

Case Report

Digital Transformation of Energy Companies: A Colombian Case Study

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Abstract: The United Nations established 17 Sustainable Development Goals (SDGs), and the fulfillment of the 7th, defined as “Ensure access to affordable, reliable, sustainable, and modern energy for all”, requires energy industry transitions and digital transformations, which implies that diverse stakeholders need to move fast to allow the growth of more flexible power systems. This paper contains the case report that addresses the commercial digital transformation process developed at AES Colombia, through the implementation of a modern platform based on specialized applications that use Industry 4.0 tools. The Chivor hydropower project, a 1000-MW powerplant that covers 6% of Colombia’s demand, which is owned by AES Colombia and constitutes its primary asset, is first described. Then, a description of Colombia’s complex market (energy matrix, trading and dispatch mechanisms, and future projects) is presented. Then, the methodology followed for the digital transformation process using modern tools is described. The project, conceived as a broad framework, comprises applications for the management of hydrological, operational, and market information, commercial information systems and platforms to facilitate consultation and analysis by different users. Such an innovative project in the Latin American context has been developed in order reduce risks and to contribute to a sustainable energy supply for the future.

Keywords: digital transformation; energy transition; energy trading; energy commercialization; risk management; Industry 4.0; artificial intelligence; renewable energy; hydropower projects



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1. Introduction

The United Nations’ 2030 Agenda for Sustainable Development [1] defined 17 SDGs, including “Ensure access to affordable, reliable, sustainable, and modern energy for all”. The fulfillment of such SDG requires changes such as new management schemes and more presence of renewable energy projects in the mix [2]. Within such renewables, and despite some of their drawbacks [3–6], hydropower projects represent valuable assets for the electric power sector, since they provide an important support for grid and mix planning within several countries [7–10], especially in developing countries in which population is growing faster [11]. According to the International Energy Agency [12], cost reductions for renewables and advances in digital technologies are opening opportunities for energy transitions, which implies that policy makers need to move fast to keep up with the pace of technological change, allowing the appearance of flexible power systems.

Energy transitions started at the end of the 20th Century at several places. However, the number of reports has grown considerably during the last five years [13,14]. One can find, among others, studies at different scales: the whole world [15]; continents such as Europe [16] and Africa [17]; countries such as Germany [18], Greece [19], Russia [20,21], China [22], Perú [23], and Australia [24]; regions such as the Basque Country (Spain) [25]; and cities such as Alkmaar (Netherlands) and Évora (Portugal) [26]. Recently, Voropai [27]

presented a review that includes the main challenges to transform electric power systems at large-scale, which involve structural and properties changes linked to the use of modern technologies that allow digitalization and intellectualization of energy systems operation.

Digital transformation of energy industries started several years ago. Kaminski [28] stated at the beginning of the last decade that social and economic forces would continue to shape modern energy markets, posing Information Technologies (IT) challenges to risk management in the energy industry, showing the importance of using stable and scalable IT platforms for Energy Trading and Risk Management (ETRM). More recently, Kolloch and Dellermann [29] used the actor-network theory to better understand managerial challenges associated with digital innovation in the energy industry and their respective ecosystems. Kloppenburg and Boekelo [30] addressed how platforms can promote decentralization of energy generation by applying smart hardware components and intelligent algorithms within energy transitions. Koronen et al. [31] performed the assessment, within EU policies, of the challenges to integrate energy system in data centers using demand response and use of waste heat. Strielkowski et al. [32] presented the implications of the electric system based on high-renewables that can use the Internet of Energy (IoE) and the consequences it brings into the renewable-based electricity market. Weigel and Fishedick [33] provided a structured overview of benefits and stakeholders in the German electric energy sector generated by digital applications. Duch-Brown and Rossetti [34] investigated EU regional markets, which represents 20% of the world energy platforms, analyzing 217 digital platforms. Quaranta et al. [35] discussed some examples of hydropower installations from energy industry in Belgium, France, Italy, Switzerland, and the USA, where solutions aimed at achieving a more sustainable design and operation of hydropower plants have been adopted. Santarius et al. [36] examined if digitalization helps or obstructs the separation of environmental throughput and economic growth. Hiteva and Foxon [37] analyzed energy services and business models in the UK, in order to understand how digitalization can create and capture economic and social values.

