred in this category are usually in infrastructure and devices and this is where the most innovation and development is required.

Running across these categories, it is proposed that there should be a component of training and strengthening in technical and systems competencies from academia, entrepreneurship, technology-based companies supported by industry to create technological prototypes that improve and allow a harmonious balance between energy consumption and environmental conservation. For Turkey as a nation, it is essential to reduce its carbon footprint and that distribution company reduces the levels of loss by technical and non-technical part of the energy flows while increasing network sustainability and energy quality. In parallel, competence development needs to support increased responsiveness and resilience of the network, and awareness of the situation of the network by companies and consumers.

Aligned to this competence development is the promotion and support of research and innovation in academic and industrial sectors to create devices and systems that support generation processes, measurement, and distribution with sophisticated technologies, that are equitable with the environment and real-time operation. These technologies need to be able to support the increase in capacity through the interconnection of renewable energies. The soft issues that these technologies must support include strengthening of strategies of prosumer communities (simultaneous consumers and generators of electrical energy), all in a constructive approach to a future where environmental sustainability and energy supply are economically viable for industrial and domestic consumers. These characteristics need to be in place to support continued growth in industrial and social prosperity for the participating countries.

Colombia

In Colombia the formulation of the document “Smar Grid Colombia Vision 2030”, for the Colombian context, an analysis of the international context is carried out, where developments of countries such as Australia, Canada, the United States, Japan, China, South Korea are observed. Where it is noted that in the aforementioned nations there are elements in common, oriented to political-social and organizational elements, in particular, the ensuring the provision of a quality electricity supply, allowing economic growth, solutions aligned to the challenges facing Colombia in the face of the fulfillment of actions for the sustainable development goals.

The document “Study: Smart Grid Colombia Vision 2030 - Roadmap for the implementation of smart grids in Colombia” Created with financial funds from the Korean Fund for Technology and Innovation. Created within the framework of technical cooperation ATN-KK- 14254-CO (CO-T1337) with the Inter-American Development

Bank - IDB, the Ministry of Mines and Energy, and the Ministry of Information and Communication Technologies. It is consolidated in 4 large parts:

1. General view and a summary of the analysis
2. Road map of the implementation of smart grids in Colombia
3. Analysis of policies and regulation of the electric sectors
4. 9 annexes that support the study.

With the consolidation of this document, true information is obtained on the current situation in Colombia and the real possibilities of the implementation of smart grids.

Smart Meter Systems

In Colombia, a limited number of distribution and commercialization companies have carried out pilots that include smart meter systems at different levels of development in cities such as Bogotá, Medellín, and Cali, however, they are isolated projects that are not framed within the guidelines of national order. There is also a roadmap that defines gradual implementation phases for the systems in Colombia by 2030. However, according to the (OECD 2014) in its study on telecommunications policies and regulation, it shows Colombia is the 3 country that advances the fastest in terms of interconnectivity, especially in mobile technology.

Several motivating elements stand out to guide a clear path to the 2030 vision, the elements are:

1. Improving the efficiency of electrical systems
2. Using and/or applying renewable energy standards and objectives
3. Improving the reliability of electricity systems
4. Promoting research and innovation with new products, services, markets
5. Generating environments for communities to be proactive
6. Optimize the use of network assets

On the issue of infrastructure, the development and strengthening of an AMI is a global priority, followed by the integration of the SGAM - SA architecture model, where most studies highlight the importance of countries having an energy policy composed of elements such as electrical energy assurance, environmental impact, conditions for electricity generation and independence, becoming prosumers, achieving a stable, flexible, and a sustainable energy supply.

The most relevant projects that are being developed with this approach are for instance, in Bogota, the Smart Metering Pilot of the Codensa company, as a result, the measurement systems have been normalized and the operation costs reduced, it is in the feasibility stage. In Antioquìa, the multiservice smart metering pilot project of the company Empresas públicas de Medellin -EPM has impacted 1000 clients, improving the quality of service and identifying commercial energy losses and costs. In the company Internexa, the SA telecommunications project has obtained a business model and an interconnection regulatory framework, improving the telecommunications backbone (UPME 2016).

