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Digital Readiness in the Central American Energy Sector

Benchmarking and Preparing for a Digital Future

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Foreword

Central America is a region of opportunity and this is also a reality reflected in the energy field.

The digital readiness study focuses on the current energy scenario of the countries that constitute the Central American Integration System (SICA, Sistema de la Integración Centroamericana), their initiatives and adaptation to global energy trends as well as on the identification of opportunities for the digitalization of the Central American electricity sector.

Talking about the regional electricity sector implies highlighting some factors that allow driving regional actions, e.g. the abundance of resources available in Central America that enable an exponential growth in the deployment of renewable energy. In 2018, 75% of the electricity generated in Central America came from renewable sources.

An absolutely essential factor is the institutional framework based on the Protocol of Tegucigalpa adopted by the Excecutive Council of SICA, the System's highest legal-political body, that addresses regional common challenges.

In this context, the Central American Sustainable Energy Strategy 2030 (EESCA, Estrategia Energética Sustentable Centroamericana 2030) and the Framework Treaty for the Central American Electricity Market (MER, Mercado Eléctrico Regional) support the creation of a solid electrical infrastructure, represented by the Central American Electrical Interconnection System (SIEPAC, Sistema de Interconexión Eléctrica de los Países de América Central).

SIEPAC is considered a regional public good through which 90.7% of population gained access to electricity in Central America in 2018, providing energy as a fundamental right for the economic and social development of the region, while promoting energy transition in SICA member countries.

Furthermore, the alignment of regional and international agreements has permitted Central America to advance strongly in the implementation of sustainable actions to achieve the Sustainable Development Goals (SDGs) and the Nationally Determined Contributions (NDCs), that demonstrates a deeply embedded process of a regional energy integration.

Under this approach, and in response to the global realities such as the challenges of the Fourth Industrial Revolution, the adoption and implementation of new emerging digital technologies are of great importance for SICA member countries to consolidate the region's sovereignty and energy independence. Therefore, we are working for a Digital Central America and a Digital SICA.

The relevance of this study is demonstrated in the joint support of the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* that implements the Renewable Energies and Energy Efficiency Program (4E) in Central America, on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ, for its acronym in German), in order to increase energy efficiency and grid integration of variable renewable energies.

The study was conducted thanks to the contributions of various actors in the value chain of the Central American electricity sector. The aim is to release, in a holistic manner, a series of recommendations for decision-makers, to encourage them to continue on the path towards improving framework conditions, and subsequently to promote the use of digital technologies in the energy sector. The most decisive factors are focused on strengthening five fundamental axes such as digital infrastructure, human capabilities, investments and capital, public institutions and governance as well as improving organizational culture in the face of digitalization.

The digitalization of the electricity sector provides a window of opportunity to foster a diversified regional energy matrix as well as the creation of specific benefits for the population, as the center and main subject of development. The implementation of new digital technologies in the energy transition is necessary to boost the regional digital vision 2030 and progressively build the Digital Central America we aspire to.

We believe in integration as a strategic instrument for development, thus we work every day to leverage and enhance the region of opportunities that we already are, a Central America that leaves no one behind, in any field.

Vinicio Cerezo
General Secretary
President of Guatemala (1986-1991)

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Abbreviations

4E	*Erneuerbare Energien und Energieeffizienz in Zentralamerika* Renewable Energies and Energy Efficiency Program in Central America
AA	Advanced Analytics
AI	Artificial Intelligence
AIG	*Autoridad para la Innovación Gubernamental* Authority for Governmental Innovation
AMM	*Administrador del Mercado Mayorista* Wholesale Market Administrator
ANN	Artificial Neural Network
APR	*Usuario Autoproductor Renovable* Renewable Self-producing User
ARESEP	*Autoridad Reguladora de los Servicios Públicos* Regulatory Authority of Public Services
ASEP	*Autoridad Nacional de los Servicios Públicos* National Authority of Public Services
BMU	*Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit* Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMZ	*Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung* German Federal Ministry for Economic Cooperation and Development
BMWi	*Bundesministeriums für Wirtschaft und Energie* Federal Ministry of Economics and Energy
BOT	Build-operate-transfer
CA	Central America
CDMER	*Consejo Director del Mercado Eléctrico Regional* Regional Electricity Market Steering Committee
CECACIER	*Comité Regional de CIER para Centroamérica y El Caribe* Regional Committee of CIER for Central America and the Caribbean
CENCE	*Centro Nacional de Control de Energía* National Energy Control Center
CHL	Chile
CIER	*Comisión de Integración Energética Regional* Regional Commission of Energetic Integration
CND	*Centro Nacional de Despacho* National Dispatch Center
CNDC	*Centro Nacional de Despacho y Carga* National Load and Dispatch Center

CNE	*Comisión Nacional de Energía* Nacional Energy Commission
CNE	*Consejo Nacional de Energía* National Energy Council
CNEE	*Comisión Nacional de Energía Eléctrica* *National Electric Energy Commission*
CNFL	*Compañía Nacional de Fuerza y Luz* National Power and Light Company
CREE	*Comisión Reguladora de Energía Eléctrica* Electric Energy Regulatory Commission
CRI	Costa Rica
CRIE	*Comisión Regional de Interconexión Eléctrica* Regional Commission for Electricity Interconnection
DEU	Germany
DSO	Distribution System Operator
ECLAC	Economic Commission for Latin America and the Caribbean
EDECHI	*Empresa de Distribución Eléctrica Chiriquí* Chiriqui Electric Distribution Company
EDEMET	*Empresa de Distribución Eléctrica Metro-Oeste* Metro-West Electric Distribution Company
EE	Energy Efficiency
EEGSA	*Empresa Eléctrica de Guatemala, Sociedad Anónima* Guatemalan Electric Company, Limited Company
EEH	*Empresa Energía Honduras* Hondurean Energy Company
EIB	European Investment Bank
ENATREL	*Empresa Nacional de Transmisión Eléctrica* National Electricity Transmission Company
ENDESA	*Empresa Nacional de Electricidad, Sociedad Anónima* National Electricity Company, Limited Company
ENEE	*Empresa Nacional de Energía Eléctrica* National Electric Energy Company
ENEL	*Empresa Nicaragüense de Electricidad* Nicaraguan Electricity Company
ENSA	*Eléctrica Noreste, Sociedad Anónima* Electric Northeast, Limited Company
EOR	*Ente Operador Regional* Regional Operator Entity
EPR	*Empresa Propietaria de la Red* Grid Owning Company OR Network Owner Company

EESCA	*Estrategia Energética Sustentable Centroamericana* Central American Sustainable Energy Strategy
ETESA	*Empresa de Transmisión Eléctrica* Electric Transmission Company
EV	Electric Vehicle
FDI	Foreign Direct Investment
GDR	*Generación Distribuida Renovable* Renewable Distributed Generation
GDP	Gross Domestic Product
GET	Global Energy Trend
GHG	Greenhouse Gas
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* German Agency for International Cooperation
GTM	Guatemala
GWh	Gigawatt hour
HDI	Human Development Index
HND	Honduras
ICE	*Instituto Costarricense de Electricidad* Costa Rican Institute of Electricity
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
INDE	*Instituto Nacional de Electrificación* National Institute of Electrification
INE	*Instituto Nicaragüense de Energía* Nicaraguan Institute of Energy
IoT	Internet of Things
KPI	Key performance indicator
IRHE	*Instituto de Recursos Hidráulicos y Electrificación* Institute of Hydraulic Resources and Electrification
kV	Kilo Volt
LUFUSSA	*Luz y Fuerza de San Lorenzo, Sociedad Anónima de Capital Variable* San Lorenzo Light and Power Public Limited Company
MEM	*Ministerio de Energía y Minas* Ministry of Energy and Mines
MER	*Mercado Eléctrico Regional* Regional Electricity Market
MINAE	*Ministerio de Ambiente y Energía* Ministry of Environment and Energy
ML	Machine Learning
MW	Megawatt

NIC	Nicaragua
NLP	Natural Language Processing
NoE	Network of Expertise
ODS	*Operador del Sistema* System Operator
OS/OM	*Operador del Sistema/Operador del Mercado* System Operator/Market Operator
PNM	Panama
PPA	Power Purchase Agreement
RE	Renewable Energies
REDCA	*Red Centroamericana de Telecomunicaciones* Central American Network of Telecommunications
RES	Renewable Energy Sources
RTR	*Red de Transmisión Regional* Regional Transmission Network
SAIDI	System Average Interruption Duration Index
SEC	Electricity and Fuels Superintendence
SEN	Secretaría de Estado en el Despacho de Energía *State Secretariat in the Dispatch of Energy*
SER	Sistema Eléctrico Regional *Regional Electrical System*
SICA	*Sistema de la Integración Centroamericana* Central American Integration System
SIEPAC	*Sistema de Interconexión Eléctrica de los Países de América Central* Central American Electrical Interconnection System
SIGET	*Superintendencia General de Electricidad y Telecomunicaciones* General Superintendency of Electricity and Telecommunications
SLV	El Salvador
SME	Small and Medium Enterprises
SNE	Secretaría Nacional de Energía *National Energy Secretariat*
TSO	Transmission System Operator
UPR	*Usuario Final Productor Renovable* Renewable Producers Final User
UT	*Unidad de Transacciones* Transactions Unit
VRE	Variable Renewable Energies

1. Introduction

Energy systems are shifting towards supplying cleaner, more sustainable, and more efficient electricity. This conversion comes at a point of growing environmental awareness, scarcity of fossil energy resources, and advances in energy system digitalization. Against this backdrop, the third phase of the German Federal Ministry for Economic Cooperation and Development (BMZ, for its acronym in German), the 4E Program (2018-2020) aims to improve the integration of variable renewable energy (VRE) and energy efficiency measures in Central America (Figure 1).

As a region, Central America presents excellent conditions for the use of renewable energy and substantial potential to save energy through efficiency measures. Pursuing cost-effective renewable energy alternatives will decrease the region's dependence on oil, reducing its currency outflows (SICA, 2007). Thus, stakeholders expect energy transition to have ecological, environmental, and economic impacts on the region.

Digitalization is key for addressing Central America's myriad energy sector challenges: aging infrastructure, electrical losses, growing demand, increasing numbers of variable renewable energy sources to integrate, growth in e-mobility, and improving security of supply. Digitalization will not only contribute to tackling these challenges but will also promote the growth of both new and under-utilized energy potential throughout the region.

There is a plenty of opportunity to digitalize Central America's energy sector[1]. To uncover the current state of digitalization and then explore its potential contributions in the future, GIZ mandated an in-depth analysis as part of the Renewable Energy and Energy Efficiency (4E, for its acronym in German) Program.

This report, *Digital Readiness in the Central American Energy Sector-Benchmarking and Preparing for a Digital Future,* considers actions that will allow the region's energy sector to increase

Figure 1. Central American countries included in this research

[1]We researched about six Cental American countries: Costa Rica, El Salvador, Guatemala, Honduras, Panama, and Nicaragua.

digitalization. For the investigation, we focused our efforts on four goals:

1. Identify global energy and technology trends that indicate developments throughout the energy value chain.

2. Identify digitalization benchmarks (self-assessed and parameter-based) for Central American energy sectors, relative to each other and non-regional peers[2], to identify region- and country-specific opportunities.

3. Facilitate the development of a regional energy vision and strategy to support energy transition (e.g. energy efficiency and network integration).

4. Develop feasible region- and country-specific road maps to prioritize and align digitalization activities.

We discuss our investigation and our findings in the chapters that follow. First, we describe our research approach and methodology (Chapter 2) as well as the assesment framework (Chapter 3). Next, we illustrate the current state of digitalization within the energy sector for the six countries we investigated, explain global energy trends, and provide the digitalization benchmark for regional and international levels (Chapters 4, 5 and 6). Finally, we suggest individual road maps, and draw conclusions as well as we discuss the development of vision and strategy (Chapters 7 and 8).

2. Approach and Methodology

This chapter describes our approach and methodology. To capture a holistic view of digitalization opportunities within Central America's energy systems, we used a top-down approach, reviewing an array of worldwide megatrends. We then focused on megatrends specific to the energy sector and considered how these affected the region's and countries' energy sectors in their current state.

Once we developed an up-to-date foundation on the current state, we identified how trends presented different challenges across the region and for each country. First, we considered how global digital technologies and related use cases might impact the region and each country. This allowed us to see areas of opportunity. To elaborate our findings, we performed a digital readiness benchmark analysis where we identified risks and quick wins. We collected our information through a combination of desk research and qualitative expert assessments (Figure 2).

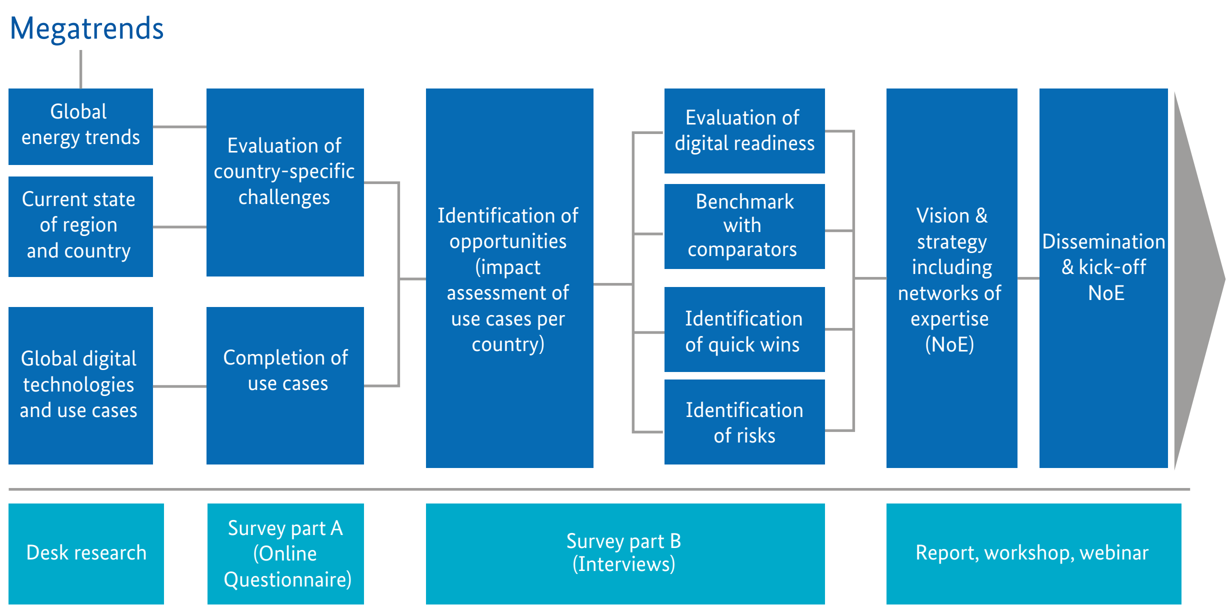


Figure 2. Schematic approach of study

[2]Germany and Chile were selected, the former because of its track record in digitalizing the energy sector, and the latter because it is considered a role model in Central America.

2.1 Desk Research

Throughout the study, we gathered or supplemented knowledge through extensive literature reviews, especially for the study's assessment framework (Chapter 3). Through systematic collection and review of literature, studies, and articles, we created an initial knowledge base of the regions' energy sector, its digital technologies, and its use cases. We collected publicly available and numeric data, and then shared it with experts, who, in turn, offered background details and new insights through two surveys (see Section 2.2). To better interpret the data provided by the experts, we consulted literature reviews.

We used Roland Berger's methodological standards in conducting the investigation:

- ***Global outreach.*** We did not limit the review to selective markets or regions but instead started with a regionally unbiased approach by activating our global network of energy experts.
- ***Quality and consistency.*** Besides following general procedures for thorough literature reviews (gather and remember, understand, apply and analyze identified sources), we checked the literature for flaws by evaluating primary data sources, checking the publisher, and cross-validating with additional literature.
- ***Expert feedback.*** In addition to reviewing literature, we reached out to internal experts to validate and enrich our findings.

2.2 Participants and Research Instruments

The main body of data for this study comprises regional expert knowledge gathered through two consecutive surveys. We surveyed experts along the whole energy value chain to gain a holistic view of the energy sector. We identified participants from a list of 81 high-profile regional experts provided by GIZ[3]. The list included experts from public institutions (e.g. universities), private corporations (e.g. distribution companies), and governmental bodies (e.g. energy ministry). In addition, we consulted with Roland Berger experts knowledgeable about non-regional peer countries.

To collect data, we administered two surveys. Participants completed Surveys A (Appendix 1) and Survey B (Appendix 2). Survey A was an online questionnaire provided in advance, while Survey B was a series of in-person interviews in Central America. We carefully designed the surveys to encourage high-quality, relevant inputs. After participants responded to each item on each survey, we asked them to rank their confidence level in the response using a Likert scale. We used self-assessed benchmark and parameter-based benchmark methods to carry out Survey B. We have included a description of each survey in Appendices 1 and 2.

3. Assessment Framework

In this chapter, we discuss how we derived global energy trends, developed the digital readiness framework, and analyzed risk.

3.1 Global Trend Analysis

Our first step was to investigate global megatrends long lasting forces or developments shaping society, the economy, and the environment now and into the future. We collected a list of global, cross-sectoral megatrends, which we describe in section 3.1.1. Next, we grouped trends that impact energy markets because it allowed us to consider them in higher resolution. We discuss the resulting *global energy trends* in section 3.1.2. Our trend clusters were present in the megatrends, suggesting they capture a valid taxonomy.

Once we finalized a set of global energy trends, we identified trend-specific parameters and mapped these along the value chain. We identified forces that would most likely shape the power market in the region until 2030 (section 3.1.3). This procedure allowed us to measure the presence of each global energy trend in each country and in the region (Figure 3).

[3] GIZ selected the experts who demonstrated strong interest in specific digital topics, who had direct or indirect involvement in digitalization, who represented different agents within the energy value chain, and most of them had participated in the study trip “Knocking on the digitalization's door - digitalization for grid integration and energy efficiency” in Berlin, Germany in November 2018.

Definition and Main Objective	Methodology	Results
Definition: Megatrends are long-lasting forces or developments shaping our society, our economy, and our environment. Main objetive: Compile megatrends to understand and convey relevant global energy trends.	1. Screen relevant trend, scenario and future studies worldwide. 2. Verify, analyze and consolidate results. 3. Break up megatrends into subtrends, look at each from a global perspective and the viewpoints of industrialized and developing countries.	Most important megatrends that will shape the world between now and 2030.

Figure 3. Megatrends approach

3.1.1 Megatrends

We aimed to understand and convey relevant global energy trends. The backbone of this step of the research is the Roland Berger 2030 Trend Compendium (Roland Berger, 2017). Megatrends represent the cornerstone for creating a vision and strategy for region- and country-specific digitalization.

Our methodological approach was top-down and consisted of three main steps: (1) screening, (2) consolidation, and (3) a final break-down of the main trends into subtrends. We based the relevance of the trends on the so-called "normal" case, i.e., a stable development of the global economy with no unexpected events. We excluded major political or financial crises, large-scale natural disasters, or similar far-reaching events from our assumptions.

Through this process, we identified the seven megatrends that will be the most influential through 2030 and the decade that follows (Figure 4). These are *demographic dynamics, globalization and future markets, scarcity of resources, climate change and ecosystem risk, dynamic technology and innovation, global knowledge society, and sustainability and global responsibility.* A thorough description and breakdown of each of the megatrends is in Appendix 3.

1. **Demographic Dynamics**
World population growing, aging, migrating, and increasingly living in big cities.
2. **Globalization and Future Markets**
Ongoing globalization caught between opponents and proponents, power shift to emerging markets.
3. **Scarcity of Resources**
Scarcity of energy resources nuanced, water stress increasing, China holding quasi-monopoly on critical raw materials.
4. **Climate Change and Ecosystem at Risk**
CO_2 emissions and average global temperature increasing, biodiversity decreasing.
5. **Dynamic Technology and Innovation**
Innovation drives prosperity, life sciences and digital transformation constitute two key fields of innovation.
6. **Global Knowledge Society**
Education improving in developing countries, global talent pool increasing, gender gap narrowing only in part.
7. **Sustainability and Global Responsibility**
Sustainability is key for governments, citizens and businesses, consumers reward corporate social responsibility.

Figure 4. Megatrends overview

3.1.2 Global Energy Trends

We defined *global energy trends* as long-term developments in the energy sector closely related to the megatrends facing our world. Moreover, global energy trends pose challenges to the energy sector across countries. To derive these, we followed the same procedure as the one used to identify global megatrends (Figure 5). Once we identified global energy trends, we grouped them for sharper resolution. Then we assigned them relevant parameters along the value chain to enhance their tangibility.

Definition and Main Objective	Methodology	Results
Definition: Global energy trends are long term developments in the energy sector closely related to overarching forces shaping our world. Main objetive: Identify global energy trends with their respective energy value chain-specific KPIs to determine country- specific challenges.	1. Derive and identify global energy trends. 2. Cluster global energy trends. 3. Determine energy value chain steps. 4. Define trend and value chain step-specific key performance indicators (KPIs).	Set of tangible global energy trends and respective energy value chain-specific KPIs.

Figure 5. Global energy trends approach

We identified and grouped trends in three steps. First, we recorded subtrends from multiple sources. We then compared these with subtrends we had recorded previously as part of the global megatrends analysis. Next, we coded subtrends according to themes, eliminating those that were unrelated to energy. Then, we clustered trends to thematically sharpen them and to avoid doublings. These clusters yielded four global energy trends: *emissions reductions, decentralization and competition, demand increase, and increased volatility and supply security* (Figure 6).