Industry 4.0 includes modern technologies that are supporting energy transitions and digitalization, which is strongly associated with energy efficiency scenarios that can contribute to climate change mitigation and the use of sustainable energy systems in the industrial sector [38]. As stated by Martínez-Galán et al. [39], most business presently rely on such technologies, because interconnected systems that share information in a flexible way help companies to have a wider view of their processes, increasing effectiveness and efficiency. Recently, Robert et al. [40] determined the main principles and characteristics that must be present in management systems based on Industry 4.0, finding that interactions and solidarity among actors are required for the appropriate implementation of such systems. Since the energy sector started implementing innovative solutions and digital transformations, Borowski [41] analyzed production processes issues in organizations using solutions based on the paradigm of Industry 4.0; surveys were performed in the energy and food sectors. Ghobakhloo and Fathi [42] performed a qualitative study of the existent digitalization literature to identify the roles of Industry 4.0 in energy sustainability, and identified that operating scenarios can be reshaped thanks to the use of more advanced and intelligent equipment. Works in [42–46] show how the use of modern digital technologies such as Big Data, blockchain, Artificial Intelligence (AI), Internet of Things (IoT), within energy industries facilitates the development of smarter energy grids and concepts that may offer more efficient and innovative approaches to energy use.

AI, IoT, machine learning, blockchain, among others, are digital technologies that have been involved at different levels and stages of energy industry: resource modelling [47], production capacity prediction [48], economic load dispatch [49], demand-side response [50], maintenance management [51], integration of distributed energy resources [52,53], smart grids [54], among others. One can find more detailed applications such as in [55], who developed a new decentralized Peer-to-Peer (P2P) energy trading platform to overcome challenges such as keeping a fair balance between economic efficiency and information privacy, inter-temporal dependencies created with the incremental use of storage devices,

and implementation of blockchain for P2P trading that can facilitate transactions in secured and fraud-resilient scenarios. Wu et al. [56] presented a systematic review of how IoT helps the digitalization of transactions in Energy Internet and how these transactions can be decentralized by using blockchain. Ahmad et al. [57] conducted a comprehensive review that allows comparing AI efforts, expectations, challenges, applications, and roles in policymaking, by analyzing how solar and hydrogen power generation can benefit from the use of AI in supply/demand management.

Energy trading started changing three decades ago, with the first efforts of EU to unify internal markets and match prices across all European economies [19]. Presently, power markets are in transition to carbon neutrality, increasing energy efficiency, and decreasing short-term time demand responses [58], which requires the implementation of new technologies and digital transformation within all stages of energy industry [59]. Regarding this, Yin et al. [60] reported a study that focuses on the relation between energy transactions and distribution marginal pricing, based on the transmission/distribution/customer hierarchy. Since consumers have become active stakeholders within energy markets, Schweiger et al. [61] presented a comprehensive study of stages and obstacles found in the development and implementation of user-centered energy business models; they included a required data, computational methods and psychological aspects. Consequently, energy transitions are required for the prosumer (producer/consumer) to be an important player within smart cities, and consequently new architectures are being proposed to help aligning the municipality goals and the direction of the city regarding IT [62], which imposes new dynamics in energy markets. In this regard, Ju et al. [63] proposed a purchase/sale transactions optimized strategy for electricity retailers with energy storage system considering two-stage demand response as an example of an effective tool for power retailers. For the case of Colombia, the National Planning Department, supported by the World Bank, has released studies regarding the energy supply [64] and the energy demand situations in Colombia [65], which led to build green-growth policies [66] that will lead the energy transition and market transformation in the following decades. Regarding energy generation, Arango-Aramburo et al. [67] studied possible roadmaps, given that the energy matrix is mostly supported by hydroelectric plants (around 70%), and proposed various scenarios for the 2020–2050 period, and although they found that the participation of hydroelectric plants will decrease with the appearance of new generation plants based on different resources, it is necessary to increase the useful life of power plants through technological development projects, which imply presently digital transformations.