An Example

Currently, the world has been transforming the processes of the energy sector, this is how the International Renewable Energy Agency (IRENA 2016) stated that the costs of photovoltaic, solar, and wind electricity, among others, will continue to fall accordingly to the combination of increasing economies of scale, supply chains, and competitive environments. According to "Smart Grids Colombia Vision 2030," wind power is 29.5 gigawatts, solar energy is around 17 gigawatts, hydroelectric is 5 gigawatts, and biomass is 4 gigawatts. The Caribbean region and La Guajira have attracted academic and investment projects due to their political-demographic characteristics that facilitate the application of techniques, procedures, and processes to achieve project objectives.

Energy Diversity

In these regions the trend of use of architecture is DER to optimally manage operations, also to monetize the contribution of the system to customers, below is Fig. 1 that presents the roles of the integrators, optimizers, and aggregators.

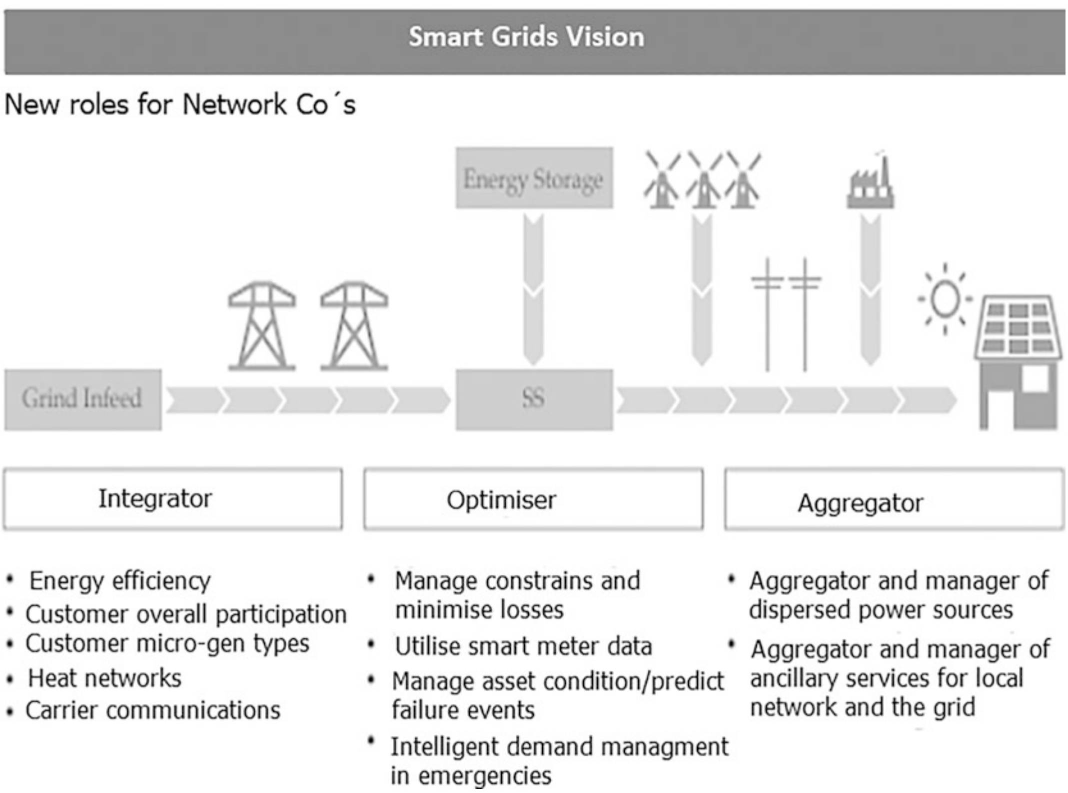
To come to this view Colombia is implementing smart network projects in different parts of the country, where the implementation of AMI is illustrated in Fig. 2.

Projects will include Pilot smart metering, energy measurement technology, intelligent supervision and advanced control (iSAAC) Phase III, Multiservice Intelligent Measurement Pilot Project, IPV6 Protocol Study in the Distribution Domain Data Model in SA, Interconnection in Backbone Access Segments in Telecommunications Network, Implementation of the Measurement Management Center, software architecture for energy consumption management and measurement.