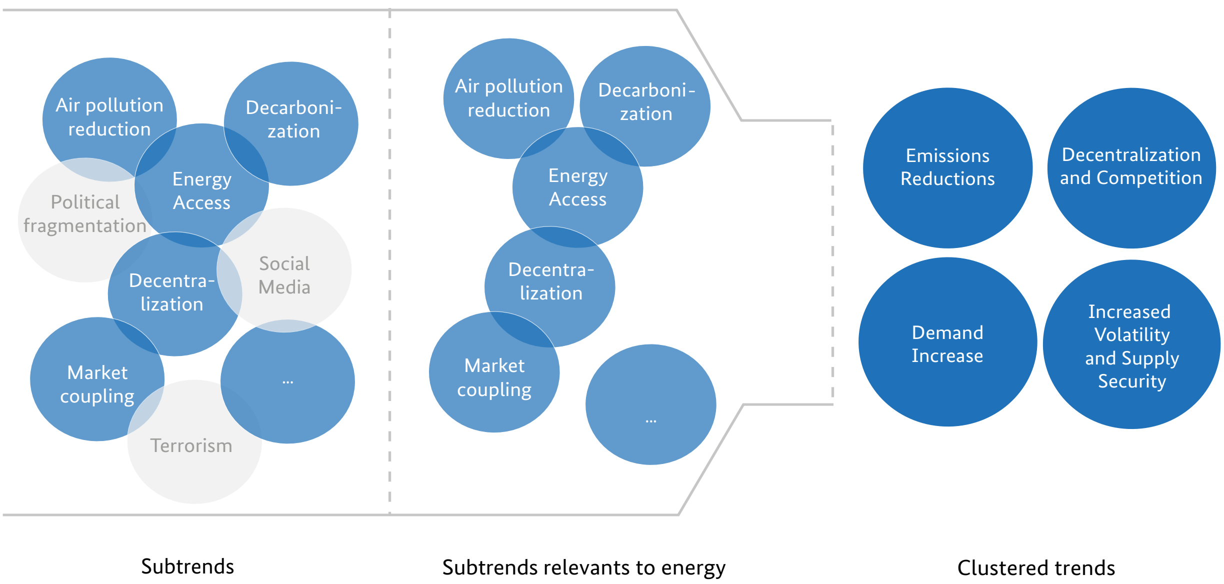


Figure 6. Global energy trends clustering

Emissions Reductions

Decarbonization
Reducing CO_2 emissions from energy generation is determinant in tackling renewable energy policies in a time of transition and climate change and to achieve global emissions targets. For instance, on a regional level, the European Union aims to achieve a 40 percent reduction in greenhouse gas emissions by 2030 compared to 1990 (EC, 2014). Globally, 196 countries have joined the Paris Agreement with the aim to contain global warming (UNFCCC, 2018).

Pollution Management
Pollution management is on the agendas of local authorities and closely related to urbanization. Ensuring healthy air quality includes reducing particulate matter and nitrogen oxides. In Europe, the yearly death toll linked to air pollution is approximately 400,000 (UN environment, 2017) and in Latin America it is approximately 200,000 (IHME, 2018). Globally, the number of fatalities linked to air pollution has increased to approximately seven million (WHO, 2018).

Decentralization and Competition

Fragmentation of Energy Supply
The spread of prosumers as well as increasing energy trading is causing fragmentation and competition—in other words, these trends are leading the sector away from vertical integration models. On the one hand, decentralization goes hand-in-hand with declining market shares for traditional energy suppliers, posing a risk to utilities. On the other, distributed energy sources enhance energy access in off-grid areas, making electricity more affordable (WEC, 2017).

Efficiency Gains of Renewable Energy
Renewable energy is becoming financially competitive and fosters competition throughout the energy sector. In 2017, more than 20 percent of solar projects that received support were selected based on competition, while the share is 30 percent for onshore wind and 50 percent for offshore wind projects (IEA, 2018). By 2040, the support for photovoltaic projects will have decreased almost 90 percent and for wind projects by 70 percent.

Demand Increase

New Users
Population growth and inclusion of off-grid users will lead to an increase in demand for electricity. By 2030, the world population will reach 8.6 billion people, a sixteen percent increase (0.98% p.a.) from 2015 (UN DESA, 2017). Additionally, thirteen percent of world population, especially in developing countries, still lack access to electricity (World Bank Data, 2018), indicating a sizeable number of potential new customers.

Consumer Behavior
Consumption patterns are shifting towards electronic devices and e-mobility. We expect energy consumption per capita in developing countries like China to double by 2040 and in developed countries like Japan, the United Kingdom, or France, we expect per capita consumption to grow by around ten percent (IEA, 2018). Additionally, there may be 300 million electric cars worldwide by 2040, increasing transport-related electricity demand from one tenth of a percent to up to three percent of total demand.

Industrialization
We expect industrialization to grow, especially in developing countries, and we expect corresponding growth in electrification of the production sector. Electrification occurs not only in the production process, but also in heating, which makes 25 percent of global demand for energy. After considering energy savings, we expect worldwide electricity demand from the industrial sector to increase by nearly 35 percent by 2040 (IEA, 2018).

Increased Volatility and Supply Security

Enhanced Grids
Flexible and better interconnected grids are key to managing electricity, especially in light of non-programmable generation. Regional initiatives to connect electricity markets are surging. By 2030, the European Union has set its member countries the target of fifteen percent interconnection of installed capacity (EC, 2014). Also, emerging regions such as Central America have started similar programs, including a project initiated by

the Central American Electrical Interconnection System (SIEPAC for its acronym in Spanish), which has kicked off the Regional Electricity Market, connecting six countries in Central America through a 300 MW high-voltage transmission line.

Storage and Reserve Capacity
The growth of variable electricity generation has increased the need to manage imbalances between supply and demand through storage and reserve capacity. We expect battery capacity in stationary applications to grow from about ten Gigawatt hours (GWh) in mid-2017 to up to 421 GWh by 2030, of which approximately 200 GWh capacity will be utility-scale batteries (IRENA, 2017).

Using these global energy trends as a foundation, we considered the future of the components along the value chain. We explore our findings in the next section.

3.1.3 Energy Parameters

Based on global energy trends, we determined a set of tangible parameters (Figure 7) that either constrain or promote performance within the value chain. First, we identified steps in the value chain (Appendix 4). We focused on cataloging those steps that intersected with global energy trends. We aimed to create a description of the value chain that was simultaneously comprehensive and easy to understand. In the final version of the energy value chain, we included four steps: *generation, trading, transmission and distribution,* and *consumption.* We placed a fifth step, *service*, as value-enhancing across the chain. Next, we determined parameters linked to both sets.

1. Energy Mix
2. Carbon Intensity*
3. Efficiency
4. Capacity Factor*
5. Total generation
6. Total Installed Capacity
7. Reserve Margin*
8. Market Liquidity
9. Net Energy Exports to MER
10. Energy Loss
11. Grid Interconnection*
12. GDP Energy Intensity*
13. Self-Sufficiency*
14. Market Diversity
15. Number of Electric Vehicles
16. Consumption Split
17. System Average Interruption Duration
18. Number of Smart Meters

[*] calculated parameter with data from listed source, calculation in parameter appendix

Figure 7. Energy parameters

Ultimately, we placed the parameters in the global energy trend/value chain intersection that best matched each parameter (Figure 8). Throughout the process, we consulted our internal network of energy experts, an iterative process that validated and complemented our preliminary results. We identified eighteen parameters that constrain performance along the value chain, these indicate the current and perceived future (2030) situation of the energy system.

The process of identifying parameters uncovered discrepancies in opinions among energy experts. Importantly, the parameters bring to light multiple potential challenges faced by national energy and electricity systems. A detailed explanation of each element is in Appendix 5.

	Generation	Trading	Transmission and Distribution	Consumption
Emissions Reductions	1 Energy Mix 2 Carbon Intensity		10 Energy Loss	12 GDP Energy Intensity
Decentralization and Competition	3 Efficiency 4 Capacity factor	8 Market Liquidity 9 Net energy exports (MER)		13 Self-sufficiency 14 Market diversity
Demand Increase	5 Total generation 6 Total installed capacity			15 Electric vehicles 16 Consumption split
Increased Volatility and Supply Security	7 Reserve margin		11 Grid Interconnection (MER)	17 System Average Interruption Duration Index
Service				18 Smart meters

Figure 8. Value chain specific parameters in the context of global energy trends

3.2 Use Cases, Digital Technologies, and Framework Conditions

To assess the digital readiness of the region and countries, we sought unanimity on its meaning. Considering that the term and its measurement are–depending on the context–loosely defined, we understand digital readiness in the energy sector context as *the ability to deploy digital technologies along the energy value chain.* We measured digital readiness through three proxies: use case deployment, technology expertise, and country-wide enabling framework conditions (Figure 9).

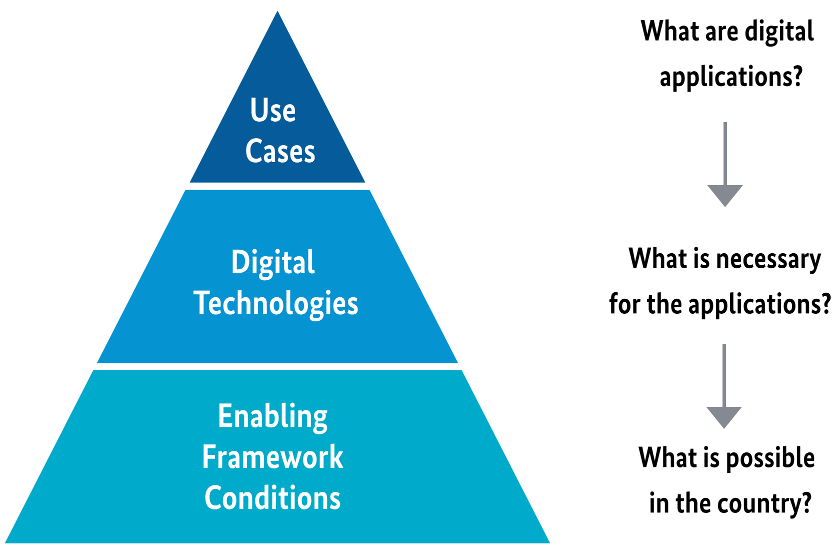


Figure 9. Digital readiness proxies

3.2.1 Use Cases

We compiled an aggregated list of use cases to catalog digitalization opportunities for the local and regional energy sector. We mapped the use cases along the energy value chain and within global energy trends (Figure 10), to later prioritize the relevance of each use case in the context of the challenges posed by global energy trends. We first assigned each case to different technological principles based on Appendix 6, as we explain in the next chapter. It is important to note that while we categorized use cases according to digital technologies, the distinctions could be imprecise, as a use case can depend on a combination of technologies. In these cases, we chose the most prominent technological principle.

Several use cases apply more than one technology and can be applied on multiple steps of the energy value chain. A detailed list of use cases and their respective descriptions can be found in Appendix 9.

	Generation	Trading	Transmission and Distribution	Consumption[2]
Emissions Reductions	1 Certification of energy products 4 Self-optimizing generation system 7 Identification of local waste streams			17 Intelligent energy consumption 19 E2E service platform (e.g. digital twins) 22 Consumption optimization through ML
Decentralization and Competition	2 Virtual power plant	8 P2P energy trading and microgrids 10 Electricity wholesale 11 Algorithmic trading and price setting		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 Asset health monitoring and alerting system 5 Output forecasting for RE		12 Load balancing through smart contracts 13 Remote monitoring and grid management 14 Vehicle to grid 15 Automated inspection and vegetation management	16 Smart contracts for variable billing 18 Services for general metering point operators

[1] including artificial intelligence
[2] including services

Blockchain | Internet of Things | Advanced Analytics[1]

Figure 10. Use case overview

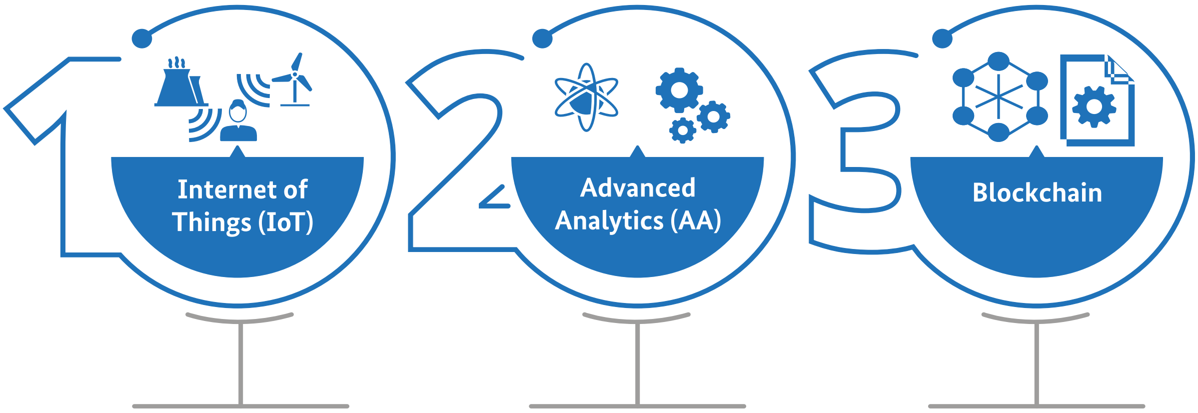
3.2.2 Digital Technologies

Along with digitalization, technologies are advancing and developing fast, with variations and new applications always on the horizon (OECD/ IEA, 2017). For a country and sector undergoing digitalization, it is paramount to understand the nature, functionality, and interrelations among different technologies. Different technology and product manifestations are often based on the same underlying principles and can be clustered accordingly.

We sorted these, finding three core technology areas for the digitalization: (1) Internet of Things (IoT), (2) Advanced Analytics (AA), and (3) blockchain technology (Figure 11). In line with the three fundamental elements of the digital world, as stated by the IEA, these three core technology areas represent the generation of data (IoT), the utilization of the data (AA), and the exchange and transmission of data (Blockchain; OECD/ IEA, 2017).

Albeit the **IoT** is a state of connectivity rather than a single technology, it serves as a collective reference for the different technologies and products that enable smart communication. A physical object is considered smart and part of the IoT as long as it is able to communicate with its environment by sending data (emitter), receiving data (receiver), or doing both (IEC, 2016). In the energy context, this includes, but is not limited to, smart meters that periodically transmit metering data, intelligent thermostats and lighting that react to changes in the environment through sensors, or remote-controlled machines that can be addressed from a central system.

When discussing **advanced analytics,** most consider artificial intelligence (AI) with its different subfields, natural language processing (NLP) or machine learning (ML). However, we may also consider prescriptive analytics (expert systems defined by humans) and predictive analytics (statistical modeling and simulation), which together constitute the field of advanced analytics (Gartner, 2018). In a best-case scenario, stakeholders can make use of the potential of data and draw insights to optimize and automate opportunities along the energy value chain.



> IoT refers to the network of physical objects interconnected through technology.

> Objects are enhanced (turned "smart") through sensors that allow them to communicate, sense, and interact with their external and internal environment.

> AA is an umbrella term for semi-autonomous (predictive, prescriptive) and autonomous (artificial intelligence) examination of data.

> Services are automated and big data analyses enabled through techniques such as semantics, machine learning, clustering, simulation, and natural language processing.

> A blockchain represents all transactions in a network as one decentralized tamper-proof ledger, with no need for intermediation by central authorities.

> Transactional data is encrypted, distributed and stored locally to many individual computers in a network (P2P), thereby verified by each participant automatically. Multiple, use case specific adjustments possible.

Figure 11. Digital core technology areas

Stakeholders can use **blockchain** technology in many ways, with different forms of blockchains possible[4]. In general, a blockchain is a distributed tamper-proof ledger representing the transactions within a network. In the energy context, its potential lies within its inherent transparency and its ability to circumvent intermediaries in trading, allowing for a broader integration of energy market participants, new financing and payment methods, and energy product differentiation (BDEW, 2018).

[4] Distinction among blockchains is based on access permissions that each have their own merits, with public blockchains (permission not required), private blockchains (permission required), and hybrid blockchains (shared permissions; BDEW, 2018),

3.2.3 Framework Conditions that Enable Digitalization

Although technology by itself is indispensable for digital readiness, analyzing the ability to deploy digital technologies along the energy value chain on a country level requires looking beyond technology measures. For instance, the government may promote the rollout of digital technologies in the energy sector, but if either the workforce or general population is not skilled enough–not ready–to use and demand these, they cannot fully use digital advantages. Therefore, we created a holistic model of five framework conditions that describe different dimensions that enable digitalization within a country.

1. **Digital infrastructure** refers to the available physical and virtual infrastructures that enable the use of digital technologies and activities within the energy sector. Implementing digital applications presumes a certain degree of advancement in a country's infrastructure, from basic widespread electrification and network coverage to advanced sensorics and smart meters that connect and generate the necessary data.

2. **Human capabilities** refers to the relevant human knowledge and capacity of the population. A skilled labor force is required to support and maintain the digital transformation of the energy sector. Still, the labor force constitutes only one aspect, as it is also important that the general population has the capacity to demand and use the digital products/services.

3. **Organizational culture** refers to the collective corporate attitude within the energy sector towards digitalization. This comprises the degree to which corporations are innovation-driven and use digital technologies and solutions, as well as how they plan strategically for the long term. Resistance to change is also important–digital transition is often accompanied by fear of obsolescence.

4. **Capital and investment** refers to the availability of capital and investments for digitalization in the energy sector, including both public and private sources. It is also connected to the strength and enforcement of legal rights, as the security and risk of investments directly influences their availability.

5. **Public institutions and governance** refers to the legal environment of policies and regulations supporting the digital transformation of the energy sector, including communicated goals and support programs such as national energy plans and remunerations concepts. In addition, the commitment to and realization of these is equally important.

3.3 Risk Analysis

We performed an analysis to identify potential risks associated with the digitalization of the energy sector. After defining the concept of risk within the context of digitalization, we conducted a hybrid four-step methodological approach that included desk research and feedback from experts to identify potential risks. This procedure allowed us to identify country-specific risks and mitigation measures (Figure 12).

To perform a holistic analysis of the digitalization opportunities in the energy sector, we needed to identify the sources of risk during the process. The availability of the framework conditions not only impacts the time needed to implement new solutions, but also broadens the spectrum of feasible possibilities (technology use cases). The absence of each of the framework conditions poses an individual risk to digitalization. Once the digital solutions have been implemented, a digital energy environment might lead to various risks.

Definition and Main Objective	Methodology	Results
Definition: Implementation of digital technologies through use cases is accompanied by varying risks. Additionally, an increasing reliance on digital technologies entails new risks. - Objetive 1: Identify risks arising from the digitalization process and a digital energy sector. - Objetive 2: Pinpoint effective measures to mitigate the risks presented.	1. Identify the pre-digital and post-digital risks. 2. Clean, condense, and cluster risk. 3. Validate and evaluate set of risks in expert interviews. 4. Gather mitigation measures from expert interviews.	- List of risks associated with digitalization. - List of risks form the digital energy sector. - Mitigation measures for identified risks.

Figure 12. Risk identification methodology

We identified two main types of risks in digitalizing the energy sector (Figure 13):

A. Pre-digital risks that arise from the implementation of digital technologies through use cases, depending on the degree of availability (or absence) of the necessary framework conditions presented above.

B. Post-digital risks stemming from an increasing reliance on digital technologies, e.g. cyber and technology risks.

From **analog**...
Digital technology use case is not applied within energy value chain

...to **digital.**
Fully operational large-scale implementation of the use case within the energy value chain

A **Pre-Digital Risk**

Risks resulting from the absence of the framework conditions
To initiate the digitalization process across the energy value chain, a set of enabling framework conditions needs to be in place.

B **Post-Digital Risk**

Risks resulting from the implementation of digital technologies and use cases
The implementation of a digital technology use cases is accompanied by varying risks. Additionally, an increasing reliance on digital technologies entails new risks.

Figure 13. Digitalization process and related risks

4. Current State of Digitalization in the Energy Sector

This chapter provides an overview of the current state of digitalization in Central American energy sectors based on the assessment framework described in Chapter 3. Therefore, it summarizes and links the information gathered from our desk research and Surveys A and B.

For the country-specific analysis on digital readiness, we followed a uniform structure for every country:

1. The first part of each country profile provides **general information** including the political, economic, and environmental background (see Appendix 7: General Parameter Sources) as well as current energy-related data (see Appendix 8: Energy Parameter Sources). This general information allows for a better understanding and contextualization of the subsequent results and is based on desk research validated with primary data sources.

2. To understand country-specific challenges of the energy system, the second part presents a global energy trend-based **impact assessment**[5], further illustrated by current **country-specific challenges.** We based the impact assessment and identified challenges using the expert opinions from Survey A (online) and Survey B (interviews).

3. The third part presents a 2030 **outlook** and outlines areas that have **potential for improvement.** We based the outlook projections and suggested improvement areas on expert assessments in Survey A.

4. The fourth part presents the current state of the **framework conditions** identified in Chapter 3, which directly or indirectly facilitate or inhibit the deployment of technologies. These potentially affect challenges and opportunities brought about by digitalization. This part is based on expert estimations from Survey B.

5. The fifth part of the country profile focuses on the identification of the most relevant **digital technologies and use cases** in each country-specific context. We base this assessment on the indications of experts in Survey B regarding (a) the frequency of considerations and (b) their relevance[6].

Additionally, this chapter briefly introduces Germany and Chile as comparators, and provides a regional introduction section explaining the main framework conditions and challenges, as well as recommendations and use cases for MER entities.

[5] We asked experts to assess the impact of each global energy trend (4) on shaping the energy system until 2030.
[6] Relevance (expected impact) in the context of the impact of the global energy trends.