This paper addresses the commercial digital transformation process at AES Colombia, developed through the implementation of an information management platform based on specialized applications that use Industry 4.0 technologies. Such a platform allows reducing risks and uncertainties, and facilitates the implementation of appropriate models to optimize energy trading transactions. This will contribute to stabilize the complex Colombian energy market that is experiencing transitions while seeking “access to affordable, reliable, sustainable, and modern energy”. The organization of the paper is as follows. In Section 2, the Chivor hydropower plant and the Colombian energy market are described; then, the AES Colombia’s digital transformation process is addressed. Section 3 shows the benefits of the new digital platform implementation. Section 4 contains the discussion, and finally, conclusions are presented in Section 5.

2. Materials and Methods

2.1. Chivor Hydropower Plant

As described in [68,69], Chivor is a 1000-MW hydropower plant (eight 125-MW Pelton turbines) that represents the main asset of AES Colombia; this plant entered service in 1977 (Chivor I) and 1982 (Chivor II). The project is located at Santa María, Boyacá, 160 km northeast from Bogotá, the capital city of Colombia, and was built to operate at least for 50 years using mainly La Esmeralda reservoir (with a basin area around 2420 km²), and two additional small reservoirs, Río Negro and Tunjita. The main reservoir uses Batá river

(flow rate: average 60 m³/s, min. historical 2.8 m³/s, and max. historical 1500 m³/s registered in 1970), and has a capacity of 769 Mm³. The reservoir has a 237-m height crest (at 1288 m.a.s.l.), and its maximum level is 1277 m.a.s.l. (to mitigate potential rising of the rivers). The hydropower plant has now two different intake systems, the original intakes are 165-ton steel/concrete structures located at 1195 m.a.s.l. and will operate until 2027, and a new intake system reported by [68] that will extend the life of the reservoir for 50 more years. Water is then conducted to the powerhouse through two independent seven-meter-high tunnels: Chivor I and II conduction (headrace tunnels). Finally, water is discharged to the river Lengupá at 464 m.a.s.l, which represents more than 700 m of total head. Considering that this hydropower plant had an initial operational expectancy until 2025, AES Colombia has been executing several projects to extend the operational time for 50 more years, including the construction of the aforementioned new intake systems, renovations of conduction tunnel linings, renovation of electrical equipment, and digital transformation of the company in order to reduce risks and uncertainties, and to optimize energy trading transactions.

2.2. Colombian Energy Mix and Market

The National Interconnected System (SIN by its initials in Spanish) connects 48% of the national territory and covers 95% of the population and accounts for 52% of the country's area, mainly supported on hydropower and thermoelectric plants [65]. With an installed capacity of 16.8 gigawatts (GW) by 2017, Colombian electrical generation system has a share of 69.85% of hydropower and 29.02% of thermal-power plants [70]. The remaining 1% corresponds to non-conventional renewable sources (i.e., solar PV and wind), Combined Heat and Power (CHP) and self-generation plants. Hydropower generation supply to the SIN increased by 21% in 2017 compared to the previous year. Nevertheless, energy resources are still mainly hydropower and classic thermoelectric plants. The Colombian electricity market began operation in 1995, as a response to the electricity shortage in 1992, with two primary purposes: to get the most efficient electricity prices, and to ensure power availability, regardless of weather conditions. The basic model used in the early stages was the marginal price, which orders the generation offers by price (i.e., closed bids) until the whole demand is covered, and the last resource price is the value to be paid to all bidders [71]. On the other hand, a capacity charge was implemented, mainly for thermal generation, to respond rapidly during dry seasons. The capacity charge was easy to report for generation utilities, using technical data from generation assets and basic models for the energy sources (fuels and reservoir levels). In 2006, the capacity charge evolved to the availability charge, which required other parameters to be measured and reported and be also aware of the competence data and strategies.