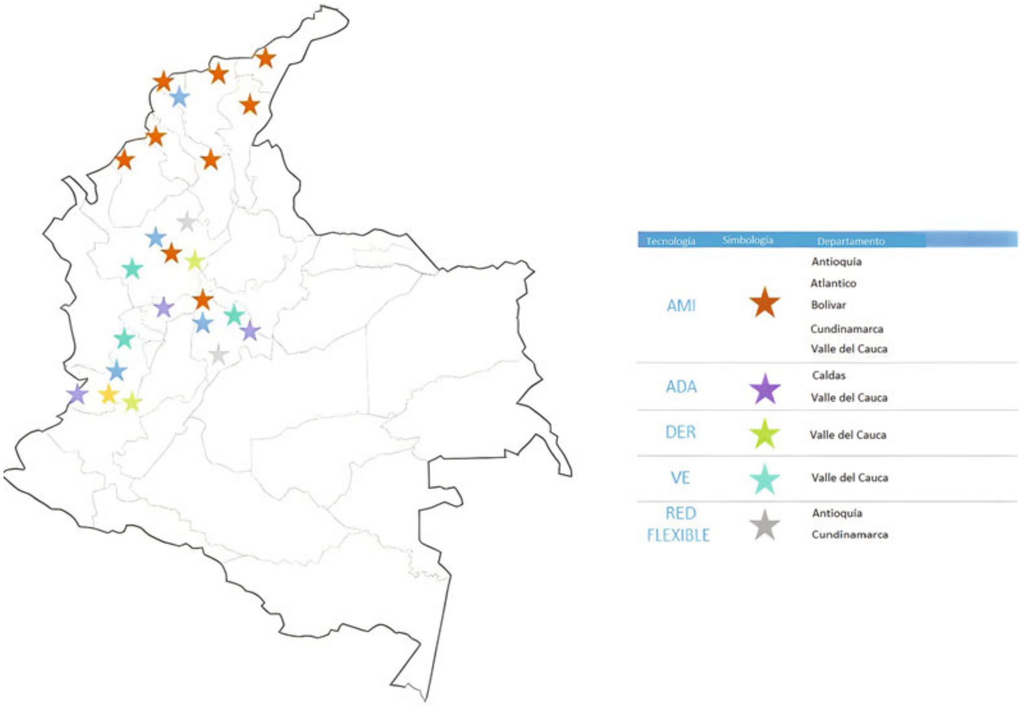
Future of the Applications Both in Colombia and Turkey

Two countries must have a clear roadmap where the sustainable development objectives are articulated, where strengthening is sought through the same education as that established in the 2030 agenda to provide and strengthen people in their knowledge, to reach their full potential within a framework of equity and dignity. Turkey had just signed the Paris Agreement when this work was written. As a result, Table 1 contains information that was current at the time the agreement was not signed. Therefore, Table 1 presents the trend about energy consumption is on the rise ranking among the top 20 countries with the highest consumption energy, emission levels increased 425 million metric tons of carbon dioxide in 2019, it is necessary and urgent to create an ecosystem that involves the government, companies, universities, organizations, among others, for strategic decision-making in the assurance of the economy, environment, regulations, education, policies.

In this framework, the future of applications focused on sustainable development and the



Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey, Fig. 1 SA Vision Source: Belmans (2010) (UPME 2016)



Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey, Fig. 2 AMI infrastructure in Colombia (UPME 2016)

Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey, Table 1 Turkey – Electricity consumption

Date	Generation GWh	Consumption GWh	Consumption per capita kWh
2019	290.442	251.376	3.023,0
2018	290.386	258.116	3.147,6
2017	283.086	247.851	3.067,1
2016	261.850	231.117	2.895,7
2015	249.245	216.658	2.751,5

Source: (IEA 2020)

possible opportunities for improving energy consumption. Oğuzhan (2014) stated that the Turkish government should focus its regulatory efforts on an energy policy that is linked to sustainable development, having three fundamental pillars: social equality, economic efficiency, and guaranteeing the ecological carrying capacity. Similarly, Erdin and Ozkaya (2019) also stated that the pressure on the environment of greenhouse gases released because of the use of fossil fuels complicates the guarantee of economic development in Turkey and puts in clear danger the existence of future generations. As a result, electrical energy must be considered a consumer commodity that is required for the day-to-day operations of business, community, and various areas of globalization. Consequently, it is concerning that the amount of energy consumed continues to rise, posing a threat to human well-being (Connoly and Prothero 2008).