Costa Rica

4.1 Costa Rica

Key Takeaways for Costa Rica

- Under current conditions, there is a high probability of slight overcapacity in generation within the next decade, due to stagnating energy demand resulting from higher energy efficiency and the transition of energy intensive production sectors towards services.
- Experts suggest that further decentralization of energy generation will be problematic for Costa Rica's state-owned utility, as previous investments must now be recovered via regulated tariffs, which increases their prices and harms their competitiveness.
- For the electricity system in Costa Rica, emissions reductions were considered the most impactful global energy trend until 2030, reflected in the parameter estimations, including the reduction of carbon intensity by thirteen percent through 2030.
- Enabling framework conditions for digitalization exist, as human capabilities seem to be fully available, while organizational culture and public institutions and governance still have significant room for improvement.
- Concerning prospective digital technologies and use cases,
  - Experts indicated that 20 were potentially relevant to Costa Rica's challenges, with the top five spanning across the electricity value chain.
  - The top use case was *remote monitoring and grid management* based on the internet of things.

4.1.1 General Information about Costa Rica

Costa Rica is located south of Nicaragua and north of Panama (Figure 14). In terms of *population, society, and technology,* Costa Rica has grown by ten percent since 2009, an increase that is also linked to increasing life expectancy at birth and the relative degree of development as measured by the HDI. Furthermore, access to internet has doubled, reaching 66 percent of the population (Figure 15).

Regarding *political, regulatory, and legal* matters, Costa Rica is involved in 45 international treaties, indicating a high level of environmental awareness. Additionally, the country has passed national laws such as the Environment Law and the Biodiversity Act.

Figure 14. Map of Costa Rica

With respect to *economic and environmental* matters, economic growth over the last decade is reflected in higher output figures, both in nominal and per capita terms. Moreover, Costa Rica has managed to contain inflation, now below two percent, setting a solid ground for investors. Finally, Costa Rica shows a sustainable carbon footprint per inhabitant, well below the three tons per capita per year critical value.

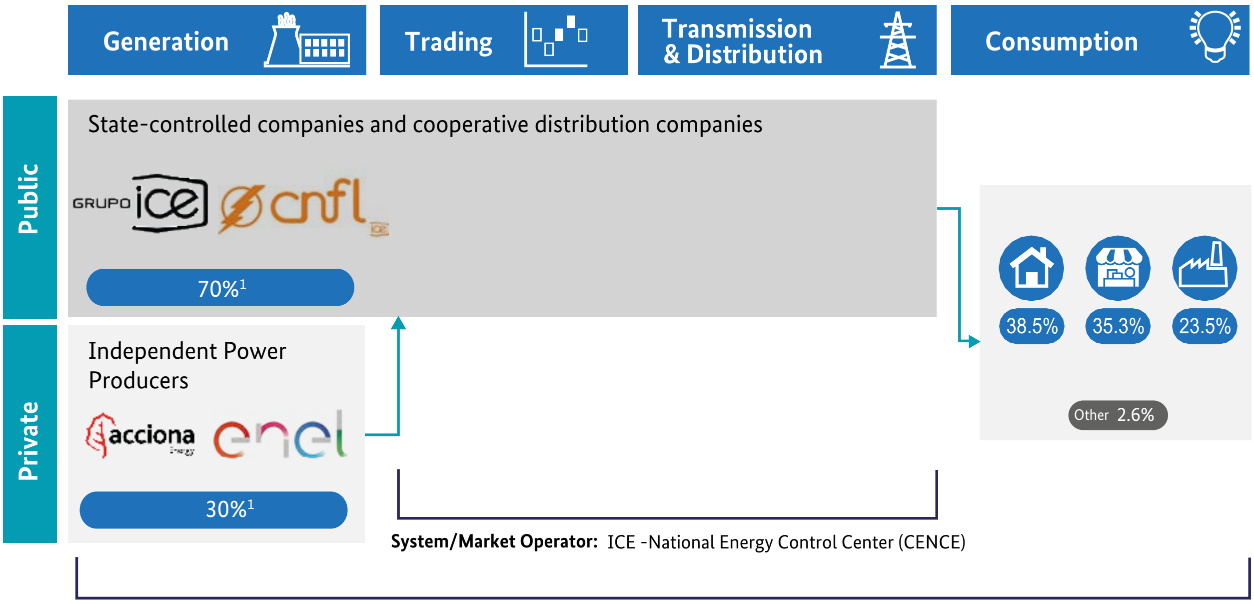
Population, Social and Technological		
- Inhabitants, 2017 (2009):	4.9 (+9.3%)	[Mn]
- Life expectancy at birth, 2017 (2009):	79.8 (+1.5%)	[Years]
- GINI coefficient, 2014 (2009):	48.6 (-4%)	[number]
- Human dev. index, 2017 (2009):	0.79 (+5.6%)	[number]
- Internet penetration, 2016 (2009):	66 (+92.3%)	[%]
- Access to electricity, 2016 (2009):	100 (+0.6%)	[%]
- Average price of 1GB mobile data 2018:	5.04	[USD]
Political, Regulatory, and Legal		
- Government: Unitary presidential constitutional republic		
- Democracy Index (2017): 7.88 (ranked 23 worldwide)		
- Participates in 45 international environmental treaties. Passed laws such as the Environment Lawm, Forestry Law or the Biodiversity act.		
Economic and Environmental		
- GDP 2017, (2009):	57.29 (+87%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	15,551 (+24%)	[USD]
- Unemployment rate, 2017 (2009):	8.1 (+5.6%)	[%]
- Inflation, 2017 (2009):	1.6 (-79.3%)	[%]
- CO_2- emissions p.c., 2014 (2009):	1.63 (-10.2%)	[tons]

Figure 15. Profile of Costa Rica

In Costa Rica, the Ministry of Environment and Energy (MINAE, Ministerio de Ambiente y Energía) makes energy policy. In its Seventh National Energy Plan of Costa Rica (MINAE 2015), Costa Rica describes plans to add renewable energies and intentions to create plans to develop distributed energy projects (MINAE, 2015). In 2019, Costa Rica published its National Decarbonization Plan 2018-2050, which aims to create a zero-net emission economy by 2050. The plan lays out specific goals, including achieving a 100 percent renewable energy sources (RES) share in the electricity matrix and establishing energy efficiency goals for buildings (Presidency of the Republic of Costa Rica, 2019).

The energy market in Costa Rica is partly liberalized. While companies can participate in the generation of (up to 30 percent of the total installation capacity) and distribution of energy, there is (yet) no wholesale market for electricity. The government-run electricity and services provider ICE Group (ICE, for its acronym in Spanish) controls the electricity market and all energy producers have to sell their electricity to them (Figure 23).

There is a market scheme for independent power producers, which is limited to renewable energy, however. There are two types of independent power producers: private plants and build-operate-transfer (BOT) plants. Private plants have a contract with ICE of up to fifteen years and a maximum share of the total installed capacity of fifteen percent (MINAE, 1990). In the reform in 1995, another fifteen percent of total capacity was granted with BOT contracts of up to 20 years (MINAE, 1995). Besides ICE, the National Power and Light Company (CNFL, for its acronym in Spanish), a subsidiary of ICE Group, two municipal companies and four rural electrification cooperatives are authorized to sell electricity directly to the end customers.



Regulator: Regulatory Authority of Public Services (ASEREP)
Policy-making entity: Ministry of Environment and Energy (MINAE)
Market participant has monopoly
[1]Share in generation capacity

Figure 16. Electricity market structure in Costa Rica

Costa Rica is member of the Regional Electricity Market (MER, for its acronym in Spanish) and is interconnected to Nicaragua and Panama via the SIEPAC transmission line. Costa Rica achieved a net energy export to the MER of 198.2 GWh (Figure 17), which represents a share of eight percent of total energy exchanged (ECLAC, 2018).

Most of the energy parameters (Figure 17) reflect Costa Rica's commitment to become a carbon-neutral economy by 2021, such as, Costa Rica's share of renewable energy of total generation is already at 99.7%, resulting in its low carbon intensity.

Following the high increase in installed hydropower capacity and a stagnating demand over the last years, the country currently has a high reserve margin and faces high outstanding investments which need to be recovered by the state through customer bills. This situation has led an increase electricity prices through supplementary charges to cover the fixed costs. The price for electricity is set by the Regulatory Authority of Public Services (ARESEP, for its acronym in Spanish) with current prices for households being USD 0.144 per kWh and USD 0.131 per kWh for industrial customers. If we compare it to the price of generation (USD 0.023 per kWh) the high level of supplements to cover infrastructure investments becomes evident. Given the need to ensure stable cash flows, the experts consider that regulation seems restrictive with respect to the demand for decentralization and self-consumption, e.g. through PV-based domestic electricity production.

The country aims to modernize the energy system by installing smart meters throughout the entire distribution network by 2025, having already installed smart meters for 72,000 ICE and 32,000 CNFL clients (ICE Group, 2018). Furthermore, Costa Rica is targeting decarbonization beyond generation, namely by electrifying the vehicle fleet. There are 600 electric cars already circulating in Costa Rica.

Parameter	Unit	Current[1]
Energy mix	[% RE]	99.7
Carbon intensity	[tons CO2/GWh]	0.7
Energy loss	[%]	10.9
GDP energy intensity	[MWh/GDP(mn)]	192.4
Capacity factor	[%]	36.3
Efficiency	[$/MWh]	22.5
Net energy exports to MER	[GWh]	198.2
Wholesale electricity market	[binary]	No
Market liquidity	[%]	-
Self-sufficiency	[%]	0.0
Market diversity	[number]	1
Grid interconnection	[%]	7.1
Reserve margin	[%]	108.6
System average interruption duration	[hours]	1.8
Number of smart meters	[number]	104,000
Total generation	[GWh]	11,210.1
Total installed capacity	[MW]	3,529.9
Number of electric vehicles	[number]	600

[1] Sources and year for current parameters are provided in the appendices.

Figure 17. Current energy parameters in Costa Rica

4.1.2 Impact of Global Energy Trends on Costa Rica

For Costa Rica's electricity system, experts ranked *emissions reductions* as the most impactful global energy trend, with 50 percent expecting a very high impact with a high confidence level in their response (Figure 18). Due to the already high level of RES in electricity generation, the trend mostly relates to the transportation sector, where 60 percent of Costa Rica's current greenhouse gas emissions come from. Thus, Costa Rica could benefit from electrifying its transport sector, such as by further developing e-mobility (World Bank, 2018).

Beyond that, 58 percent of the experts considered decentralization and competition a trend with a rather high impact on the country's energy sector, with another 25 percent of experts assigning it a very high relevance (Figure 18). Decentralization is about to debut in Costa Rica, following recent regulatory initiatives to allow decentralized production and self-consumption. Experts predict that users will become highly engaged in self-production given its lower costs compared to the retail prices currently offered by state-owned ICE Group, which include the high levies on consumer bills explained above. Attractive decentralized systems could lead to increased customer churn that challenges ICE Group, and potentially lead to higher prices for remaining customers.

Increased volatility and supply security followed as the third most relevant trend (Figure 18). While the system average interruption duration is low, the increase in intermittent renewable energy sources is a challenge to the system due to their volatile nature.

Demand increase is the fourth most-relevant trend. Thirty-three percent of the experts anticipate the trend to be rather relevant and eight percent very relevant (Figure 18). Experts predict that the transport sector, led by electric vehicles, and population growth to contribute to demand growth. At the same time, they expect demand increase to be partially offset by more efficient consumption. Thus, part of the increasing generation from additional capacity is expected to be exported to the MER.

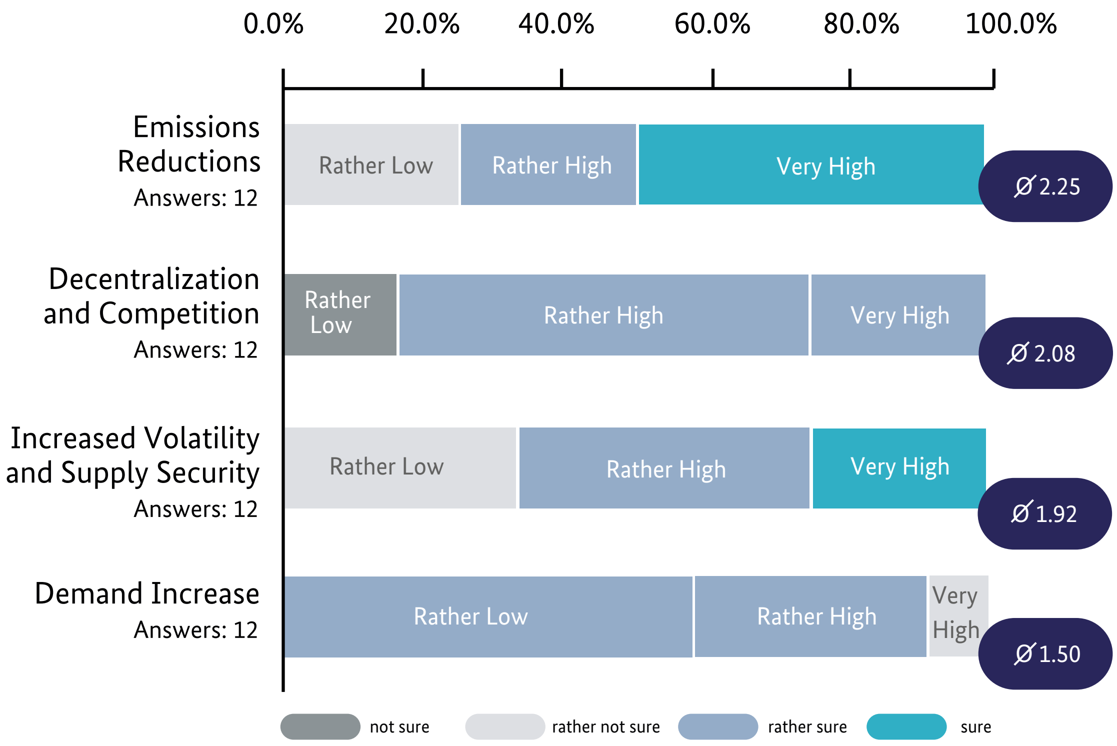


Figure 18. Global energy trends impact assessment in Costa Rica by 2030

4.1.3 Outlook and Improvement Areas for Costa Rica

Emissions Reductions

The global energy trend towards *emissions reductions* is evident in the reduction of *carbon intensity* through 2030, which is estimated to decrease between 18 to 23 percent (Figure 19). In addition, experts foresee the electrification of the vehicle fleet to scale up in coming years, with experts predicting from 22.500 to 70,000 electric vehicles through 2030. Additionally, energy losses are expected to decrease from 10.9 percent to approximately eight percent. Upgrades of the electricity system to smart grids will yield improvements in this parameter. According to the experts, reducing losses by six percent could make an investment in smart grids profitable.

To counter the challenges posed by impacts of emissions reductions, the experts suggest the parameter energy loss has the highest potential for improvement (Figure 20). Additionally, they suggest the parameter GDP energy intensity has a high level of potential for improvement as well. While most stakeholders consider decentralizing electricity production, smart grids, and microgrids as useful tools to reduce energy losses, establishing adequate public policy to foster a shift of the economy from industry towards services might be effective to lower the electricity consumption per unit of GDP. Nevertheless, experts are cautious, as overall electricity demand might also increase, led by population growth and an increasing number of electric vehicles. It is therefore unknown which effects will dominate, with the parameter potentially remaining flat.

Decentralization and Competition

Costa Rica is experiencing decentralization and competition through an increasing share of self-sufficiency that is expected to reach between 10.0 to 12.4 percent by 2030. As mentioned above, users may turn to self-consumption to save costs given supplemental fees in customer bills. Furthermore, according to the experts, *decentralization* in the market poses a risk for ICE Group. In light of the national situation, experts predict that state-owned companies might expand their business fields and reinvent themselves, e.g. taking an active role as service companies.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Energy mix	[% RE]	99.7	99.7	99.3	+-0.0 to -0.4	no consensus
Carbon intensity	[tons CO2/GWh]	0.7	0.6	0.6	-23.1% to -18.1%	▼ 77%
Energy loss	[%]	10.9	8.0	8.1	-2.9 to -2.9	▼ 93%
GDP energy intensity	[MWh/GDP(mn)]	192.4	197.5	223.5	+2.7% to +16.2%	no consensus
Capacity factor	[%]	36.3	43.3	44.2	+7.0 to +8.0	▲ 79%
Efficiency	[$/MWh]	22.5	18.0	18.2	-20% to -19%	▼ 77%
Net energy exports to MER	[GWh]	198.2	250.0	437.7	+26.2% to +120.9%	▲ 92%
Wholesale electricity market	[binary]	No				Yes 100%
Market liquidity	[%]	-				
Self-sufficiency	[%]	0.0	10.0	12.4	+10.0 to +12.4	▲ 100%
Market diversity	[number]	1	3	16	+2 to +15	▲ 67%
Grid interconnection	[%]	7.1	9.5	11.0	+2.4 to +3.9	▲ 93%
Reserve margin	[%]	108.6	102.0	91.0	-6.6 to -17.6	▼ 79%
System average interruption duration	[hours]	1.8	1.0	1.1	-44.4% to -38.5%	▼ 100%
Number of smart meters	[number]	104,000	780,000	968,922	+676,000 to +864,922	▲ 100%
Total generation	[GWh]	11,210.1	14,945.8	16,461.9	+33.3% to +46.8%	▲ 92%
Total installed capacity	[MW]	3,529.9	4,250.0	5,019.3	+20.4% to +42.2%	▲ 93%
Number of electric vehicles	[number]	600	25,000	68,297	+24,400 to +67,697	▲ 100%

1.Sources and year for current parameters are provided in the appendix.
2.Based on the median 2030 forecast provided by the experts.
3.Weighted average including the confidence of the assessment.
4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.
5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend
- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 19. Energy parameters in Costa Rica by 2030

Regarding *competition,* experts predict that efficiency will increase, as reflected in declining electricity prices (77 percent consensus). Furthermore, experts expect the capacity factor to pick up, making installed capacity more profitable, in part due to higher exports to the Regional Electricity Market (MER). Concerning the presence of an electricity market, experts unanimously expect the creation of a wholesale market until 2030 (100% consensus). This would foster competition, as ICE Group is currently the major retailer of electricity and the only buyer. Experts forecast that by 2030, there will be between three and sixteen providers.

Experts suggest that political action could potentially improve efficiency. Supplemental costs related to installing hydro-generation units in recent decades have driven electricity prices upward for households. Thus, experts suggest that efficient management and changes to the electricity cost structure will be key in achieving more competitive electricity prices. The parameter wholesale electricity market is associated with the second highest potential for improvement for decentralization and competition. Although experts see the government as reluctant to liberalize the market, they think that pressure from stakeholders in the power sector, coupled with an increasing amount of intermittent generation, will increase the need for a wholesale electricity market.

Increased Volatility and Supply Security

When experts responded to survey questions on the development of grid interconnection, they were rather confident in their assessment that interconnectivity would increase between nine and a half to eleven percent by 2030. Given the increasing installed capacity, additional growth in interconnectivity will only be possible through the expansion of the SIEPAC cross-border grid. In this sense, public involvement is indispensable, so that experts suggest that if regional governments play an active role, there is high potential to increase SICA's capacity, which could double by 2030. All experts agree that the system average interruption index will decrease and are rather sure about the installation of smart meters, which is expected to reach between 780,000 to 970,000 by 2030. The rollout of smart meters will be possible through

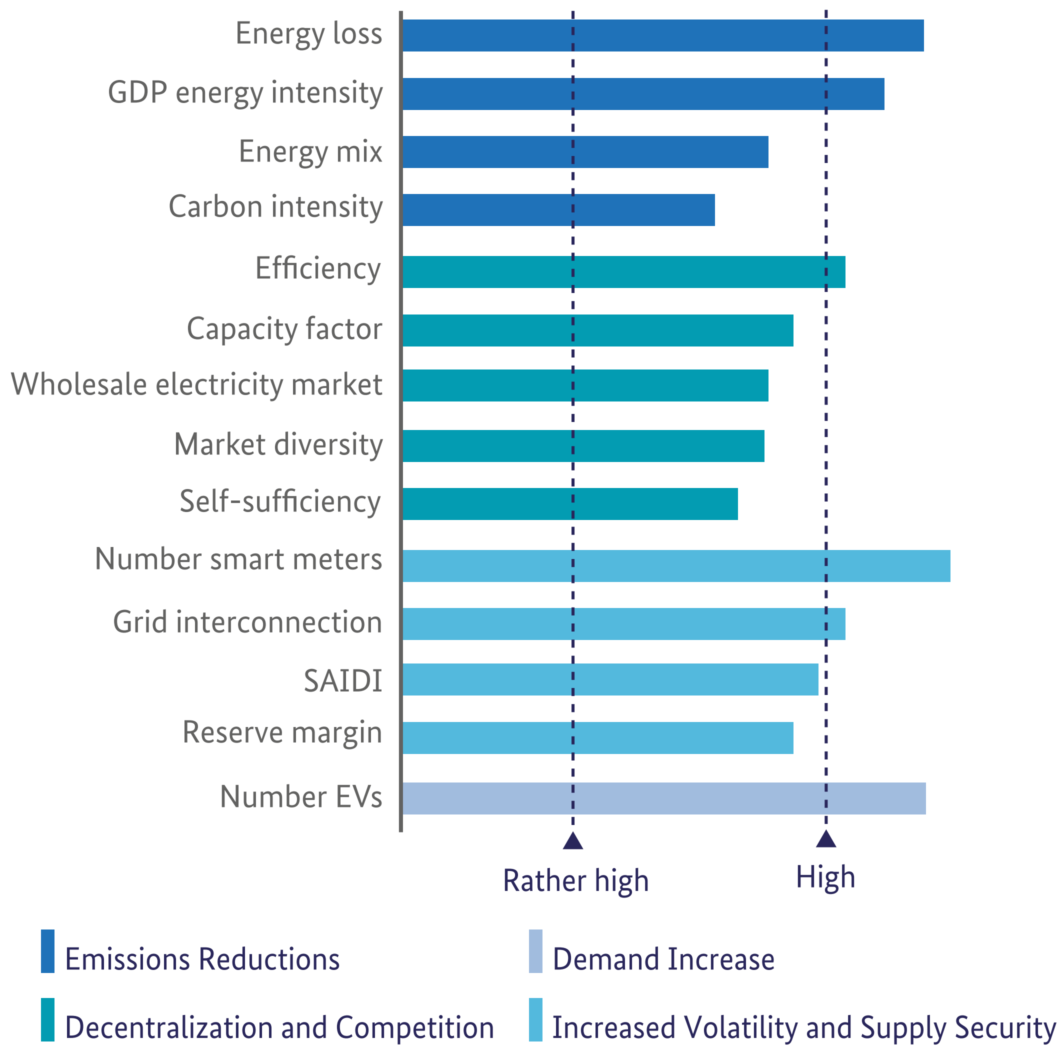


Figure 20. Improvement potential of energy parameters until 2030 in Costa Rica

appropriate political action, with the experts therefore suggesting that *smart meters* are the parameter with the highest potential to improve through political action. Furthermore, ICE Group and its affiliated distributor CNFL plan to install smart meters throughout the entire network by 2025.