In 2014, another important event took place. It was the 1715 law that promotes the introduction of non-conventional sources of energy, i.e., wind, SPV, biomass, large and small scale [72], which would add to the generation mix but could also participate (with specific calculation models) in the availability charge. With time, the introduction of this new generation resources would demand detailed and more complex data analysis, including forecasts, simulations and rapid response from the market agents. In this regard, traditional generation utilities are called to update and improve their decision procedures, analysis tools and data acquisition; especially, under the appearance of energy commercialization schemes that allow users to participate in the electricity market with self-generation and CHP surplus, as established by the Energy and Gas Regulatory Commission (CREG by its initials in Spanish) in the Resolution No. 30 May 2018 [73]. Additionally, the Colombian government launched the "Energy Transformation Mission" to build the roadmap for future energy: efficient, reliable, sustainable in 2019 [74]. One relevant subject of interest is "decentralization, industry digitalization and efficient energy management". Nodal prices, real-time data, advanced metering infrastructure (AMI), online bids, and demand response are some of the schemes present in the short term; therefore, all agents must be prepared to evolve in a digital transformation.

As has been shown, the Colombian electricity market is complex and those who participate in trading operations are exposed to risks [75]. Such risks are difficult to assess and manage since electrical energy is a non-storable primary good that does not allow keeping inventories as hedge against fluctuations. Hence, the mitigation of such risks has traditionally been carried out through the operation of bilateral contracts, which are generally of the type “pay the contracted and pay the demanded”, also known as forward contracts, which are difficult to rescind and generate credit risk [76]. Future contracts also exist in Colombia, and considered to be an alternative to bilateral contracts to access financial coverage that, due to its standardized nature and form of settlement, eliminates the credit risk and provide the possibility of increasing the number of potential negotiators [75].

2.3. AES Colombia Digital Transformation

According to what has been stated up to this point, the Colombian energy market is highly complex and depends mainly on hydropower generation, which is influenced by different external variables that are difficult to control by the stakeholders. Therefore, trading agents on the stock market are exposed to several risks, which are difficult to manage by applying only traditional methods that have been used in the financial market. This was the scenario for AES Colombia until 2020, because the company used standard methods such as handling large volumes of information by using spreadsheets that were disaggregated, independent and duplicated by different users. This situation generated errors, inconsistencies, and reprocesses, leading to a lack of reliability, integrity and timeliness of the information. Consequently, AES Colombia determined that there was a need to perform a digital transformation by implementing a new infrastructure that comprises modern tools to conduct data management processes, energy purchase and sale transactions, and contract administration. This platform would represent a significant improvement in data and information management to increase financial benefits in the energy purchase/sale transactions carried out daily by the company, as well as contributing to the stability of the complex national energy market, reducing risk exposure and uncertainty scenarios.

2.3.1. Project Description

AES Colombia decided to start the digital transformation of the organization with the development and implementation of technological applications that support the operational and commercial management, facing the requirements of internal and external clients, with three main goals: (i) Customer service. Provide the user with a communication platform that satisfies informational requirements, facilitating online and real-time consultation. (ii) Portfolio. Implement a commercial management tool that supports risk management and portfolio administration. (iii) Stock transactions and contracts. Optimize internal processes associated with the provision of supplies, analysis and presentation of the offer on the stock exchange, through a technological platform that allows managing information in an appropriate way, facilitating decision-making in uncertain scenarios. This modern technological platform has been developed through the implementation and articulation of commercial applications into the proposed architecture, Figure 1.