This is where a big potential to construct a smart grid prototype that allows an appropriate design to take advantage of renewable energies and produce electric power prosumers arises because renewable energies play a significant role in ensuring sustainability. As mentioned, Lund (2010) explained that renewable energy can provide sustainable energy and energy security, generating an intensive global energy future that is technically possible. The government of Turkey is currently seeking to increase the proportion of renewable energy resources (RES), having an increase in an installed capacity greater than 30% of what is currently registered, this indicator has as a goal of compliance with the year 2023, it is contemplated in the process of investing approximately USD 110 billion (Erdin and Ozkaya (2019). Turkey represents one of the fastest-growing countries for the energy market (OECD 2019). There are a variety of options available in Turkey to create an alternative energy system that takes advantage of renewable energies while meeting energy demand, but this requires a long-term energy policy (Oğuzhan 2014). To do so, the country must prepare human talent with technical skills, soft skills, and transversal training that allows them to understand energy problems in the context of communities, from which assertive solutions for generation, monitoring, and control can be developed.

Colombia, for its part, is not far from the search for technological solutions appropriate to its context, to achieve the country's energy efficiency. According to Acosta Pérez (2019), Colombia is one of the biggest challenges is the incorporation of the consumer as an active role that changes the paradigm from only consumption to the generation of electrical energy, and its responsible use to this new role has been called "prosumer" (Castro et al. 2017). For this, an opportunity arises in the training and culture processes hand in hand with the implementation of a smart grid with robust characteristics in its architecture of self-management, cybersecurity, active consumer, asset optimization. To achieve effective proposals that contribute to a properly functioning electrical network, you must have an ICT infrastructure that facilitates and supports applications, for this, you must take into account prioritization elements:

1. Strengthen education and culture in community contexts against the energetic ecosystem.
2. Achieve the inclusion and implementation of renewable energy systems.
3. Systematization of energy consumption, through smart grid architectures.
4. Security, integrity, and privacy of information.

Consistent with the prioritization that was obtained from the review of documents from the Ministry of Mines and Energy, UPME, IPSE, and other entities directly related to the Colombian energy system, it is recognized that education, training, and awareness toward communities and/or end-users. It will be the most important exercise since the impact of the projects will bring greater benefits.

Results and Discussion

Colombia and Turkey are collaborating to shape a new future for each of their countries, with smart grids being addressed in studies and research. There are also ongoing projects that are having a good influence. Smart grid deployment provides scalability, dependability, security, sustainability, and competitiveness, to name a few benefits. Table 2 shows the advantages and risks that smart grid adoption has brought to Colombia and Turkey.

The literature review presents that, Colombia and Turkey the path toward the energy transition is on the way, the planned projects, documents, norms, and laws allow migrating to the implementation of smart grids to reduce the use of conventional energy and thereby decrease carbon emissions. Among these, the appropriation of the AMI architecture stands out, as an effective transition strategy, which has been generating good results and tangible benefits such as those mentioned in this document.