Demand Increase

The trend towards *demand increase* is reflected in the parameters *total generation, total installed capacity,* and the number of electric vehicles. Growth in demand will most likely come from population growth and, marginally, from a higher number of *electrical vehicles,* which are expected to reach between 25,000 to around 68,000 vehicles by 2030. There are already incentives for electric vehicles and legislators are developing a law to create a charging station network. Experts predict total generation in 2030 to increase between 33.3 to 46.8 percent from current levels. The growth in installed capacity would come from the expansion of wind energy infrastructure.

The experts believe political action will give the parameter *number of electric vehicles (EV)* a high level of potential to improve. A reliable and broad infrastructure of EV chargers is necessary to attract customers. Costa Rica has a law, which aims to incentivize and promote electric transportation and accelerate implementation of electric vehicle infrastructure. The law has granted 50 percent or 100 percent tax exemption on imports of electric cars depending on price (SCIJ, 2017). At the same time, electricity distributors are obliged to build and operate at least one recharging center every 80 kilometers in national roads or every 120 kilometers on cantonal roads (SCIJ, 2019).

4.1.4 Enabling Framework Conditions in Costa Rica

Digital technologies have the potential to help overcome some of the challenges presented above; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section presents the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.

As illustrated in Figure 21, Costa Rica displays diverse framework conditions, hinting at fully capable human capabilities alongside inhibiting regulations. Nevertheless, there is a cross-sectoral change of thinking in process, gaining momentum throughout the energy value chain. Major improvements are observable in digital infrastructure, with smart meters being rolled out on a large scale.

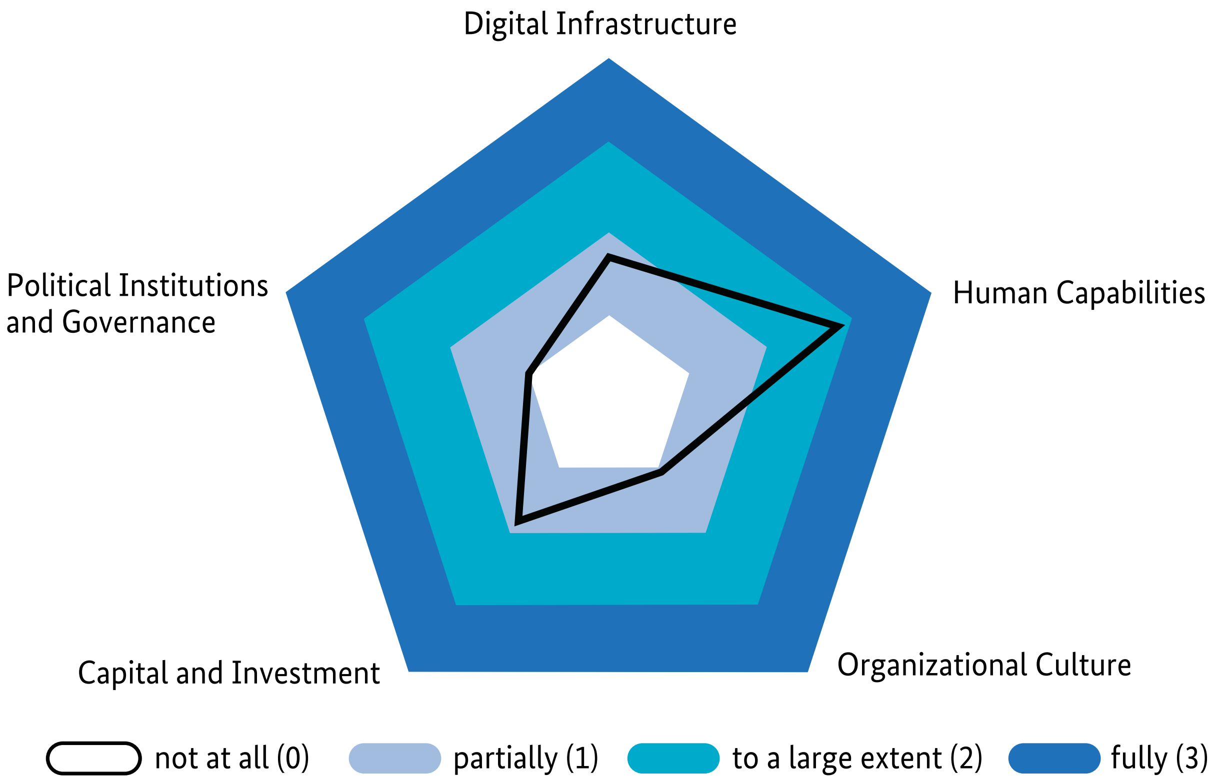


Figure 21. Availability of framework conditions in Costa Rica

Digital Infrastructure

The enabling digital infrastructure for the described technologies and applications in Costa Rica is partially in place (Figure 22) with regional differences prevailing. Its 3G network coverage is only at 20 percent, and while the broadband backbone is available, fiber to the home is lacking. Additionally, there is a lack of data generation and storage – and thus a lack of big data – and issues arise from incompatible band frequency systems.

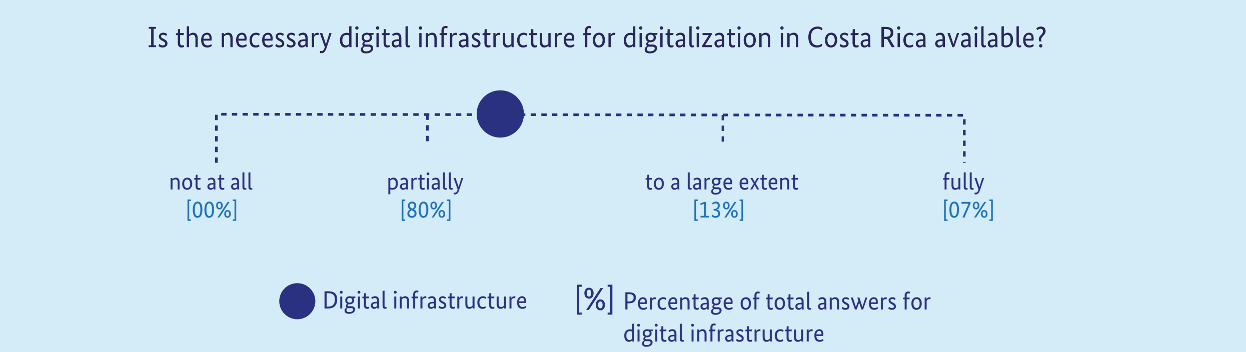


Figure 22. Digital infrastructure in Costa Rica

However, stakeholders throughout the value chain are aware of these issues and are taking action. They are pursuing an intelligent network strategy, with various initiatives to renew the grid. Smart meter deployment has begun on a national scale–half a million have already been paid for and are currently being installed–with the goal of full coverage by 2025. Although connecting fiber networks to residential properties remains a significant problem, nationwide projects are addressing its expansion. In addition, additional sensors are deployed, e.g. in supermarket trials, and a process to align the system discrepancies has been initiated. While there is currently only one conventional data center, a green hub for data centers is planned.

Digital Infrastructure in Costa Rica: Recommendations from Country Experts

- Implement (intelligent) hardware like smart meters especially in rural areas
- Increase bandwidth rollout, especially fiber to the home
- Create a shared platform to consolidate technologies and approaches
- Implement central data gathering to use information for network optimization, e.g. from consumers
- Consider mobile payment options for digital applications, given the smartphone penetration
- Initiate large scale infrastructure deployment for electric vehicles.

Human Capabilities

In terms of human capabilities, Costa Rica is positioned well (Figure 23). The change from industrial production to providing services in Costa Rica's economy already indicates knowledge capabilities. There is evident academic awareness of digitalization, with specific educational careers being adjusted. Local expertise in the respective technologies is prevalent, with different sectors already undergoing digitalization, as well as technology hubs, e.g. on Blockchain forming.

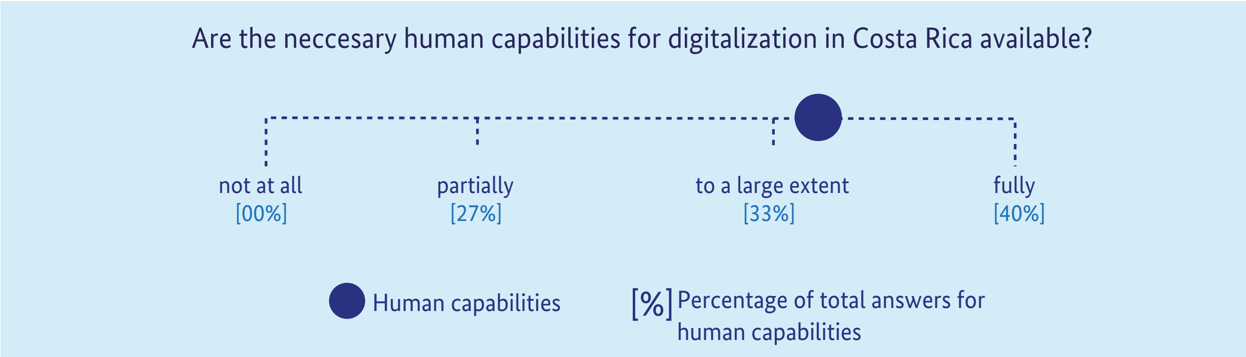


Figure 23. Human capabilities in Costa Rica

Still, the experts' diverging assessments indicate a discrepancy within the population–there is a significant gap between population classes. While there is an academic upper class that has the necessary knowledge, the lower, and to a certain degree the middle, class have not learned how to productively use the internet. Additionally, there is a significant lack of technicians to implement proposed technologies and applications. Moreover, due to the focus on the transition towards decarbonization in the energy sector, energy-specific digitalization knowledge lags behind that of other sectors.

Human Capabilities in Costa Rica: Recommendations from Country Experts

- Organize pilot projects on digital technologies among universities and industry
- Increase the match between IT and energy, e.g. through interdisciplinary courses
- Harmonize actors' knowledge by increasing cross-sectoral knowledge transfer
- Distributors/entities take the lead to educate consumer
- Supply schools with working IT equipment
- Educate lower and middle-income households through communal projects
- Create pre-university programs (e.g. technicians)
- Educate on patents and copyrights for protection
- Invest in employee education as companies prepare for digitalization
- Foster technology specializations.

Organizational Culture

The organizational culture in Costa Rica is a limiting factor for the digitalization (Figure 24). Innovation is considered the sole responsibility of the operators, and their public monopolistic standing does not promote a culture of innovation. Their rationale is that additional costs for innovation will lead to an increase in tariffs, which in turn incentivizes self-sufficiency and prosumers. Therefore, a conservative mindset is prevalent. Oftentimes, rather than investing in state-of-the-art but less-established equipment, older, "proven" equipment is procured. This is further fueled by a significant resistance to change displayed by employees. Hence, innovation usually has to come from the outside, but as the energy market is monopolistic and there is currently little interdisciplinarity between energy and technology, established energy market participants make most decisions.

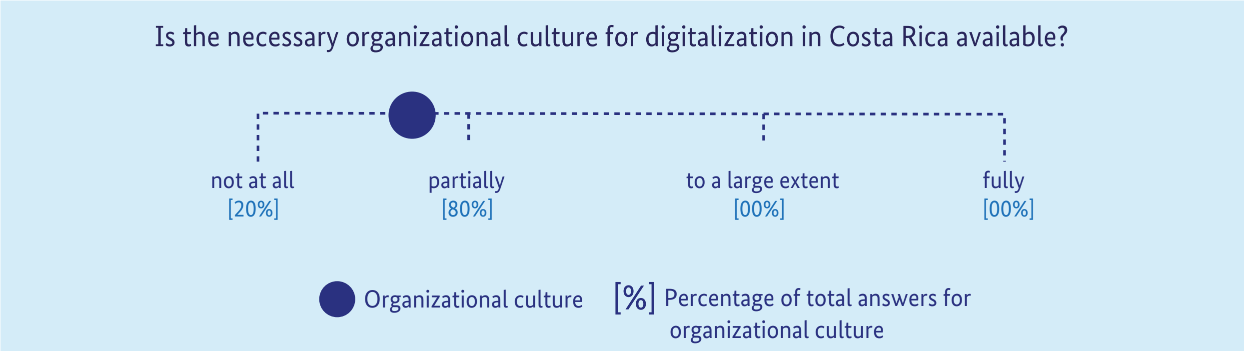


Figure 24. Organizational culture in Costa Rica

Although Costa Rica's organizational culture is rather conservative towards the digitalization of the energy sector, change is nevertheless ongoing. There is public and political pressure, influencing high-level management's investment decisions. The percentage of innovation advocates within the companies are growing, and the attitude of smaller, private firms towards digitalization is open-minded.

Organizational Culture in Costa Rica: Recommendations from Country Experts

- Conduct pilot projects in cooperation with universities
- Implement holistic change management and transparency, especially for personnel
- Communicate clear, tangible benefits of technology application
- Top-level to initiate innovation initiatives to address mid-level management resistance
- Benchmark and compare with other countries (especially higher-level management)
- Develop know-how of middle and higher management (knowledge diffusion)
- Institutionalize innovation process and strategic alignment
- Reform electricity market for more people to participate in innovation
- Stimulate small and medium enterprises (SMEs) to support cooperation with utilities.

Capital and Investment

In theory, capital and investment are available in Costa Rica (Figure 25). There are two main ways of external financing, either through international and public banks, or through increased tariff rates if a national provider is involved. The Ministry of Science and Technology also set up a seed fund, focused on information and communication technology (ICT) and smart grids. Aside from external financing, companies may resort to internal resources as well.

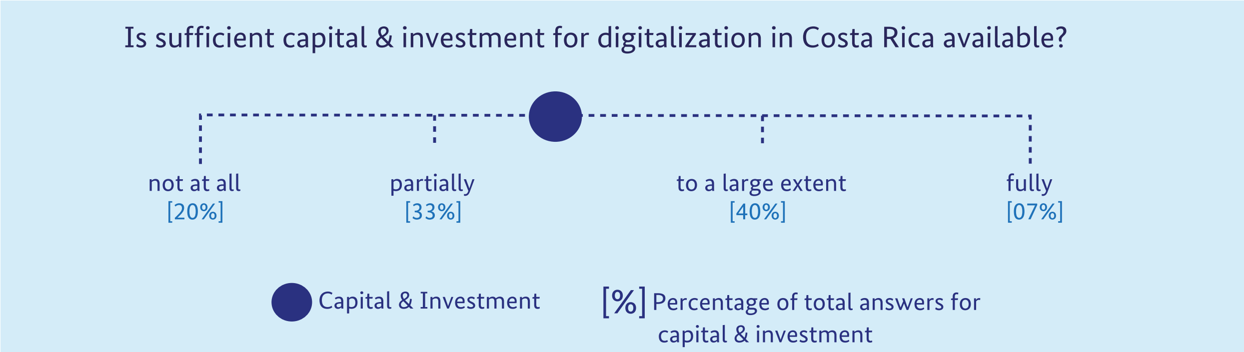


Figure 25. Capital and investment in Costa Rica

There are numerous obstacles that greatly limit the availability and provision of capital, reflected in the experts' heterogeneous assessments depending on their position in the sector. Partially due to a slight economic slowdown, its companies are facing a limitation of internal resources for the previously mentioned smart meters, which were funded with multilateral lender support. External capital is expensive, and the return of technology investments is hard to estimate, complicating the creation of concrete business cases to obtain funding from national public banks and other financial institutions. In addition, there is a perceived hesitation to invest, given the current stagnation in demand, the insecurity of remuneration through the tariff as set by the regulator, and a high national debt.

Capital and Investment in Costa Rica: Recommendations from Country Experts

- Improve target analysis on technologies to focus on the most relevant problems to solve and to maximize limited budget.
- Diversify company product/service portfolio, e.g. big data-based services, to increase financial strength
- Develop new financial instruments (in trusts), so multilateral lenders can invest, focus trusts on, e.g. energy efficiency
- Stimulate startups by allowing risk capital and institutional investors to invest in funds and venture capital
- Create robust business cases to convince banks with limited technical knowledge
- Focus credits and capital on innovative technologies and digitalization
- Increase knowledge in digitalization of bank employees
- Open market to foreign direct investment (FDI) with respective rules
- Consider necessary technology investments within tariff policy
- Increase banking access to finance digital projects.

Public Institutions and Governance

A prevailing perception is that governance and regulation are slowing down the implementation of the energy transition in general and digital technologies specifically (Figure 26). Even though the current energy system has undergone timely adjustments in recent times, a strong need for a general overhaul remains, especially due to its limited focus on energy generation based on renewables. With respect to digital technologies, there is no specific regulation in place. Besides regulation, missing standards and missing quality requirements on equipment can be harmful to the grid (e.g., the integration of low-quality solar panels). Electricity tariffs from the state-owned utility are perceived to be expensive. Due to the highly regulated electricity market and monopoly held by the state-owned utility, the generated distributed energy is not allowed to be fed in.

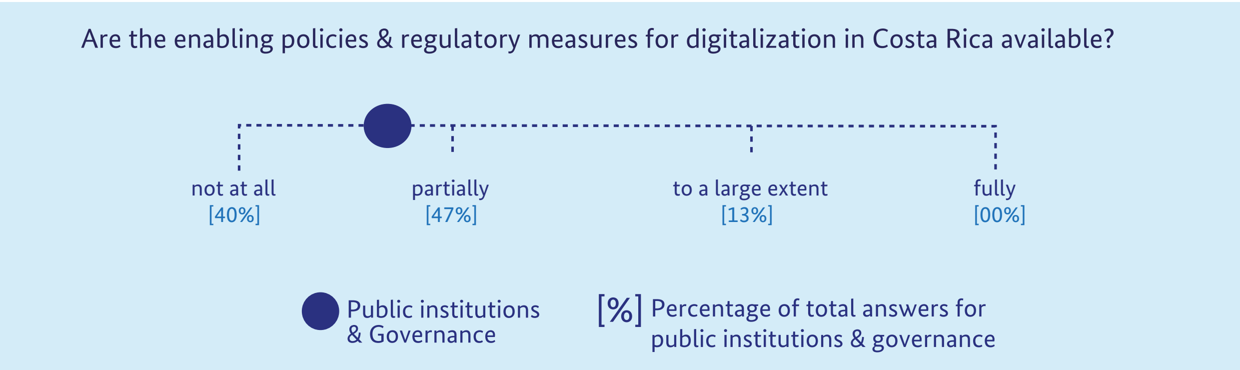


Figure 26. Public institutions and Governance in Costa Rica

Still, governmental awareness is increasing, and the state-owned utility is cooperating with the regulatory authority on new draft legislations. policy makers are developing and communicating strategic goals, such as large-scale smart meter deployment by 2025, and tax exemptions such as those for electric vehicles. These actions will enable the implementation of digital technologies.

Pubic Institutions and Governance in Costa Rica: Recommendations from Country Experts

- Prioritize on relevant topics according to impact and risk
- Convert planned measures into laws
- Provide legal regulation and standardization of equipment
- Develop law on data privacy
- Open market and legalize decentral production
- Allow state-owned regulator to work with new business models for financing aside from tariffs
- Create new tariffs that allow for flexible integration of innovative projects
- Increase exchange with Latin-America best practices regarding digitalization/regulations
- Exclude import taxes on respective technologies and applications.

4.1.5 Digital Technology Use Cases in Costa Rica

Of the use cases identified for this study (Appendix 9), experts explicitly addressed seventeen during the interviews (Figure 27). This is in line with Costa Rica's energy sector, considering its focus on RE while bearing in mind the absence of an electricity wholesale market.