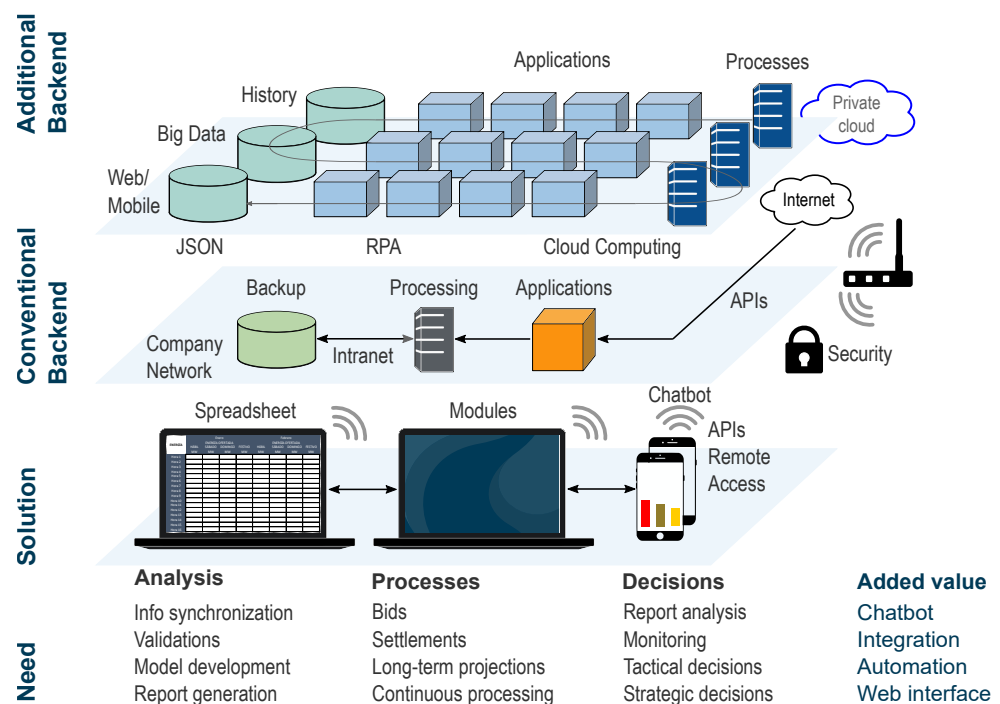


Figure 1. AES Colombia digital platform proposed architecture.

2.3.2. Methodology

The successful implementation of the digital transformation process required the following 14 steps to adopt the proposed architecture within AES Colombia, but that can be useful for another energy company: (a) Diagnostics and analysis of the current situation of different areas of the company, in terms of the use of tools for the collection, storage, analysis, preparation of reports and their socialization. (b) Assessment of the company's level of maturity to face the processes that must be implemented in the digital transformation process. (c) Review and adjustment of the company's strategic objectives, mission, vision and values towards digital transformation. (d) Identification of stakeholders, both internal and external, that can be affected by the implementation of the project. (e) Analysis of innovation capacities to take advantage of the benefits of the implementation of the digital strategy, and analysis of the state of maturity of digital tools available at different lines of business or areas of the company. (f) Development of a new business model, which includes the mechanisms for approaching customers. (g) Training program implementation to manage the change in digital transformation and the operation of the platform with its applications. (h) Communications plan implementation to create a culture of change towards digital transformation and to socialize the activities of the digital transformation project with employees. (i) Resources are identified and quantified as required, as well as the design of the administrative structure for digital transformation. (j) Action plan, which includes working together with corporate areas such as: marketing, operations and processes, financial management, portfolio management, and human resources, among others. (k) Implementation of commercial applications to create the digital platform. (l) Impact assessment through planning and monitoring performance indicators for the platform and applications. (m) Adjustments to the platform and its applications that are considered convenient for its appropriate performance. (n) Documentation.

3. Results

Some functionalities and advantages of the implemented platform include, among others: decreasing response times and increasing the depth of the analysis of the company's portfolio; minimizing the risks of financial losses in energy purchase and sale contracts through short, medium and long-term planning tools, and the automation of processes

in commercial operations; increasing the depth of the analysis of energy trade contracts, performing automatic supervision, with quick access to market data; projecting energy prices on the stock market with the support and analysis of expert personnel; continuous learning of the energy market by comparing data and information from projections with real values to improve the quality of future estimates; automation of information access at any time, simulation, projection, settlement calculations, access to historical data and validation; automation of information processing, reducing the execution of manual operations; automatic execution of parallel processes, saving the time of basic repetitive tasks and complex optimization processes; automatic review of trading contracts with current regulations; automatic report generation with information on the settlements of energy purchase and sale contracts; simulation of multiple energy dispatch scenarios using mathematical logic and variables updated by the National Dispatch Center; to prevent possible financial losses, the platform applications evaluate the economic result with each scenario to optimize and support the energy supply strategy of each day; and simulation and evaluation of stock price scenarios, based on the dispatches of the electricity market projected for the stochastic series of the hydrological contributions of the power plants, for risk reduction.