For the two nations, there are future challenges such as the consolidation of public policies and a robust legal structure that allows a series of benefits to the end-user community of the energy service and to the industry that implements new technologies and architectures such as those mentioned in this document. Another great challenge is the intelligent control of energy storage that

Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey, Table 2 Benefits and risks of implementing smart grids

Benefits	Risks
Creation of new jobs, economic improvement of the region.	It is necessary to strengthen policies or regulations against the modernization of conditions and other elements for the implementation of the smart grid.
Investment in infrastructure and more efficient technology.	Initially, investments in infrastructure, technology, and others have high costs.
Reduction of greenhouse gas emissions and protection of the environment.	It is observed the need for the smart grid to coexist with traditional networks, for a long time, until they are fully implemented.
Generation, distribution, and energy consumption with adequate monitoring and control.	Lack of qualified human talent to participate in the execution of smart grid implementation projects.
Updated information on supply and demand, additionally control of the quality of the service.	Insufficient parts, spare parts, or components in Colombia and/or Turkey to be able to massif the implementation of smart grid.
Energy management and administration through intelligent equipment that is reflected in energy efficiency and economic benefits.	Communities that inhabit the countries with distrust and doubt in the face of the maturity of the technology and its proper use in the territory.

occurs in the regions, for which the technologies of Industry 4.0 play a fundamental role in terms of the optimization and quality of the devices that are involved in the smart grids. An additional challenge is the formulation of strategies for energy diversity. To this extent, countries must provide conditions for disruptive processes that allow the teaching-learning of local human talent that can face the challenges that arise for the energy transition and industry 4.0 learning from a perspective and worldview of the context. Therefore, the characterization of communities should be the starting point before planning any type of project. Colombia and Turkey have a wide horizon and great possibilities to take advantage of their natural resources and thus reduce carbon emissions and greenhouse gases, but a strong commitment is necessary at all levels, that is, from the government to the most remote community of the territory, and this process will be achieved in a phased manner, applying the correct technologies, understanding the context, and having legal support for it.

Proposing a Data Structure Architecture for Smart Grids

This section presents the necessary data structure architecture for smart grids. Therefore, the topics about big data, data structure are discussed, respectively.

Smart Grids and Big Data

Smart grid is the next-generation energy system capable of managing electricity demand, supply, and efficiency by using advanced digital information and communication technologies to generate the entire system's higher performance and efficiency (Diamantoulakis et al. 2015). The advance in big data trends and data processing makes its relationship with networks increasingly close and, in the same sense Wilcox et al. (2019), presents that the operation of smart grids and future energy management will be increasingly data-driven.

While Munshi and Mohamed (2017) argues that, the massive amount of data evolving from smart grids must be sufficiently managed, respectively. This is the great challenge from data science that requires advanced IT infrastructures, techniques, challenges associated with interoperability, storage, security, and integrity to deal with the amounts of data and their analysis generated from intelligent energy management systems. Big Data technology encompassing the analysis and transformation of data into useful knowledge with the help of different ICT technologies has become a priority development area for companies in general.

For organizations concerned with the generation and supply of electricity, this process is of great relevance (Colmenares-Quintero et al. 2021). Data analysis allows organizations to be proactive, forward-looking, anticipating outcomes, and behaviors based on data rather than hunches or assumptions (Kannan et al. 2018). It consists of theory-based mathematical models, such as regression models, decision trees, and neural networks or data-driven models, such as clustering or segmentation, that support the development of data mining and machine learning (Cattaneo et al. 2018) for descriptive and predictive analysis that are useful for decision-making (Hastie et al. 2008).

Data Architecture

Organizations today face both challenges and opportunities arising from the exponential generation and availability of data such as web application data, historical transaction data, and Internet sources.

According to Cai and Zhu (2015), Zhang et al. (2018), the characteristics of big data in smart grids are also following the universal modus operandi of big data of 5 Vs: Volume, variety, speed, veracity, and value.

Architecture describes the basic structure with its elements, the relationships between these elements, and the system's relationships with the environment (ISO 2000). It describes the principles for the design, development, and use of the system (IEEE 2000). Data architecture represents the data structure of an information system where entity types, modeling, storage, and processing of data and their relationships with each other are shown.

Data architecture is "useful for analyzing large existing data systems, providing the basis for the classification of data analysis processes and technologies. The classification of processes, technologies, and services into groups (components) further facilitates decision-making regarding the implementation of system processes and functionalities" (Sang et al. 2017).

Similarly, big data architectures may refer to the necessary data structures of an entire enterprise as the enterprise data architecture or refer to an application system's data architecture in a section of the enterprise (Mohammad et al. 2014). These architectures comprise an abstract view of the systems and the role of the various system components, their behavior, and how they interact with each other (Calheiros 2018).