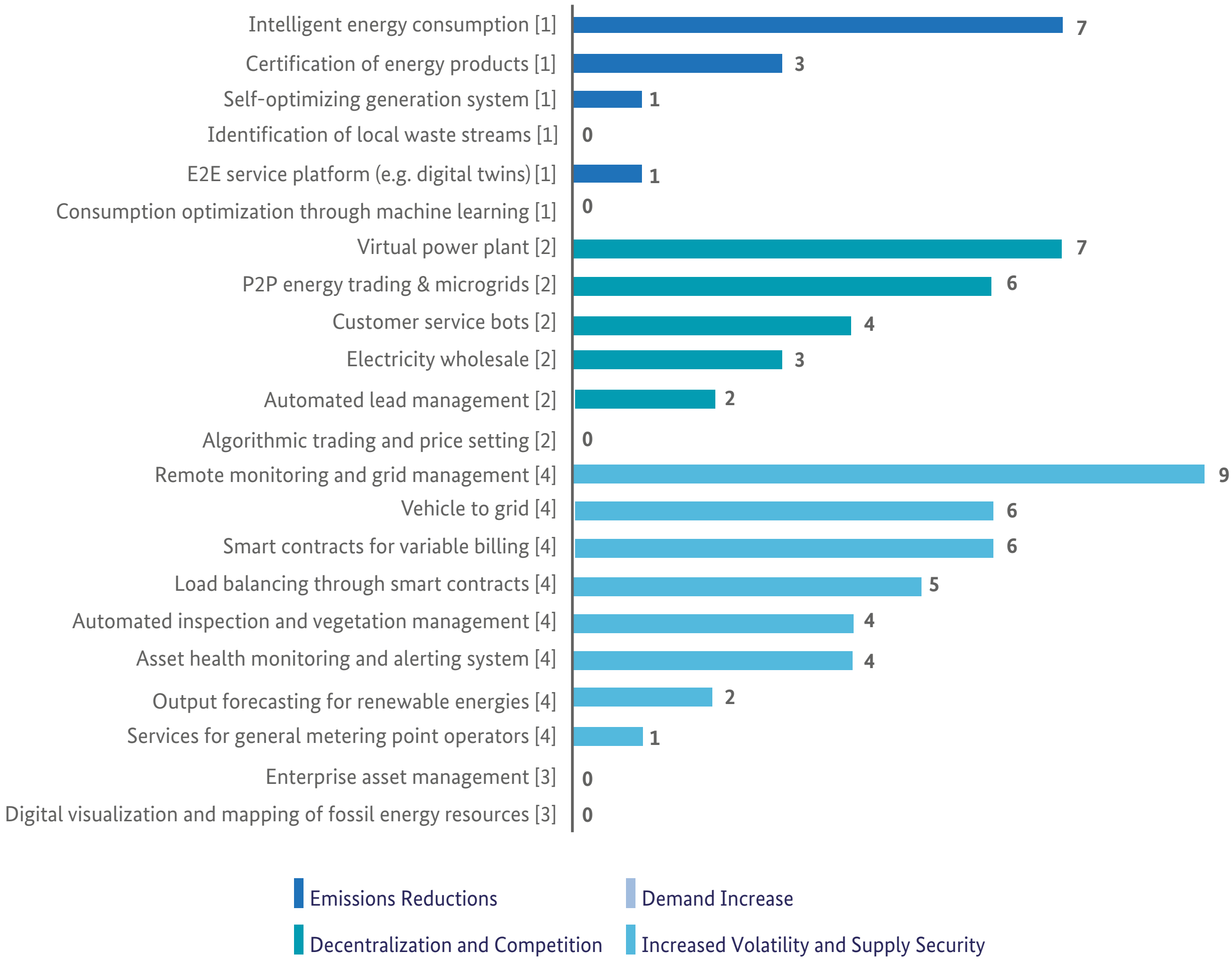


Figure 27. Addressed use cases in Costa Rica

Of the use cases mentioned by experts, *remote monitoring and grid management* was the most prominent one (mentioned by nine experts), followed by *virtual power plants* and *intelligent energy consumption* (mentioned by seven experts each), and *P2P energy trading and microgrids* and *vehicle to grid* (each mentioned by six experts). The perceived relevance of each use case can be seen in Figure 28.

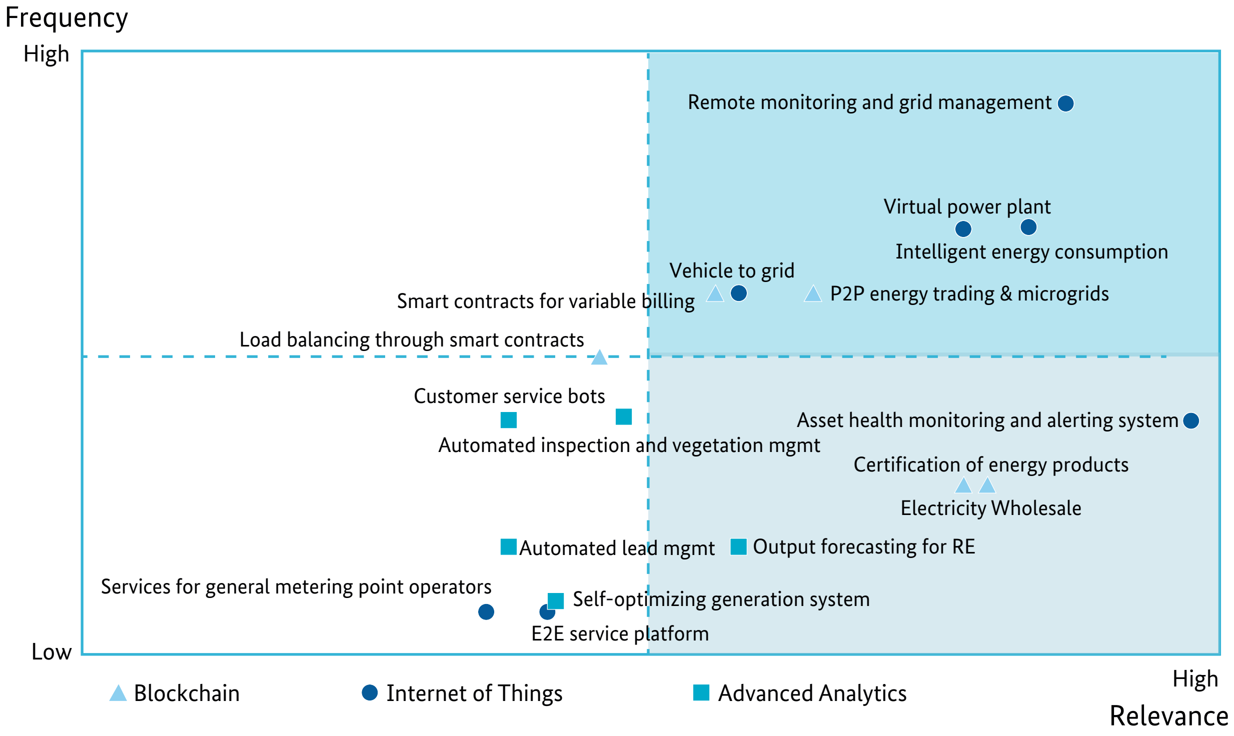


Figure 28. Use case assessment by relevance and frequency in Costa Rica

Of the top ten use cases experts addressed, the top five by relevance are highlighted in bold. These span across the whole value chain as can be seen in Figure 29.

	Generation	Trading	Transmission and Distribution	Consumption[2]
Emissions Reductions	1 Certification of energy products 4 Self-optimizing generation system 7 Identification of local waste streams			17 **Intelligent energy consumption** 19 E2E service platform (e.g. digital twins) 22 Consumption optimization through ML
Decentralization and Competition	2 **Virtual power plant**	8 **P2P Energy trading and microgrids** 10 Electricity wholesale 11 Algorithmic trading and price settings		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 Asset health monitoring and alerting system 5 Output forecasting for RE		12 Load balancing through smart contracts 13 **Remote monitoring and grid management** 14 **Vehicle to grid** 15 Automated inspection and vegetation management	16 Smart contracts for variable billing 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain Internet of Things Advanced Analytics[1]

Figure 29. Priority use cases in Costa Rica

Digital Technology Use Cases in Costa Rica

- **Remote monitoring:** pilot project on smart demand response initiated – real time client monitoring and hardware in place, however, missing processing of data

- **P2P energy trading and microgrids:** although this is generally considered relevant, it is currently perceived as not possible as companies do not want to allow it (monopolistic market)

- **Certification of energy products:** response to the demand of international companies for proof of energy origin.

El Salvador

4.2 El Salvador

Key Takeaways for El Salvador

- High probability of decrease of energy imports due to increase in electricity generation capacity through the addition of renewables as well as a planned gas power plant.
- For the electricity system in El Salvador, *decentralization & competition* was considered the most impactful global energy trend until 2030.
- This impact is reflected within the respective parameter estimations, including e.g. the share of self-sufficiency increasing to between 6.5% to 7.2%.
- With respect to the enabling framework conditions for digitalization,
  - Experts suggest that the digital infrastructure is enabling with good network coverage, but there is a need for real-time, proven, and harmonized data of the energy sector.
  - There is partial absence of regulation and missing knowledge on digital technology implementation.
- Concerning prospective digital technologies and use cases,
  - Experts mentioned eighteen as potentially relevant as country-specific challenges.
  - The top five span across the electricity value chain, with the top one being intelligent energy consumption and output forecasting for RE based on the internet of things and artificial intelligence, respectively.

4.2.1 General Information about El Salvador

El Salvador shares a border with Guatemala in the north and Honduras in the east (Figure 30). Since 2009 *population and society and technology* have shown increasing dynamics, represented by a four percent population increase and a higher life expectancy reaching 73.5 years. Income has become more equally distributed, lowering the GINI coefficient by four points to 42. In addition, the internet is now available to one third of the population.

Figure 30. Map of El Salvador

In terms of *political, regulatory and legal matters,* the government of El Salvador actively provides legal incentives for renewable energy production, such as tax exemptions and priority dispatch, and launches renewable energy projects.

The *economic and environmental* situation has experienced an overall improvement since 2009, reflected in the GDP increase of both nominal and per capita. The level of unemployment has decreased to 4.5 percent, while inflation has remained at the level of 2009. Moreover, El Salvador has achieved a decrease in CO2-emissions per capita of 6.1 percent over the last decade.

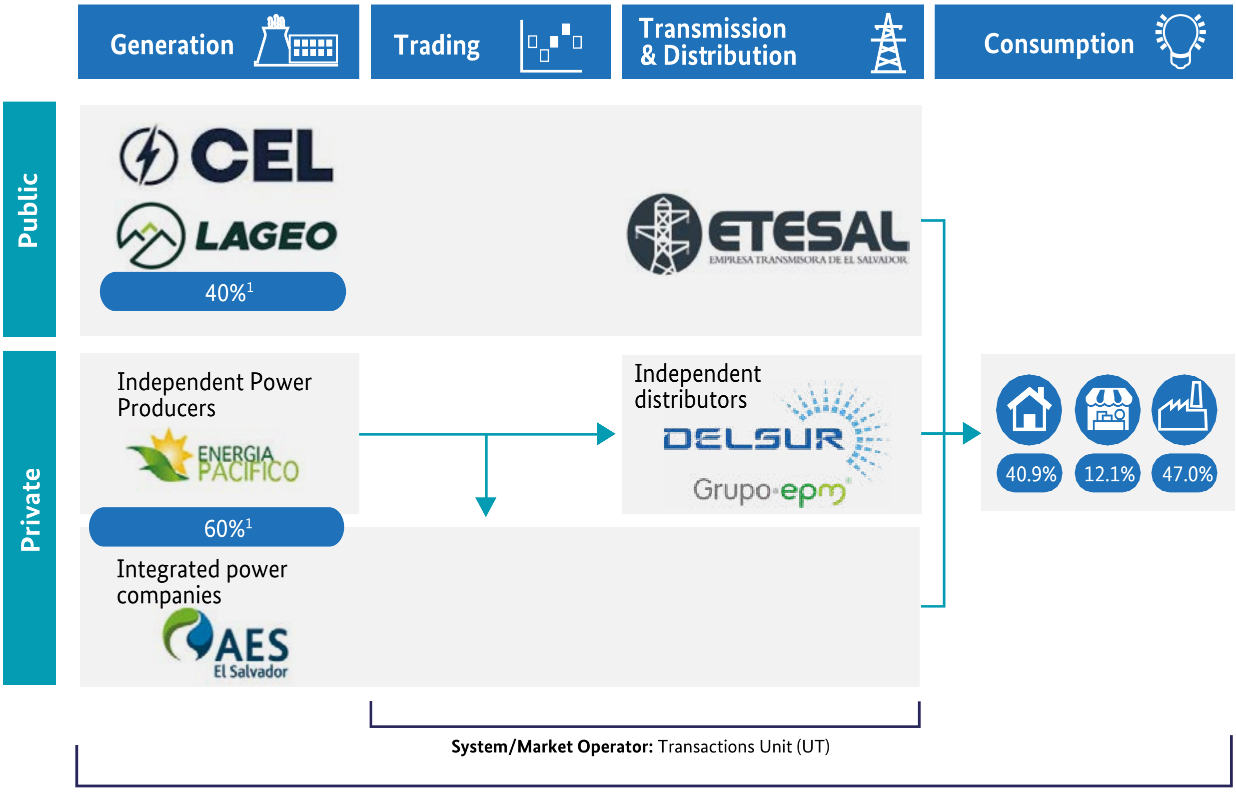
Population, Social and Technological		
- Inhabitants, 2017 [1] (2009):	6.4 (+3.9%)	[Mn]
- Life expectancy at birth, 2017 (2009):	73.5 (+2.7%)	[Years]
- GINI coefficient, 2014 (2009):	42 (-9.2%)	[number]
- Human dev. index, 2017 (2009):	0.67 (+2.3%)	[number]
- Internet penetration, 2016 (2009):	29 (+139%)	[%]
- Access to electricity, 2016 (2009):	98.6 (+8.3%)	[%]
- Average price of 1GB mobile data 2018:	4.55	[USD]
Political, Regulatory, and Legal		
- Government: Unitary presidential constitutional republic		
- Democracy Index (2017): 6.43		
- Legal incentives for renewable energy production (tax exemption, priority dispatch), 100MW solar PV and 70 MW wind projects		
Economic and Environmental		
- GDP 2017, (2009):	24.81 (+41%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	7,292 (+18%)	[USD]
- Unemployment rate, 2017 (2009):	4.5 (-38.7%)	[%]
- Inflation, 2017 (2009):	1.0 (+/- 0%)	[%]
- CO_2- emissions p.c., 2017 (2009):	1.0 (-6.1%)	[tons]

1) 20% of El Salvador´s population lives abroad (Index Mundi)

Figure 31. Profile of El Salvador

The National Energy Council (CNE, in Spanish Consejo Nacional de Energía) is the responsible authority for energy policy in El Salvador. In 2010, it published its current National Energy Policy 2010-2024. In this policy paper, El Salvador lays out its plans to access energy, to improve the role of the government in the energy sector, to decrease its fossil fuel dependency, and to mitigate climate change (CNE, 2010). In addition, El Salvador published its strategy on renewable energy development in 2012. In this plan El Salvador describes the planned capacity additions until 2026, aiming to diversify its power matrix (CNE, 2012).

The energy market in El Salvador is liberalized, allowing all participants to operate in generation, transmission, and distribution of electricity. Transactions Unit (UT, for its acronym in Spanish) operates the transmission grid and manages the energy exchange market (Figure 32). In recent decades, the electricity market became strongly deregulated, including privatization along the value chain. This has led to the growth of new business models and facilitated the energy transition. As the regulation is imprecise at some points, there has been an absence of investment due to insecurity for private market participants. There is a diversified wholesale electricity market with 31 electricity retailers.



Regulator: General Superintendency of Electricity and Telecommunications (SIGET)
Policy-making entity: National Energy Council (CNE)
[1]Share in generation capacity

Figure 32. Electricity market structure in El Salvador

We present the current energy parameters in Figure 33. The growth of renewable energy is mainly driven by the government's strategy to diversify the power matrix. Since 2013 the government has led four auctions for renewable energy contracting over 285 MW of capacity (Bloomberg New Energy Finance, 2018). In addition, renewable energy power plants receive priority dispatch from the transmission provider as well as income and import tax relieves. El Salvador has a net energy export balance of -1,585.3[7] due to its high energy imports mainly from Guatemala. The average price of electricity was USD 0.1735 per kWh in 2017 (ECLAC, 2018).

The price is based on a regulated tariff that is set by the regulator, the General Superintendency of Electricity and Telecommunications (SIGET, for its acronym in Spanish). This tariff is based on the five-year cost and investment plans presented by the market participants. If any additional investments into technologies are planned, a tedious procedure needs to be initiated.

El Salvador is a member of the MER and is interconnected to Guatemala and Honduras. El Salvador is a major energy importer with a negative net energy export balance (Figure 33).

[7]This sum resembles 65% of the total MER energy exchanges (CEPAL 2017) and around 25% of annual national consumption (SIGET, 2017).

Parameter	Unit	Current[1]
Capacity factor	[%]	30.1
Efficiency	[$/MWh]	87.6
Net energy exports to MER	[Gwh]	-1,585.3
Wholesale electricity market	[binary]	Yes
Market liquidity	[%]	8.1
Self-sufficiency	[%]	2.9
Market diversity	[number]	31
Grid interconnection	[%]	8.8
Reserve margin	[%]	77.9
System average interruption duration	[hours]	6.5
Number of smart meters	[number]	600
Energy mix	[% RE]	74.8
Carbon intensity	[tons CO2/GWh]	62.8
Energy loss	[%]	11.5
GDP energy intensity	[MWh/GDP(mn)]	204.5
Total generation	[GWh]	5,072.8
Total installed capacity	[MW]	1,922.7
Number of electric vehicles	[number]	n.a

1] Sources and year for current parameters are provided in the appendices.

Figure 33. Current energy parameters in El Salvador

4.2.2 Impact of Global Energy Trends on El Salvador

The global energy trend towards *increased volatility and supply security* has the highest impact on El Salvador (Figure 34). Twenty-one percent of experts rate this trend as having a very high impact and 57 percent as having a rather high impact. The addition of volatile renewable energies such as wind and solar will have an impact on the stability of the power sector. Also, El Salvador has a high negative net energy export value of -1,583.3 GWh, indicating dependency on its neighbors to supply electricity. There is also strong insecurity among the private market participants due to imprecise regulation.

The second most impactful trend in El Salvador with 21 percent of the panel expecting a very high and 57 percent a rather high impact is *decentralization and competition.* This trend is mainly driven by regulatory incentives for distributed projects and self-producers. While decentralization can strengthen the electricity system, it can also lead to challenges which have to be addressed such as changing demand on the wholesale market.

Beyond that, the trend *emissions reductions* is ranked as the third trend with a rather high impact according to 57 percent of the experts. This is a result of the government policy of diversifying the energy matrix. In upcoming years, many renewable energy projects are planned (CNE, 2012).

Seven percent of the experts predict a very high and 43 percent a rather high impact of the global energy trend *demand increase* on El Salvador's energy sector. The demand increase is balanced between, on the one hand, a growing economy and population, while on the other hand, the many energy efficiency measures that have been undertaken. Even though the population grew only 3.9 percent, the GDP grew 41 percent between 2009 and 2017 (Figure 31). However, while such an increase in GDP likely comes with increased energy usage, energy efficiency initiatives offset these and reduced the electricity demand. Still, demand increase could pose a challenge due to the already high level of energy imports.

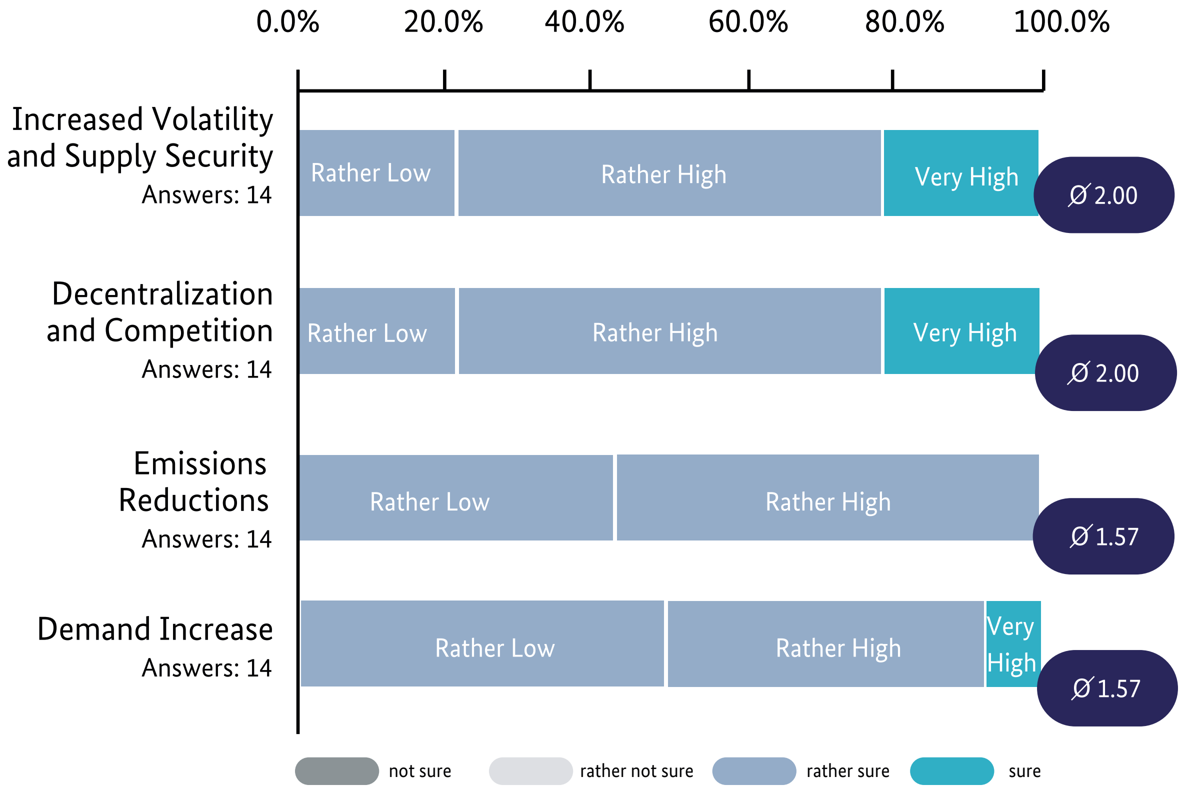


Figure 34. Global energy trends impact assessment in El Salvador by 2030

4.2.3 Outlook and Improvement Areas for El Salvador

Increased Volatility and Supply Security

The most impactful global energy trend is *increased volatility and supply security* (Figure 35). This trend is reflected in the system average interruption duration, which is estimated to decrease from 6.5 hours to around 5 hours on average. Currently, system interruptions are often due to aerial (rather than underground) power lines. In addition, experts predict that the grid interconnection will increase to between 9.5 and 10.7 percent. This addition could come as a result of the second circuit of SIEPAC.