The purpose of using modern technologies used in Industry 4.0 within the modular architecture to automate processes, optimize operations and improve analysis performance within the digital transformation (DT) is to increase the speed and reduce the operational load of the analysts in the commercial area, using the best technology and information available. An important result in this digital transformation process regards data normalization that allows mapping, transformation and combination of disparate data sources generated at different administrative and operational areas of AES Colombia, and third-party data sources and at the same time. This permits the performance of knowledge-based analytics about the service provided by the company by using an advanced data analysis engine that uses Artificial Intelligence algorithms. This engine has been created to process large-volume data sets for decision-making processes regarding, for instance, to customer segmentation. Some time-reduction scenarios are shown in the following sections.

3.1. Example of Price Projections

The platform allows performing short/medium/long-term price projections with simulations that consider variables related to demand growth, occurrence of El Niño or La Niña, hydrology, thermoelectric plants production costs, fuel Availability, average fuel prices (gas, diesel, coal, etc.), new generation projects, among others. Table 1 shows the comparison of time spend for price prediction simulations, before and after the DT.

Table 1. Time comparison for price prediction simulations.

Indicator	Time before DT (h)	Time after DT (h)
Projection requirements	27	4.8
Information update	16	0.1
Scenario definition	3	0.5
Scenario simulation	4	4
Results generation	4	0.2
Total	54	9.6

3.2. Example of Report Generation

Analysts can download reports to spreadsheets with hundreds of variables from the Colombian energy market in real time, using information from the National Dispatch Center and the Administrator of the Commercial Exchange System, for any time frame. Table 2 shows the comparison of time spend for reports generation, before and after the DT.

Table 2. Time comparison for reports generation.

Indicator	Time before DT (h/Month)	Time after DT (h/Month)
Daily bid, daily Report	30	15
Market share	8	1
Monthly commercial margin	6	0.5
Agents hiring	2	0.5
Consumption validation	2	0.1
Daily offer reports	60	15
Total	108	32.1

3.3. Example of Offer Projections

Energy offer can now be computed using different scenarios using information from the National Dispatch Center. This part of the platform allows comparing economic results for such scenarios, which provide the company an optimized way to set-up the daily offer strategy. Table 3 shows the comparison of time spend for computing daily offers based on available information, before and after the DT.

Table 3. Time comparison for offer projections.

Indicator	Time before DT (h/Month)	Time after DT (h/Month)
Projection requirements	76	30

Although there are several advantages derived from the implementation of the digital transformation, the greatest challenge faced with these implementations is to guarantee appropriate communication between the work teams at the local and global level to ensure beneficial impacts for the different stakeholders. Risks that represent downsides during the execution of the project can be appear in three cases: (i) if due to world changing conditions, the Colombian market becomes unstable, (ii) resistance to change by employees and key stakeholders towards digital transformation, and (iii) difficulties to feed data and information to the applications of the platform.

The main weaknesses that have been faced with this transformation are related to both human and technical factors. The major resistance to change, especially change referring to new procedures to be implemented because of governance requirements, is that it has been difficult for users to adopt new ways of working, given the dependency of their tasks on outputs from other users as a condition to achieve successful results. On the other hand, when it comes to steps that must be done sporadically, users usually ask for advice and even new training to keep the outputs as expected. Knowing that motivation and proficiency are factors with high impact on project success, a change management plan has been deployed as a measure for attending these situations, which are predictable in most of the cases. Consequently, the methodology in this field must be formally established to ensure effectiveness and wide usage of the systems that have been implemented. From the side of technical factors, issues with time response and server capacity have been challenging, but in some way this topic is easier to solve when compared to previous issues. It is important to note that all the efforts to improve better relations among users, procedures and tools are in the scope of the project as a permanent goal since these are joined, forming a set which evolves continuously, affecting each other. From that perspective, the change should be managed as a goal that never ends if we want to harvest the best results along this digital transformation pathway.