Big data analysis requires all forms of different information and communication technologies to be related in an integrated analysis environment. Large-scale data architecture provides the framework for reasoning with all forms of data, consequently contemplates models, abstracts, and rules that direct how data should be stored, ordered, coupled, and implemented in data systems in an application domain.

Reference Models for Big Data Architecture

Table 3 presents the reference models. These models are also mostly presented in layers such as: (1) Data Source; (2) Storage, Processing, and Loading; (3) Data Analysis and Visualization, regardless of the names assigned to them.

Challenges in Designing Big Data Architectures for Smart Grids

there are various challenges related to big data and smart grids, such as ranging from the integration of different hardware, software, and communications technologies with different energy technologies such as wind, solar, biomass, or water that are acquiring a higher level of maturity and development. The interoperability of the different systems deployed on the smart grid makes it complicated and difficult to obtain data for their real application (Zhang et al. 2018).

Recently, software-defined cloud computing and networking technologies have proven to be very useful for efficiently implementing big data solutions: further work is needed to ensure that computing and networking facilities are scaled up to the ever-increasing scale of the data (Ali et al. 2018). Another important aspect is the need for the human capital skills involved in these processes (technicians, analysts, and end-users) to generate value for the information analyzed and obtain relevant decision-making impacts. More emphasis on aspects such as business models from the user's perspective, consumer-oriented applications, best practices and process models, and the commercialization of large data analyses are possible trends.

Smart Grids to Lower Energy Usage and Carbon Emissions: Case Study Examples from Colombia and Turkey, Table 3 Reference Models Big Data Architectures

Reference model	Data source	Data storage, processing, and loading	Data analysis and visualization	
Microsoft	Data sources	Data transformation Data infrastructure	Data usage	
Big data architecture framework (BDAF)	Data models, structures, and types	Big data management infrastructure and services	Big data analytics and tools	
IBM reference architecture	Data sources	Streaming computing Data integration	Analytical sources	Actionable insight
ORACLE	Data sources	Infrastructure services Big data processing and discovery	Information analysis	
PIVOTAL	Capture infrastructure	Data storage and analytics Big data applications	Big data applications	
SAP big data architecture	Ingest	Store and process	Consume	
NBDRA	Collection	Preparation, curation Storage Data organization and distribution Computing and analytic	Analytics, visualization, access	

Source: (NIST 2015)

The literature review about challenges in designing big data addressed that legal and ethical aspects such as regulation, privacy, and data security have emerged as remarkable issues in recent years. Such scenarios include cyber-attacks, metadata falsification, packaging, and phishing attacks are evident. These scenarios must be supported by legal issues that are a challenge for countries where the development of these technologies advances faster than the evolution of laws and regulations.

Conclusion

The study discusses how decreased energy usage and carbon emissions might be accomplished in Colombia and Turkey utilizing smart grid architectural models relevant to SDGs to fill a gap in the literature. Along with the smart grid models, Education 4.0, Energy 4.0, Artificial Intelligent Systems, and POWERBI (processing analysis) are all needed to attain this goal. On the other hand, the acceleration of technology adaptation in various communities has increased due to the pandemic generated by COVID-19. This pandemic period also created great opportunities to face the challenges of sustainable development. It is therefore essential to think about strengthening the pedagogical models in the processes of teaching defined in plans or curricular models that train children, adolescents, and young people.

In Colombia, through different institutions, organizations, among others, the option to improve the conditions and quality of life of its inhabitants is promoted by putting the SDGs into practice, based on the premise that the environment, society, and the economy, must interact together for optimal development of coexistence and respect for our ecosystem. Meanwhile in Turkey, the shift to digital infrastructure in energy production and consumption has accelerated, smart grid technologies have begun to be deployed, and the use of innovative technologies such as digital games for future generations' education has begun to expand in educational institutions.

Cross-References

- ▶ Big data for smart cities and inclusive growth
- ▶ Smart city: A universal approach in particular contexts

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