To cope with the trend *increased volatility and supply security* there is high potential for improvement for the parameters *number of smart meters, system average interruption duration, and grid interconnection.* Increasing the number of smart meters would give El Salvador the chance to predict demand pattern.

Decentralization and Competition

The trend *decentralization and competition* is present in the expected increase in self-sufficiency as well as the decrease in energy imports (Figure 35). Until 2030 the share of self-sufficiency will increase to between 5.5 and 6.8 percent. This is a result of government incentives that make it more attractive to use more decentralized systems. In addition, the net energy exports to MER are projected to be reduced to between -112.9 and 0 GWh. Experts believe that the energy imports will decrease due to increased power generation capacity in El Salvador. As a result, the prices of energy could also decrease as the transportation costs from other countries are more expensive. This is reflected in the expected decrease of efficiency.

To counter the challenges coming from the trend *decentralization and competition,* the experts conclude that the parameter *self-sufficiency* has the highest level of potential for improvement (Figure 36). This emphasizes the need for *regulations* by the government. In addition, political action can lead to rather high level of potential for improvement for the parameter *efficiency.*

Emissions Reductions

The *emissions reductions* trend is reflected in the energy mix, energy loss, and GDP energy intensity. Until 2030 the share of renewables in the energy mix is projected to increase to around 80 percent. In addition, experts forecast that the energy loss will decrease from 11.5 percent to around 10 percent.

While the energy loss value is already low, an increase in distributed generation contributes to the reduction of energy losses. Although automatization and digitalization will increase energy usage, energy efficiency and GDP are expected to grow as well and lead to a slight decrease in GDP energy intensity.

In the field of energy loss and share of renewable energy in the energy mix, there is a high level of potential improvement through additional political action. To increase the share of renewable energy in the energy mix the government could implement additional incentives. The government could reduce energy losses such as through renovating the transmission lines and using distributed energy generation systems.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Capacity factor	[%]	30.1	31.7	32.4	+1.6 to +2.3	no consensus
Efficiency	[$/MWh]	87.6	80.0	84.2	-9% to -4%	▼ 77%
Net energy exports to MER	[GWh]	-1 585.3	0.0	-112.9	100.0% to 92.9%	▲ 80%
Wholesale electricity market	[binary]	Yes				
Market liquidity	[%]	8.1	10.5	10.3	+1.9 to +2.2	▲ 86%
Self-sufficiency	[%]	2.9	5.5	6.8	+2.6 to +3.9	▲ 100%
Market diversity	[number]	31	50	49	+19 to +18	▲ 85%
Grid interconnection	[%]	8.8	9.5	10.7	+0.7 to +1.8	▲ 64%
Reserve margin	[%]	77.9	77.9	70.9	-0.0 to -7.0	no consensus
System average interruption duration	[hours]	6.5	5.0	5.2	-23.1% to -20.8%	▼ 93%
Number of smart meters	[number]	600	20,000	54,792	+20,000 to +54,792	▲ 100%
Energy mix	[% RE]	74.8	80.0	80.5	+5.2 to +5.7	▲ 93%
Carbon intensity	[tons CO2/GWh]	62.8	62.8	60.0	-0.0% to -4.4%	no consensus
Energy loss	[%]	11.5	10.0	9.8	-1.5 to -1.7	▼ 80%
GDP energy intensity	[MWh/GDP(mn)]	204.5	195.0	202.5	-4.6% to -1.0%	▼ 70
Total generation	[GWh]	5,072.8	7,200.0	7,320.2	+41.9% to +44.3%	▲ 100%
Total installed capacity	[MW]	1,922,7	2,651.5	2,763.3	+37.9% to +43.7%	▲ 100%
Number of electric vehicles	[number]	n.a	1,000	6,474	+900 to +6,374	▲ 91%

1.Sources and year for current parameters are provided in the appendix.

2.Based on the median 2030 forecast provided by the experts.

3.Weighted average including the confidence of the assessment.

4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.

5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend
- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 35. Energy parameters in El Salvador by 2030

Demand Increase

The global energy trend *demand increase* can be observed in the parameter total generation, which is estimated to increase by between 41.9 and 44.3 percent until 2030. This comes together with an increase in total installed capacity, not only driven by the rising energy demand but also by the plan to shift from energy imports to energy generation in El Salvador. The growth of the installed capacity will be attributed to new renewable energy projects as well as the planned natural gas plant in the Port of Acajutla. Once construction is completed, this plant alone will add 378 MW to the total capacity of El Salvador (Energy from the Pacific, 2019). The experts foresee that the number of electric vehicles will reach between 1000 and 6500 by 2030.

Here, political action would have a very high impact on the number of electric vehicles. The experts suggest that implementing monetary incentives (*e.g.,* tax exemptions), rewards (*e.g.,* preferential parking) and providing support in the set-up of necessary infrastructure (*e.g.* charging stations) are good starting points.

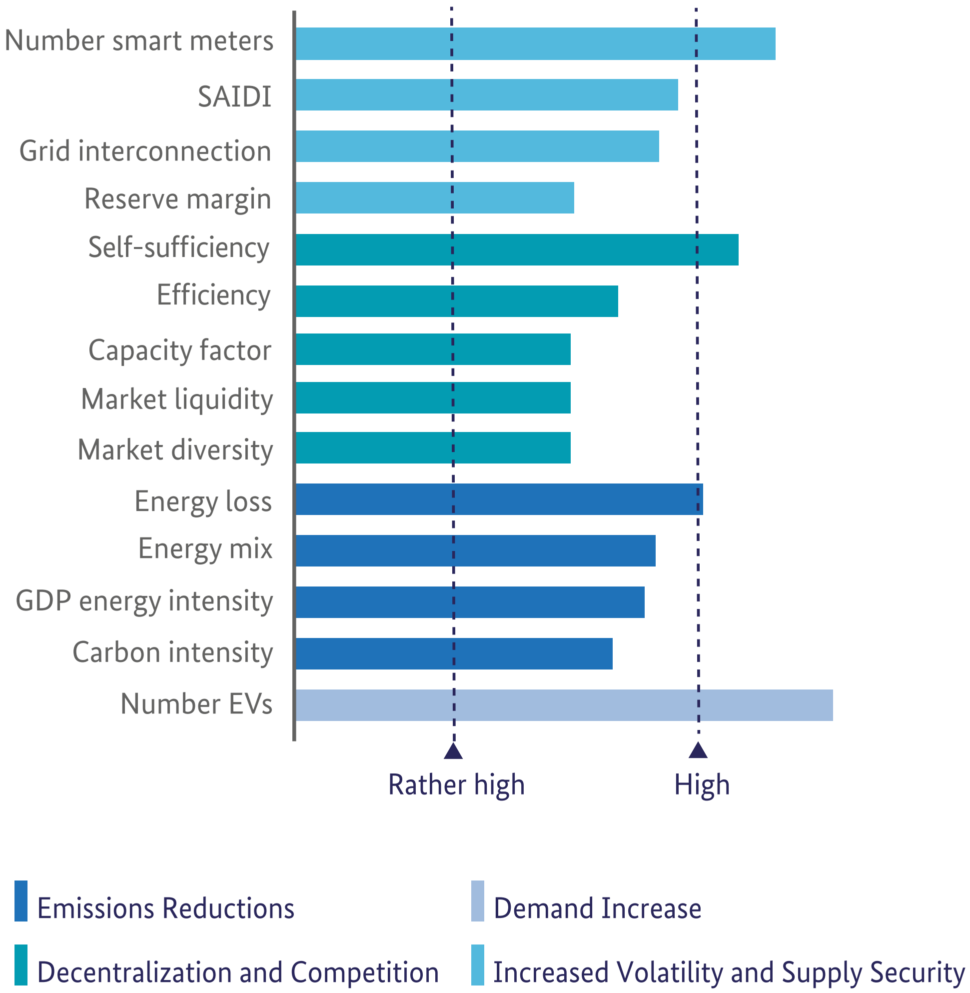


Figure 36. Potential improvement of energy parameters until 2030 in El Salvador

4.2.4 Enabling Framework Conditions in El Salvador

Digital technologies have the potential to help overcome some of the challenges that arise from global trends; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section indicates the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.

As illustrated in Figure 37, El Salvador's energy sector is partially ready for digitalization. While digital infrastructure is generally considered sufficient to implement selected digital technologies, lack of implementation knowledge and adapted regulation impedes progress. Still, corporations are increasingly pursuing an innovation-driven approach, indicating ongoing change.

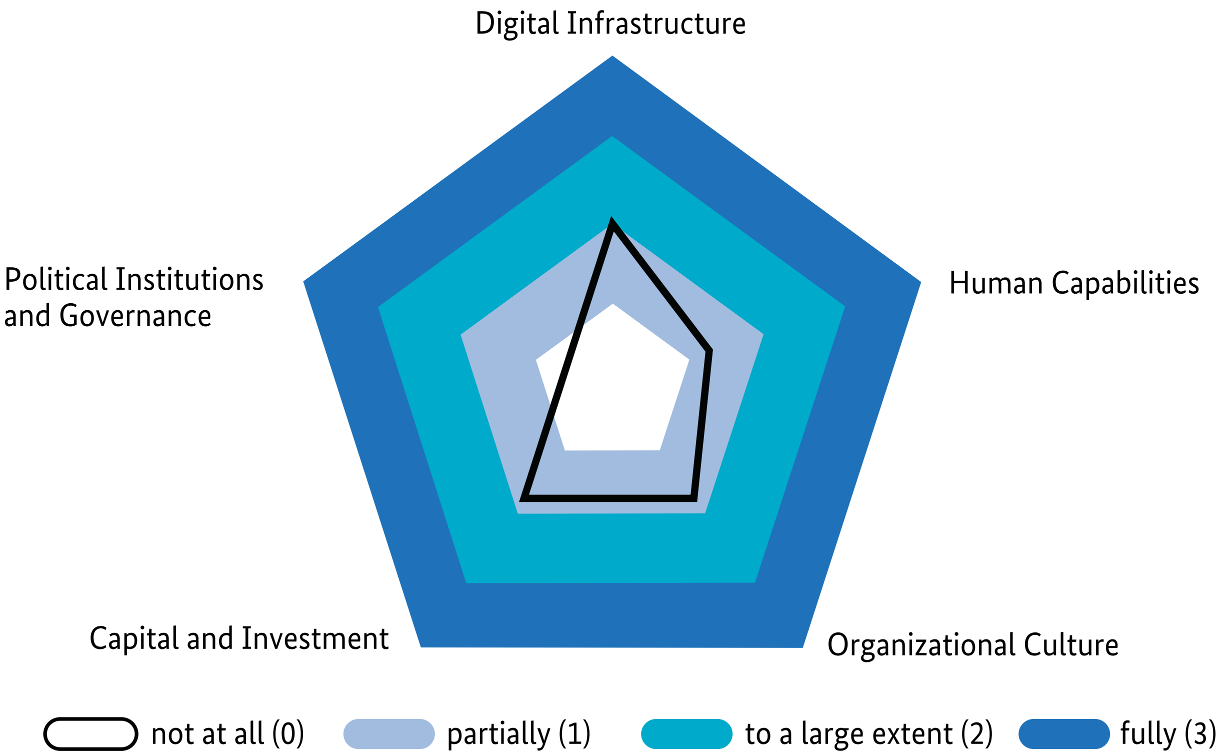


Figure 37. Availability of framework conditions in El Salvador

Digital Infrastructure

According to the experts, the digital infrastructure in El Salvador is sufficient to start the digitalization of the electricity sector (Figure 38). There is good network coverage, with at least 3G, and in some areas, 4G, available. The electricity market is open to private participants, with distributors having set up their own data centers. Moreover, general broadband coverage is available throughout the country.

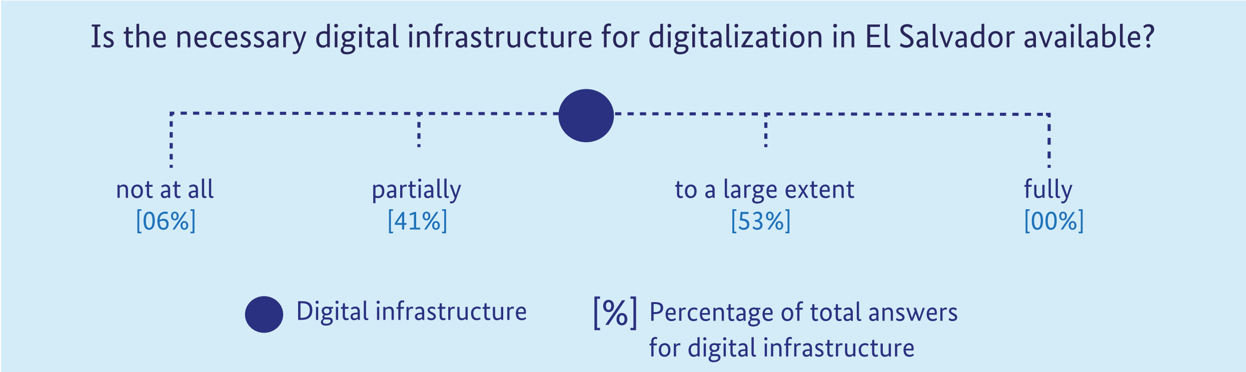


Figure 38. Digital infrastructure in El Salvador

However, it is also mentioned that there is lack of investment in new infrastructure, due to the absence of viable business cases. Besides, while broadband coverage is available, high-speed connections are expensive. In addition, smart meter deployment has been slow- going, with 95 percent of homes still having electromagnetic meters.

Digital Infrastructure in El Salvador: Recommendations from Country Experts

- Formulate smart metering strategy and implementation plan.
- Create accurate business cases for digital infrastructure.
  - Increase network speed e.g. by supplying affordable high-speed broadband capacity.
  - Create a centralized data base to increase big data potential, e.g. based on the blockchain.

Human Capabilities

In El Salvador, knowledge on digitalization and especially technological implementation is just beginning to develop (Figure 39). Although there are universities offering degrees and education on technological topics, coverage is not sufficient. There is a discrepancy between what universities offer and what the industry needs, such as network integration, operation, programming, and value creation. Therefore, digitalization-centered education is often provided by external sources (e.g. internet). Aside from the academic aspect, within the broad population there is a general reservation towards technological advancements; that is, people prefer to pay cash and are slow to trust digital transactions, and operators conduct many processes manually.

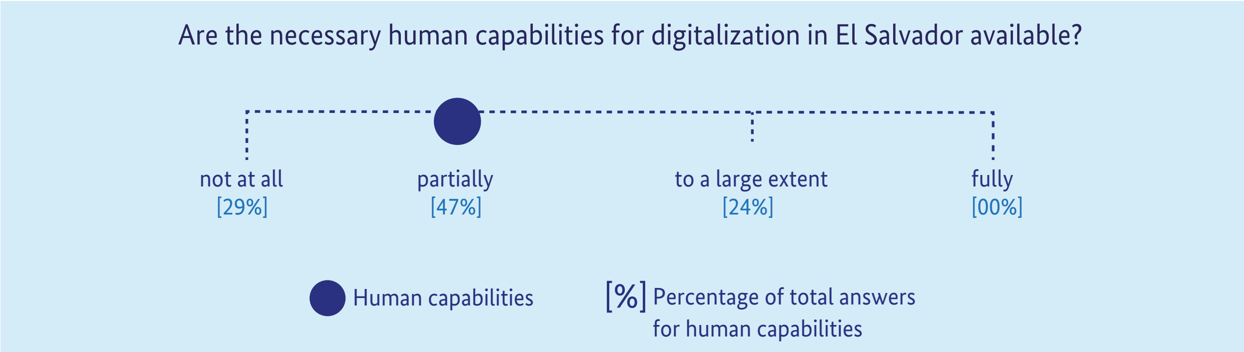


Figure 39. Human capabilities in El Salvador

Nevertheless, basic technological education is available, with specialized experts partially in place.

Human Capabilities in El Salvador: Recommendations from Country Experts

- Stronger communication and promotion of national energy strategy.
- Offer specialized university programs.
- Incentivize participation in complementary online courses for students and employees.
- Reform careers with a digital perspective and promote programming education.

Organizational Culture

Cultural change with a focus on digitalization is ongoing (Figure 40). The level of cultural change varies, strongly depending on the type of company and place on the value chain. Some companies already have dedicated innovation departments exploring digitalization, but this is not yet the standard on a sectoral level.

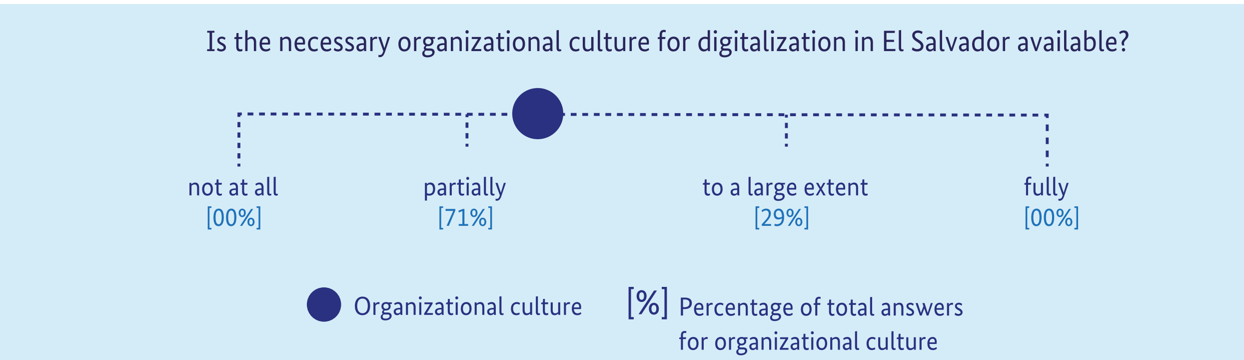


Figure 40. Organizational culture in El Salvador

Family-owned companies are often lack institutionalized innovation processes and ISO norms. Moreover, out-of-the-box thinking tends to be rare, while following regulations is the norm for people in institutions. A certain reservation towards technology prevails in some organizations, creating a mindset problem, as IT is not considered a strategic asset.

Organizational Culture in El Salvador: Recommendations from Country Experts

- Promote strategic thinking and cultural change with respect to digitalization
- Institutionalize innovation management processes
- Create awareness of data potential, e.g. through congresses
- Hire new, younger personnel in order to facilitate change of culture through new perspectives
- Increase exchange between academia and companies
- Support interpreneurship and entrepreneurship
- Establish regulator as role model by introducing proactive regulation.

Capital and Investment

Most of the experts agree that capital and investment are partially available (Figure 41), with private and public banks offering financing, as evident in large investments in the energy sector in recent years.

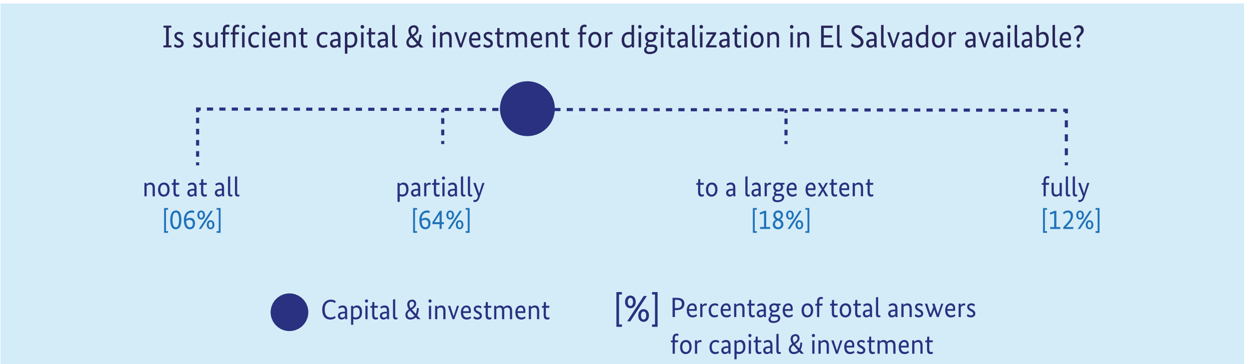


Figure 41. Capital and investment in El Salvador

However, due to these large investments, banks are now more reluctant to grant further financing, especially in regard to the knowledge gap on digital topics. Considering the novelty of digital applications, companies often face the issue of accurately articulating their needs and quantifying the benefits, with banks on the other side being used to robust business cases. This leads to banks requiring funds to be backed by hard assets. In addition, the financial institutions are currently undergoing a transformational process, adding further complexity in terms of structure, processes, and directing of capital.

Capital and Investment in El Salvador: Recommendations from Country Experts

- Enhance digital knowledge of financial institutions
- Develop consistent business cases
- Institutionalize funding circle (angel investors, VCs…)
- Allow securing funds with digital assets (software-backed) rather than hard assets (i.e. hardware-backed) only.