4. Discussion

As has been shown with some results obtained using the new platform, information will no longer be processed manually with spreadsheets, which allows storing and

processing of information in a reliable and timely manner, among many other functions. In addition, reports can be generated in real time for the various areas of the company that make decisions regarding the operation of the electric power market. The digital transformation process generated several value-added functions such as carrying out reconciliations of contracts with customers, reviewing price trends, generating reports to compare the number of contracts with the generation potential in a given period of time, support for the analysis of all commercial transactions in which the company incurs, in the short, medium and long term, determining the amount of energy to generate or availability to honor the contracts, among others.

Regarding energy transitions, AES Colombia created a powerful centralized platform with different areas of the company to perform transactions and maintain relationships with external users, in the context of the digital transformation process. This platform centralizes contracts, income and costs and allows the company to know in real time its position at global and local levels in the country's context, contributing to Colombia's energy companies transition, which is an example for the Latin American context.

The size of the digital transformation project required designing and implementing a change management program, which includes, among other aspects, purchasing management and coordination, planning and execution of communications, definition of commercial sales processes to take full advantage of the technological applications that have been integrated in the platform. The platform and its applications allow evaluation of market models, impacts of new regulations, reservoir management, contracting levels, cost declaration, and incorporation of new plants. Additionally, the contribution and impacts of unconventional energy plants to the Colombian energy system, among other factors. With this platform it is possible to know the relationships of the stock prices and the prices of contracts to determine end-user rates; in this way, the interaction of the unregulated and regulated wholesale markets and the impact of one on the other can be represented, thus allowing the generation of financial reports for various users within the company. This represents a clear example of a successful digital transformation process of an energy company that adds insightful ideas to the state of the art.

The project, conceived as a broad framework of digital transformation using Industry 4.0 tools, comprises applications that range from the management of hydrological, operational, and market information, passing through commercial information systems to reach platforms whose ultimate purpose is to facilitate consultation and analysis by internal and external clients. All these applications connections demonstrate the relevance of modern technologies such as Artificial Intelligence, machine learning, and blockchain to perform knowledge-based analytics by using an advanced data analysis engine created to process large-volume data sets for decision-making processes.

The execution of the project allowed the transition from a local management strategy to a global one that requires synergies, learning processes, teamwork, communication skills, and mastery of different technological tools. The implementation of the new platform entails the management of structured data volumes that potentiate the generation of value regarding the information required for risk management and decision-making. The latter are key elements for a complex market, such as in the Colombian case, since the new platform supports short-term decisions and the optimization of the operation using modern tools to process significant volumes of market information, providing better scenarios, reliability and integrity.

Challenges were addressed with the fluid adoption of new procedures, which implied a determined effort through mechanisms such as regular training, practical guidelines for using the tools properly, follow-up meetings and socialization of the experience of each user, to ensure that the systems are used in daily basis for all the activities; it is worth emphasizing the importance of enhancing our culture within the user group, this is a long-term commitment that involves time, effective communication and willingness. Finally, despite being a technological project, the success factor and the big challenge is related to human being, and that is where efforts must be focused.

It is worth mentioning that until 2012, the company only had the Chivor Hydropower Plant in Colombia. In search of the company's energy transition, in 2012, a small hydroelectric plant came into operation with an installed capacity of 20 MW. In 2019, AES Colombia started operating the Castilla solar PV park with 21 MWp. Additionally, during 2020 the company started building the largest wind project in Colombia with 649 MW. In this regard, the wind and solar projects will help AES Colombia optimizing the portfolio using the digital transformation project that has been addressed in this work. In particular, the operation of wind energy plants operation must be considered in analyzing the transactions on the stock market, which is currently developed under a day ahead scheme; with these plants' incorporation, it will migrate towards an intraday model. Although they are oriented towards self-generation, the models must consider the company's projects and other fields installed to guarantee a correct reading of the market. The implemented platform will be required to facilitate this reading and favor adaptation to these changes. In this way, artificial intelligence and automation processes constitute a competitive advantage for the organization.

As addressed in the introduction section, energy transitions started at several places at the end of the 20th Century, including some events that have been reported in Colombia by Martínez and Castillo [77] for the energy sector. However, no reports have been found in the literature for the region and Colombia that address the main challenges to transform electric power systems at large-scale using modern technologies that allow digitalization, as described by Voropai [27]. Consequently, this case report addressing the commercial digital transformation process at AES Colombia, developed through the implementation of a novel information management platform based on specialized applications and Industry 4.0 technologies, constitute one of the first reports for digital transformation processes in the region. The results have shown that such a platform allows reducing risks and uncertainties, and facilitates the implementation of appropriate models to optimize energy trading transactions, contributing to achieve enterprise sustainability and to stabilize the complex Colombian energy market while seeking "access to affordable, reliable, sustainable, and modern energy". The digital transformation process involved several technological challenges; however, because the implementation recently started, this study has been limited to the first findings regarding time reductions obtained with the new platform; further studies must be conducted with emphasis on management strategies to tackle cultural changes that are expected for all the stakeholders, based on continuous assessment and improvement.

5. Conclusions

This work addressed the execution of the commercial digital transformation project that has allowed AES Colombia to transition from a local management strategy to a global one that involves synergies, learning processes, teamwork, communication skills, and mastery of different technological tools. The implementation of such tools, which extensively use Industry 4.0 tools, entails the management of structured data volumes that potentiate the generation of value regarding the information required for risk management and decision-making.

The main advantages derived from the implementation of the digital transformation are linked to the changing nature of the Colombian market (that relies mostly on hydropower), the growing and varied expectations of customers and the uncertain environment that characterizes decision-making in commercial matters in the energy market. All these factors have been covered by the implemented platform, translating into reliability, timeliness, ease of access and integrity of the information, and strengthening of the relationship with the client for an energy company whose main asset is a hydropower plant.

Although hydropower plants often create negative environmental and social impacts over specific regions, AES Colombia is extending the life of the Chivor Hydropower Plant [68], its main asset that covers 6% of Colombia's demand and that was built in the 1970s. This, together with the digital transformation project, represent key efforts to benefit

the entire national electricity sector, thus contributing to its stability and helping to make sustainable energy available at all times to the entire population and any productive sector in the country, thanks to the use of modern tools that allow reducing risks and improving decision-making processes.

The commercial digital transformation process at AES Colombia opens to possibilities related to improving systems and energy production forecasts, adopting new variables, developing business solutions and procedures that support them. Market trends require new technologies in line with their evolution. It will imply carrying out a periodic validation of the obtained results with the new platform against the real information and carrying out a follow-up to changes in the operation and the market to ensure the incorporation of necessary adjustments that allow the decision tools' continuous updating.

Since commercial transactions imply the management of information inputs from various sources that complement each other, the use of specific applications, which allow using high volumes of data and facilitate the provision of information in real time, constitute important tools to support decision-making processes within the digital transformation of energy companies.

Although digital transformation processes involve several technological challenges, they should be conducted with emphasis on the human being since cultural changes are expected in all the stakeholders. Therefore, activities such as regular training, practical guiding, follow-up meetings, socialization of the user experience, among others, are key to emphasize the importance of enhancing the culture towards using new systems and technologies. From that perspective, such transformation processes should be managed with never-ending goals that imply continuous assessment and improvement.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
DT	Digital transformation
ETRM	Energy Trading and Risk Management
CHP	Combined Heat and Power

CREG	the Energy and Gas Regulatory Commission
IEA	International Energy Agency
IT	Information Technologies
IoE	Internet of Energy
IoT	Internet of Things
SDG	Sustainable Development Goal

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