Public Institutions and Governance

Experts indicated that public institutions and governance have a strong potential for improvement (Figure 42). Two of the challenges faced by the regulator are the pressure to reduce consumer prices and the slow pace of the market in terms of digital technology innovation. The latter results in neglect regarding digital technology investments, creating insecurity and potentially hindering investment.

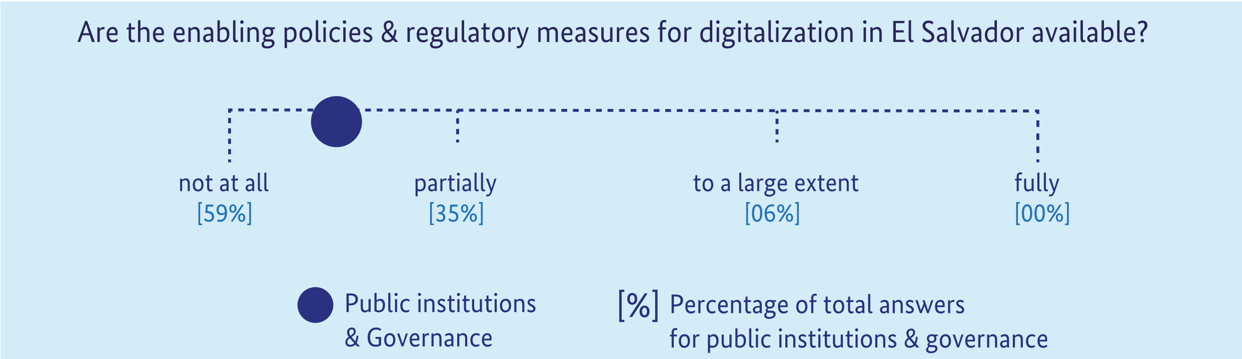


Figure 42. Public institutions and governance in El Salvador

There are three types of distributed electricity generation from renewable energy sources: 1) Renewable Distributed Generation (GDR, for its acronym in Spanish), which is distributed generation through auctions (for plants whose installed capacity does not exceed 20 MW), 2) Renewable Self-producing User (APR, for its acronym in Spanish): prosumers who produce energy for self-consumption but through the reserved block as part of GDR auctions, APR can feed their excesses into the grid and have access to a remuneration based on the prices awarded in the auctions, 3) Renewable Producers Final User (UPR, for its acronym in Spanish): prosumers, whose electricity sources are used for self-consumption and work with a net balancing scheme, with rare exceptions that allow to feed energy into the grid. With respect to the integration of decentralized generation, one is legally required to register with the ministry and regulator in order to sell generated electricity, resulting in decentralized residential generation of prosumers mostly not being included in the regulation. With this lack of transparency, demand and production capacity forecasts are less precise. Lastly, aside from the regulatory perspective, taxes on innovative technologies (e.g. electric vehicles) are further hindering the progress of digitalization. Nevertheless, stakeholders are aware of these issues, which are also recognized by the regulator.

Public Institutions and Governance in El Salvador: Recommendations from Country Experts

- Create incentives for digitalization of energy market participants
- Create and clearly communicate digital goals on governmental level
- Take long-term perspective and build up digital technology knowledge (regulator)
- Implement basic digital technologies, e.g. electric billing and online payment methods
- Facilitate and incentives smart meter deployment with respective laws and regulation
- Create transparency on distributed generation units and simplify feed-in requirements
- Adjust import legislation, e.g. ISO norms.

4.2.5 Digital Technology Use Cases in El Salvador

Of the use cases identified for this study (Appendix 9), experts explicitly mentioned eighteen of them during interviews (Figure 43).The focus lies especially on use cases that facilitate the integration of RE into the system, as well as on use cases that hinder electricity theft.

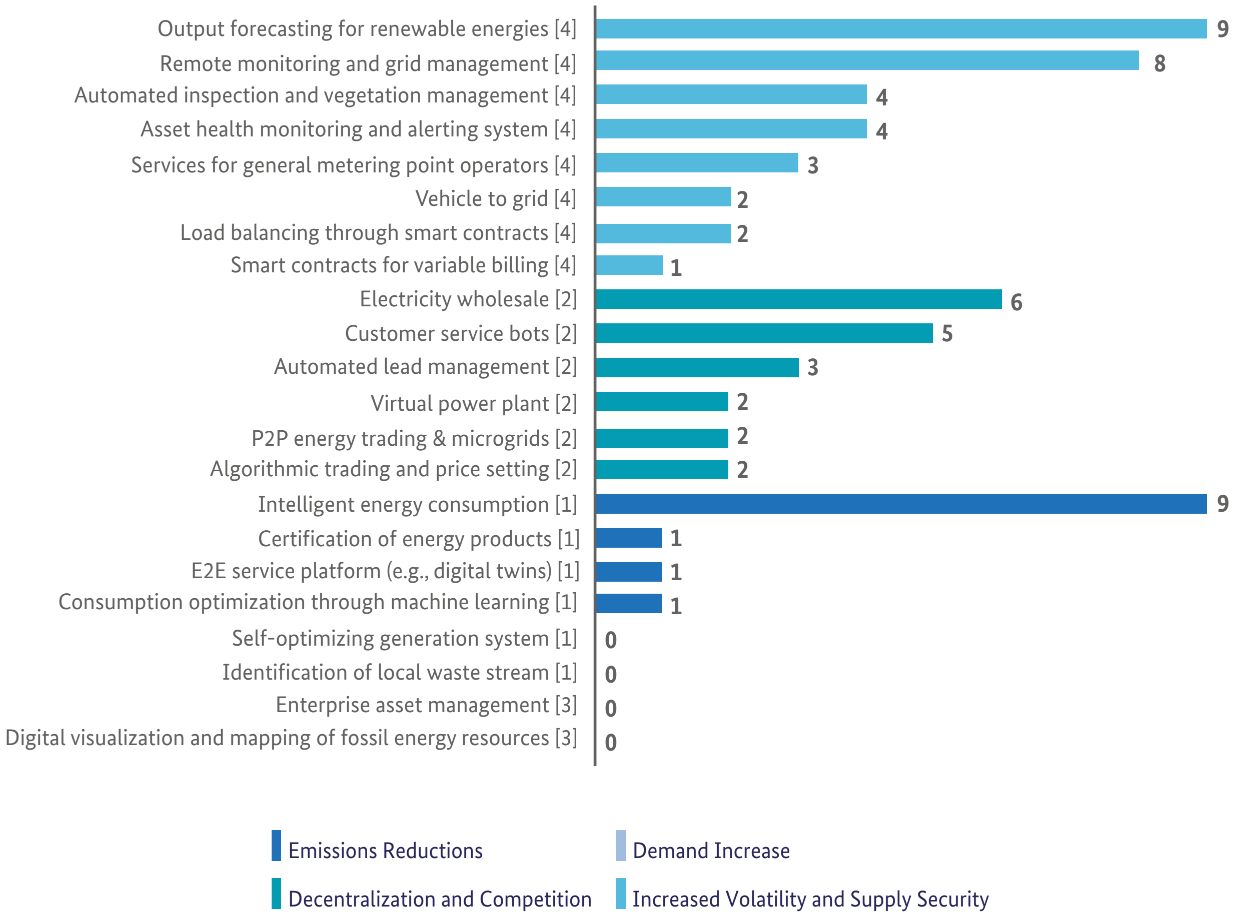


Figure 43. Addressed use cases in El Salvador

The most prominent use cases mentioned by the experts were output forecasting for RE and intelligent energy consumption (addressed by nine experts each), followed by remote monitoring and grid management (addressed by eight experts), electricity wholesale (addressed by six experts), and asset health monitoring and alerting systems (addressed by four experts). The perceived relevance of each use case can be seen in Figure 44.

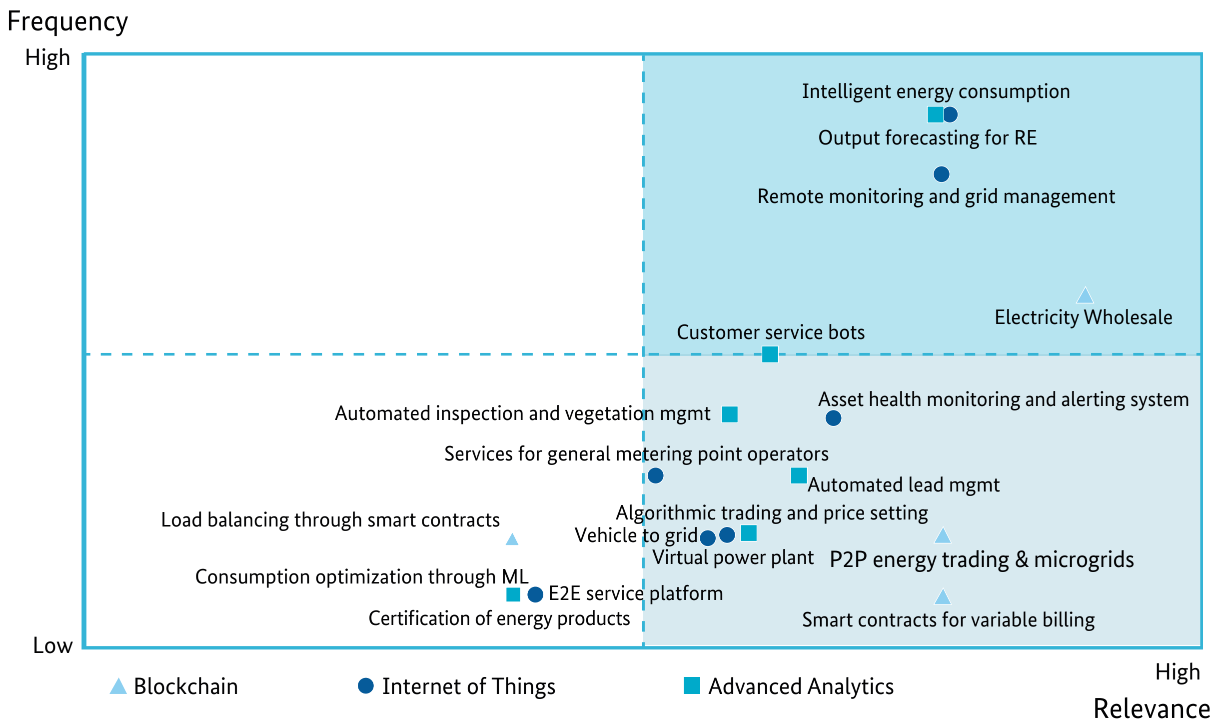


Figure 44. Use case assessment by relevance and frequency in El Salvador

Of the top ten use cases that were addressed, the top five sorted by relevance are highlighted in bold, spanning across the whole value chain as can be seen in Figure 45.

	Generation	Trading	Transmission and Distribution	Consumption[2]
Emissions Reductions	1 Certification of energy products 4 Self-optimizing generation system 7 Identification of local waste streams			17 **Intelligent energy consumption** 19 E2E service platform (e.g. digital twins) 22 Consumption optimization through ML
Decentralization and Competition	2 Virtual power plant	8 P2P Energy trading and microgrids 10 **Electricity wholesale** 11 Algorithmic trading and price settings		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 **Asset health monitoring and alerting system** 5 **Output forecasting for RE**		12 Load balancing through smart contracts 13 **Remote monitoring and grid management** 14 Vehicle to grid 15 Automated inspection and vegetation management	16 Smart contracts for variable billing 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain | Internet of Things | Advanced Analytics[1]

Figure 45. Priority use cases for El Salvador

Digital Technology Use Cases in El Salvador

- **Virtual power plant:** pilots in implementation in cooperation with specialized company.
- **Asset health monitoring and alerting system:** current lack of hardware, but pilot programs are starting and sensors in substations already indicate maintenance needs.
- **Output forecasting for RE:** currently only imprecise data available. Pilots are starting, e.g. with support of the program develoPPP from the German Federal Ministry for Economic Cooperation and Development (BMZ) in cooperation with GIZ, DelSur and CENACE, energy and meteo systems launched the project "Wind and Solar Power Predictions in El Salvador and Mexico" in 2017.
- **Electricity wholesale:** currently available only over intermediary (Banco de America Central) and not automated, but process and regulation in place.
- **Remote monitoring and grid management:**
  - Differences along the value chain, with a few SCADA systems in place and other infrastructure for data being installed, however, slowly due to high investment requirement.
  - Currently data are analyzed manually without further analytics.
- **Automated inspection and vegetation management:** pilot programs in development in cooperation with local university (UCA), currently drones used to film network, but watched manually.
- **Intelligent energy consumption:** dependent on smart meter deployment, beginning with industrial clients and transmission system operators.
- **Customer service bots:** first bots are already online and being tested.

Guatemala

4.3 Guatemala

Key Takeaways for Guatemala

- The electricity market of Guatemala is shaped by the successful liberalization with several independent power producers and non-state-owned electricity companies.
- For the electricity system in Guatemala, experts consider *increased volatility and supply security* the most impactful global energy trend through 2030.
- This impact is reflected within the respective parameter estimations, including e.g. the increase in grid interconnection to between 10.4 and 13.5 percent by 2030.
- With respect to the enabling framework conditions for digitalization, digital infrastructure is available in urban but not rural areas and capital and investments seem available, while policies and regulation are slow to promote change. In general, there are strong differences within the respective framework conditions.
- Concerning prospective digital technologies and use cases,
  - thirteen are potentially relevant for country-specific challenges,
  - the top five spanning across the electricity value chain, and the top one being remote *monitoring and grid management* based on the internet of things.

4.3.1 General Information about Guatemala

Guatemala shares borders with Mexico in the north and El Salvador and Honduras in the south east (Figure 46). From 2009 to 2017, Guatemala has shown an improvement in population, society and technology matters. In addition to the population growth of 18 percent, Guatemala has experienced a positive change in life expectancy, an increase of its HDI and an increase in internet penetration with now over a third of the population having access to the web.

Figure 46. Map of Guatemala

Regarding *political, regulatory and legal* matters, Guatemala's environmental responsibility is reflected in the adoption of a national energy policy for 2013-2027, which identifies RES as a guiding principle.

In terms of *economic and environmental* matters, Guatemala has doubled its GDP in nominal terms since 2009 while the GDP per capita slightly increased by 11 percent. The inflation level has more than doubled and reached 4.4 percent, reflecting only moderate stability of prices.

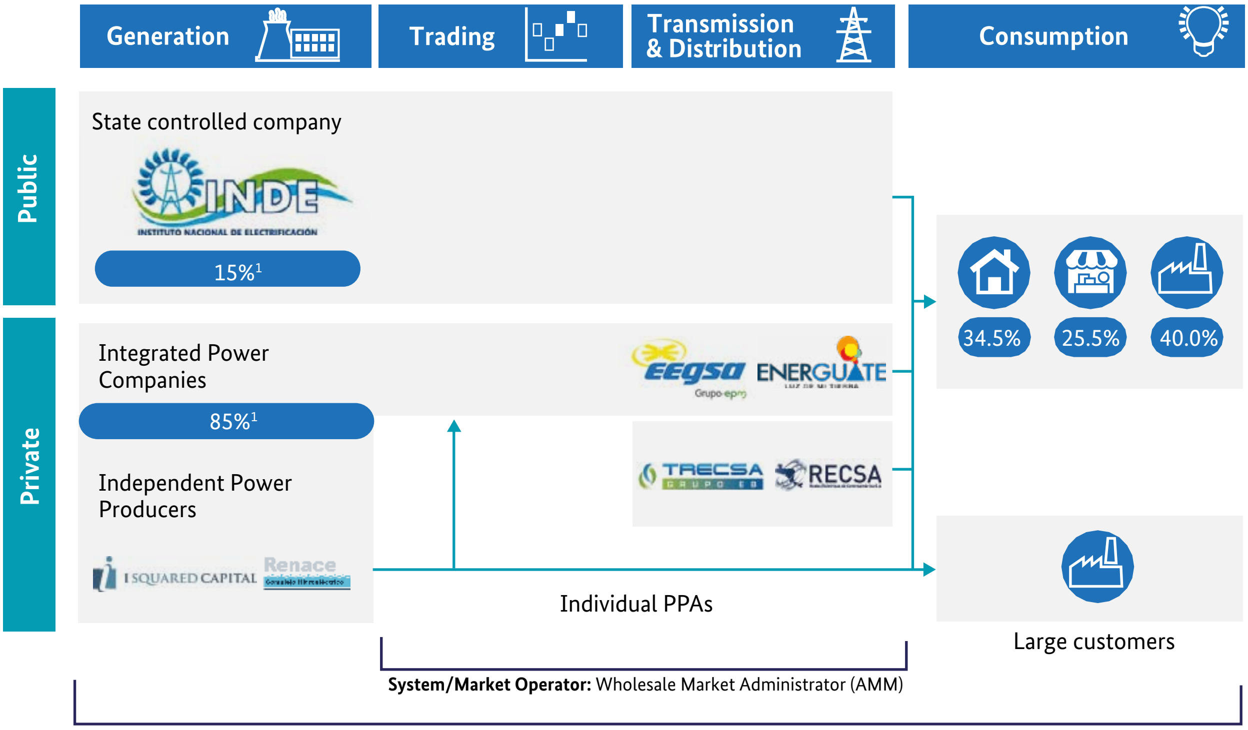
Population, Social and Technological		
- Inhabitants, 2017 (2009):	16.91 (+18.1%)	[Mn]
- Life expectancy at birth, 2017 (2009):	73.4 (+3.2%)	[Years]
- GINI coefficient, 2014 (2009):	48.3 (-11.5%)	[number]
- Human dev. index, 2017 (2009):	0.65 (7.6%)	[number]
- Internet penetration, 2016 (2009):	34.5 (+271%)	[%]
- Access to electricity, 2016 (2009):	91.8 (+10.6%)	[%]
- Average price of 1GB mobile data 2018:	4.53	[USD]
Political, Regulatory and Legal		
- Government: Unitary presidential republic - Democracy Index (2017): 5.86 - National energy policy (2013-2027) sets RES as a guiding principle Generation target of 64% from RES by 2032		
Economic and Environmental		
- GDP 2017, (2009):	75.62 (+100.4%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	7,424 (+11.3%)	[USD]
- Unemployment rate, 2017 (2009):	2.7 (-11.8%)	[%]
- Inflation, 2017 (2009):	4.4 (+138%)	[%]
- CO^2- emissions p.c., 2014 (2009):	1.15 (+30.9%)	[tons]

Figure 47. Profile of Guatemala

In Guatemala, the Ministry of Energy and Mines (MEM, for its acronym in Spanish) is responsible for drafting the energy policies. In 2012 the ministry finalized the Energy Policy 2013-2027, which sets the goals of covering the energy demand, strengthening the electric power transmission, diversifying the energy mix, and reducing oil dependence. Guatemala sets a specific goal for generating 80 percent of energy from renewable energies (MEM, 2012). Furthermore, Guatemala specified its goals for sustainable development in the plan on generation and transmission in 2016 (MEM, 2016). Here, Guatemala lays out a strategy to increase the share of renewable energy and an expansion plan for the transmission system. In the beginning of 2019, Guatemala published its Rural Electrification Policy 2019-2032 (MEM, 2019). Currently, Guatemala is working on its 2050 strategy plan.

The energy market in Guatemala is liberalized. Through the 1996 General Electricity Act, the energy market in Guatemala was de-nationalized, allowing all types of companies to participate in the generation, distribution, and transmission of electricity. Today, National Institute of Electrification (INDE, for its acronym in Spanish) owns only 14.8 percent of the capacity, with other generators taking the rest of the market (Energia de San Jose SA: 8.97%, Duke Energy Guatemala 5.9%; Thomson Reuters Practical Law, 2018).

In addition to the partly state-owned company INDE, there are seven transport agents (e.g. DUKE, RECSA, TRECSA), two utilities that cover the 93 percent bulk of Guatemala's customers: Guatemalan Electric Company (EEGSA, for its acronym in Spanish) and Energuate (formerly DEOCSA/DEORSA; Koberle, 2012) and nineteen municipal companies that cover seven percent of customers. The National Electricity Energy Commission (CNEE, for its acronym in Spanish) is the authority responsible for creating and enforcing energy regulation. There is a wholesale market for electricity, which is organized by the Wholesale Market Administrator (AMM, for its acronym in Spanish). AMM oversees the contracts as well as matching supply and demand in the national grid.



Regulator: National Electric Energy Commission (CNEE)
Policy-making entity: Ministry of Energy and Mines (MEM)
[1]Share in generation capacity

Figure 48. Electricity market structure in Guatemala

The price of electricity for the public ranged from USD 0.162 per kWh at the supplier EEGSA to USD 0.225 at the supplier ENERGUATE in 2017 (ECLAC, 2018). The price for electricity is determined by electricity market regulator CNEE. The final electricity tariff is calculated by summing up the average cost of electricity supply from the wholesale market, taking into account the direct contracts with generators, and then adding the charge for the use of the transmission system and the charge for the distribution system. Unregulated customers with large demands can bypass the transmission and distribution system and purchase electricity directly through contracts with generators as well as intermediaries (IDB, 2017).

Guatemala is a member of the MER and interconnected to the electricity markets with Honduras and El Salvador. Guatemala is a major exporter on the network, as seen in the net energy exports to MER parameter, 70 percent of the total energy exchanged (Figure 49). In addition, Guatemala is connected to the transmission system in Mexico. Since 2010 Guatemala has imported energy from Mexico, and since 2017 it has also exported energy to Mexico.

Parameter	Unit	Current[1]
Grid interconnection	[%]	7.4
Reserve margin	[%]	132.6
System average interruption duration	[hours]	3,6
Number of smart meters	[number]	2,000
Capacity factor	[%]	32.2
Efficiency	[$/MWh]	49.7
Net energyexports to MER	[Gwh]	1,721.9
Wholesale electricity market	[binary]	Yes
Market liquidity	[%]	30.5
Self-sufficiency	[%]	0.0
Market diversity	[number]	23
Total generation	[GWh]	11,489.9
Total installed capacity	[MW]	4,068.8
Number of electric vehicles	[number]	n.a
Energy mix	[% RE]	68.5
Carbon intensity	[tons CO2/GWh]	91.4
Energy loss	[%]	17.1
GDP energy intensity	[MWh/GDP(mn)]	151.9

[1] Sources and year for current parameters are provided in the appendix.

Figure 49. Current energy parameters in Guatemala

4.3.2 Impact of Global Energy Trends on Guatemala

According to the experts, the trend *increased volatility and supply security* has the highest impact on Guatemala's energy sector with 33 percent giving it a very high and 44 percent a rather high impact (Figure 50). Here, the experts see challenges for Guatemala in the increase in renewable energy capacity as well as in the participation in the regional power market. In addition, transmission losses are a challenge. Current efforts for the expansion of transmission lines are impeded due to social unrest.

Fifty-six percent of the experts see the global energy trend *decentralization and competition* at least as having a rather high impact on Guatemala. Decentralized energy systems are a viable option to provide electricity to the tenth of the population that does not have access to electricity. In terms of competition, Guatemala faces the challenge of overcapacity.

Forty-five percent of the experts attribute *demand increase* a rather high impact or greater. The experts see the need for an increase in demand due to the current oversupply of electricity generation capacity. Experts expect the demand to pick up in the future due to increased residential use of electricity. Electromobility may be another aspect to consider. Furthermore, the transformation of rural population to urban population will result in an increase in individual consumption. In addition, there are efforts by the wholesale market administration to increase energy use.

Emissions reductions is the least impactful trend in Guatemala with 22 percent giving it a very high and 33 percent a rather high impact. Guatemala has a clear policy with commitments to decarbonize the country. Challenges in the decarbonization include the transport sector, a source of many emissions, as well as the coal and diesel-based plants. While these conventional plants provide stability for the grid, they lead to higher emissions. In addition, social conflict leads to a delay as the public sometimes opposes the construction of plants and transmission lines.

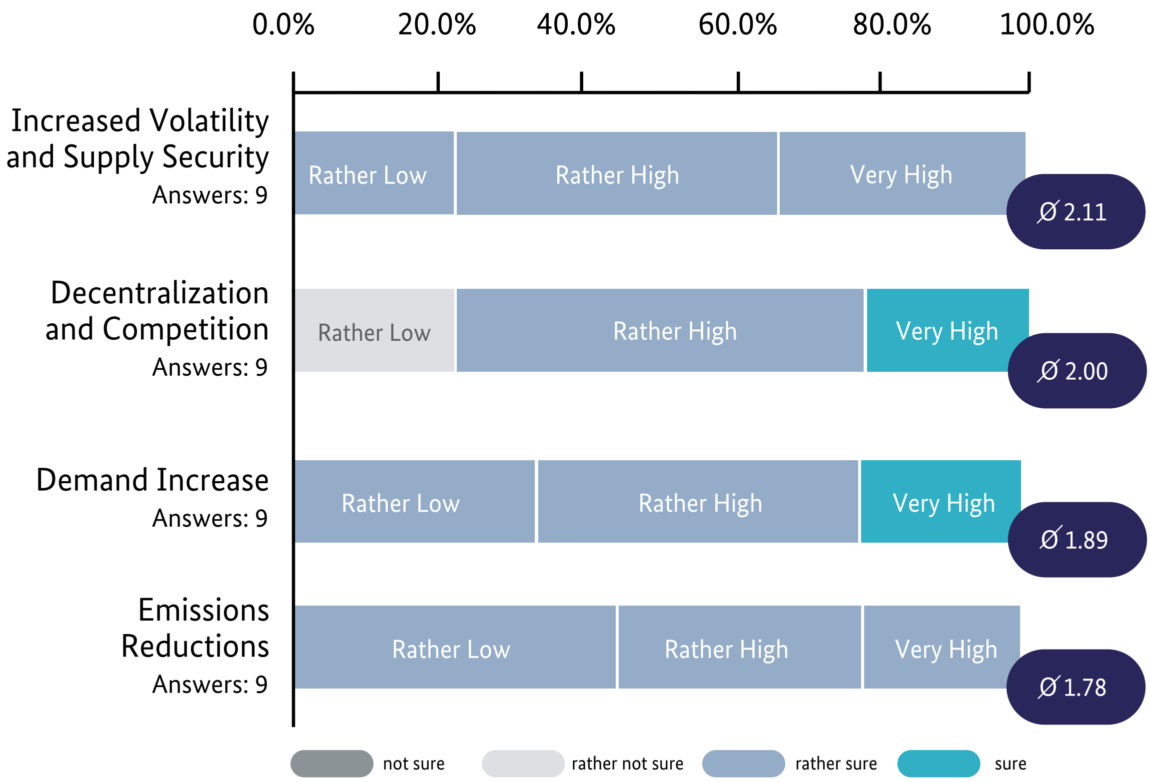


Figure 50. 2030 Global energy trends impact assessment for Guatemala

4.3.3 Outlook and Improvement Areas for Guatemala

Increased Volatility and Supply Security

The global energy trend increased *volatility and supply security* can be observed in Guatemala in the parameter reserve margin (Figure 51). Until 2030, the margin is expected to be between 95 percent to 100 percent, down from 133 percent. This decrease will come through better utilization of current generation capacity, also resulting in an increased capacity factor. The parameter grid interconnection is forecasted to increase from 7.4 percent to around 10 percent. This increase could come from the planned additional circuit of SIEPAC. The system average interruption duration is expected to decrease to around 3.0 hours. This reduction will depend on great extent on the investments from distributor agents into the infrastructure in the countryside.

The experts rate the parameter grid interconnection as having the greatest potential for improvement (Figure 52). The government could invest more political capital in the planned expansion of the second circuit of SIEPAC. This could further improve the stability of the grid as well as increase the amount of net energy exports.

Decentralization and Competition

Self-sufficiency is expected to grow slightly. Currently there is regulation in place that allows for decentralized production. However, for self-producers, although it is not possible to sell the electricity, there is a chance to participate in the net-metering scheme. In its 2019 electrification policy, Guatemala aimed to improve the legal framework for self-generation of electricity through RES. Guatemala aims to address approximately 4,300 electrification projects through INDE. Through 2030, Guatemala wants to guarantee universal access to energy services (MEM, 2019). The experts expect the capacity factor to increase to around 39.5 percent. This increase will be realized through better use of installed capacity. Currently, the generation capacity is not fully utilized. In addition, experts forecast that net energy exports will grow to between 1,960 and 2,350 GWh in 2030 due to the addition of the second circuit to the SIEPAC. While there is no parameter rated as having a high potential for improvement for the trend decentralization and competition, experts think there is a rather high potential for improvement for the parameters market liquidity and self-sufficiency.

Demand Increase

Experts predict that the total demand for electricity will grow to between 17,081 and 17,358 GWh, resulting from growing demand in the residential segment. There are no large capacity additions planned, so the total installed capacity is only expected to grow by between nine and sixteen percent. The increased generation will come from better utilization of the generation capacity. The growth in capacity will mainly come from additions of RES. Experts expect the number of electric vehicles to increase.

Also, the parameter number of electric vehicles shows a high amount of potential improvement from political action. There is a need for government programs to create the required infrastructure.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Grid interconnection	[%]	7.4	10.2	9.8	+2.8 to +2.4	▲ 75%
Reserve margin	[%]	132.6	95.0	100.1	-37.6 to -32.5	▼ 75%
System average interruption duration	[hours]	3.6	3.0	3.0	-16.7% to -17.9%	▼ 89%
Number of smart meters	[number]	2,000	275	8,074	+ 275 to +8,074	▲ 83%
Capacity factor	[%]	32.2	39.5	39.3	+7.3 to +7.1	▲ 63%
Efficiency	[$/MWh]	49.7	60.5	71,2	+22% to +43%	▲ 88%
Net energy exports to MER	[GWh]	1,721.9	1,960.0	2 350,4	+13.8% to +36.5%	▲ 71%
Wholesale electricity market	[binary]	Yes				
Market liquidity	[%]	30.5	35.0	34.3	+4.5 to +3.8	▲ 71%
Self-sufficiency	[%]	0.0	0.6	1.1	+0.6 to +1.1	▲ 75%
Market diversity	[number]	23	26	25	+3 to +2	▲ 75%
Total generation	[GWh]	11,489.9	17,081.0	17,358.5	+48.7% to +51.1%	▲ 100%
Total installed capacity	[MW]	4,068.8	4,450.0	4,713.5	+9.4% to +15.8%	▲ 75%
Number of electric vehicles	[number]	n.a	1,000	67,433	+900 to +67,333	▲ 100%
Energy mix	[% RE]	68.5	75.0	74.4	+6.5 to +5.9	▲ 88%
Carbon intensity	[tons CO2/GWh]	91.4	82.7	95.8	-9.5% to +4.9%	▼ 67%
Energy loss	[%]	17.1	13.0	13.9	-4.1 to -3.1	▼ 88%
GDP energy intensity	[MWh/GDP(mn)]	151.9	140.0	141.2	-7.9% to -7.1%	▼ 100%

1.Sources and year for current parameters are provided in the appendix.

2.Based on the median 2030 forecast provided by the experts.

3.Weighted average including the confidence of the assessment.

4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.

5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend
- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 51. Energy parameters in Guatemala by 2030

Emissions Reductions

The trend emissions reductions can be observed in the parameter energy mix. Experts forecast that the share of renewable energy will increase to around 75 percent by 2030. While there were already auctions for renewables in 2014, in February 2019 the electricity company of Guatemala announced three tenders for the supply of energy with an auction for solar in May 2019 (Bellini, 2019).

Experts predict that energy loss will decrease from seventeen percent to between thirteen and fourteen percent. Here, the challenges are technical and non-technical losses due to bad transmission lines and ongoing energy theft. The decrease in technical losses partly depends on investments in the distribution networks, especially in the interior areas of the country. For these, private companies were assigned through a tender process. Nevertheless, this development is partially challenged by social conflicts, originating from construction projects. Energy loss and GDP energy intensity are estimated to have a high level of potential to improve through political action. The government could take action by attracting investment in the grid infrastructure or expanding decentralized electricity production.

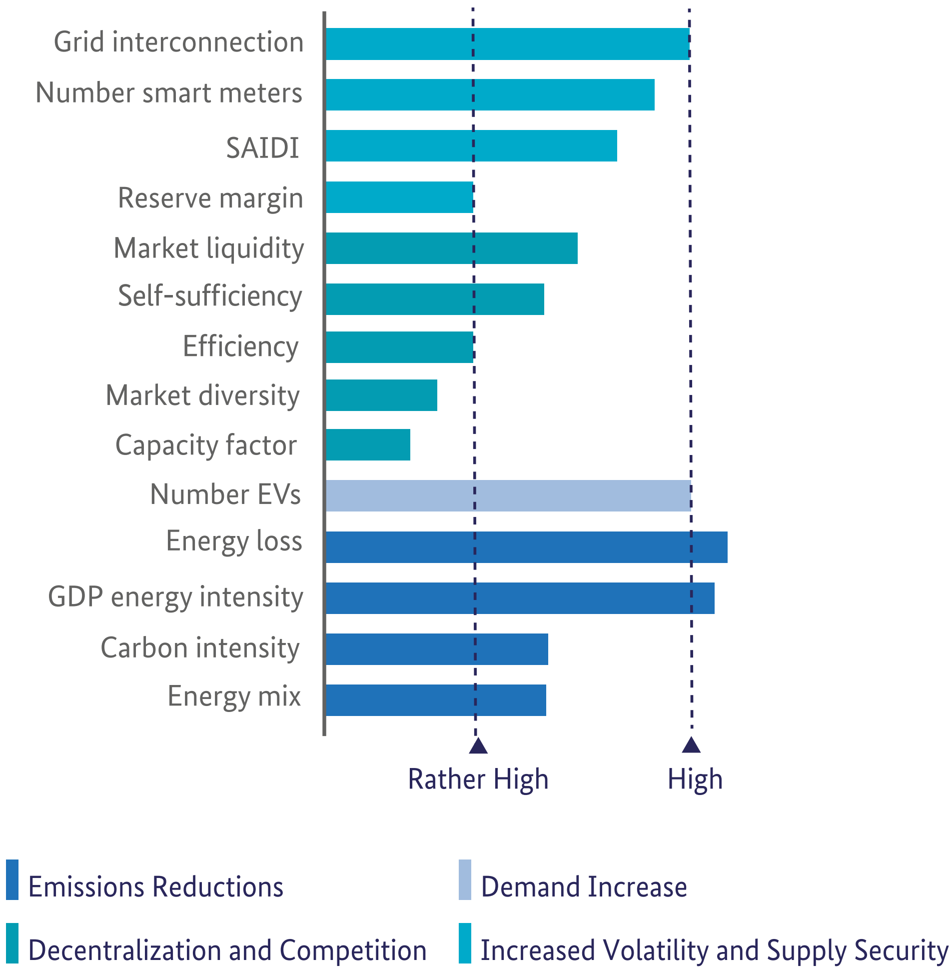


Figure 52. Improvement potential of energy parameters until 2030 in Guatemala

4.3.4 Enabling Framework Conditions in Guatemala

Digital technologies have the potential to help overcome some of the challenges that arise from global trends; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section indicates the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.
Guatemala's overall digital readiness is lanced by opposites within the respective framework conditions. Digital infrastructure is advanced in urban areas but lacking in rural ones. The private sector is pushing digitalization, whereas the public sector resists change. While both human and financial capital is available in general, transference into the digital context is a challenge due to a lack of specific knowledge. Thus, Guatemala is only partly digitally ready (Figure 53).

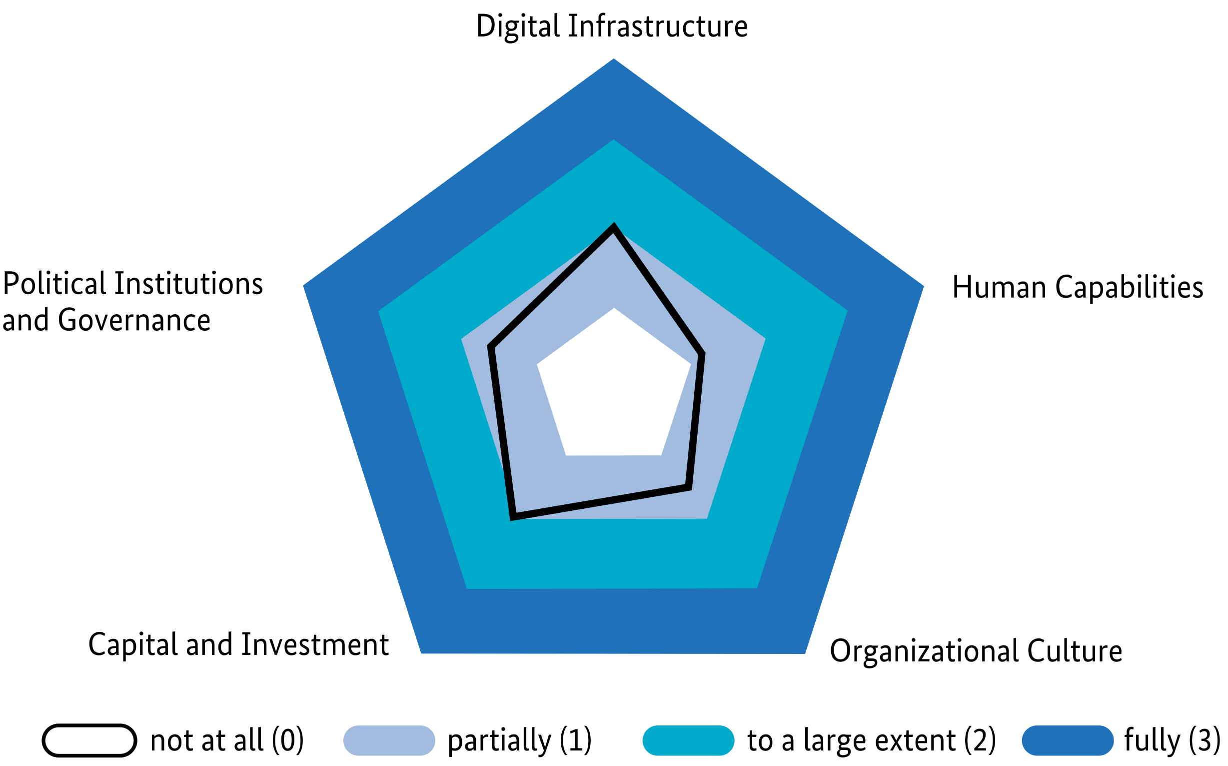


Figure 53. Availability of framework conditions in Guatemala

Digital Infrastructure

In Guatemala, while overall the digital infrastructure is considered to be enabling (Figure 54), there is a significant difference between rural and urban areas. On the one hand, digital infrastructure in urban areas is advanced, with good access to broadband and the deployment of smart meters. Since 2008, there is a strategic approach towards digital infrastructure with the government involved such as the development of a fiber optic ring.

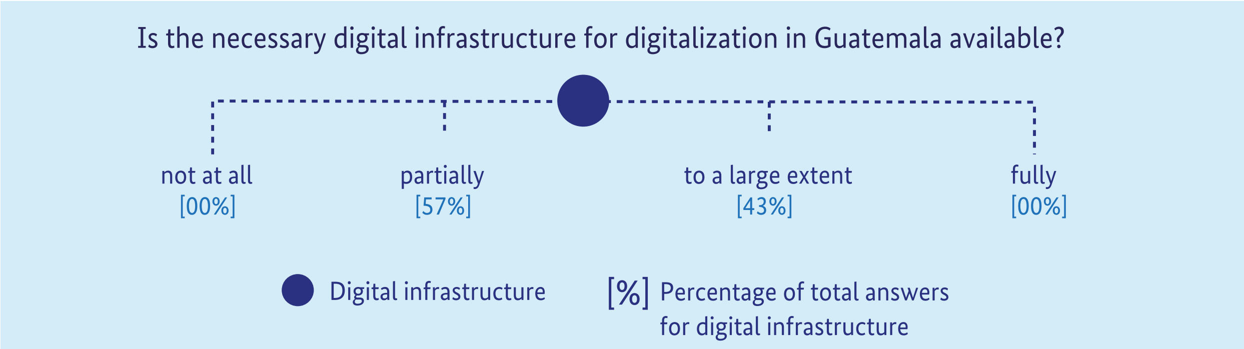


Figure 54. Digital infrastructure in Guatemala

On the other hand, rural areas are significantly less advanced. Although there are ongoing governmental efforts, rural electrification remains a problem. Many rural areas are not connected, and where they are, the connection can be unstable with low bandwidth due to satellite connections instead of fiber optics. As a result, connecting generation plants in rural areas is costly.

Digital Infrastructure in Guatemala: Recommendations from Country Experts

- Increase bandwidth and facilitate internet access
- Electrify rural areas (e.g. through development of micro-grids)
- Establish connections throughout rural areas using innovative technologies (e.g. network providing balloons).

Human Capabilities

Regarding human capabilities, there is a discrepancy in the experts' assessments, with the majority leaning towards limited availability (Figure 55). The experts with opposing opinions refer to a small group of people with digital knowledge. General academic knowledge is available, with a few adapted programs offered by universities, such as programs on data science, but lacks vision on the potential.

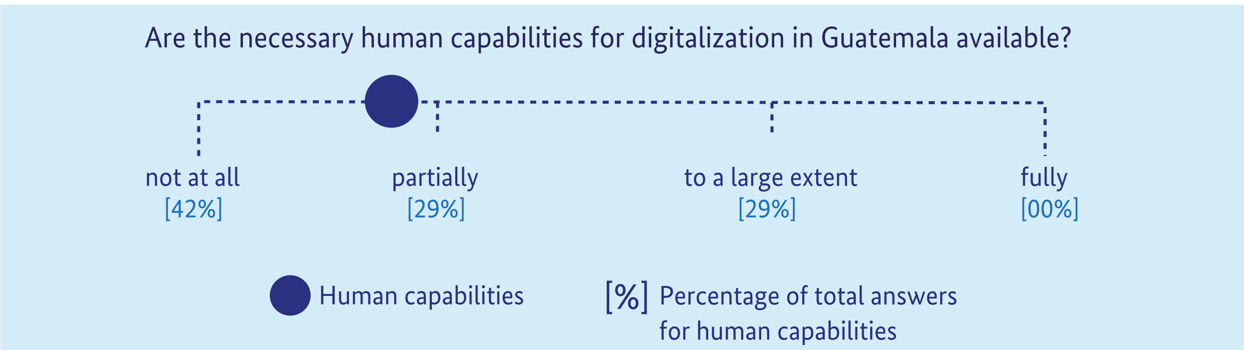


Figure 55. Human capabilities in Guatemala

Hence, there is a strong need for specific technological knowledge. Currently there is only unguided niche research available; therefore, implementation know-how is an issue. With limited access to new technologies, knowledge transfer from educated academics is slow. Although some companies have employee capacity building mechanisms institutionalized, they are seldom directed towards digitalization topics due to a general lack of digital knowledge throughout the companies.

Human Capabilities in Guatemala: Recommendations from Country Experts

- Institutionalize digital capacity building in companies, especially for higher management
- Start collaboration between companies and academia on digital topics
- Enhance cross-country exchange, including best practices in other countries
- Create learning journeys to transfer existent human capital to technology potential.

Organizational Culture

The organizational culture in Guatemala differs substantially between the public and private sector, as indicated by the spread in the experts' answers (Figure 56). In private companies, the culture embraces digitalization, with institutionalized innovation concepts, pilot implementations, and the promotion of smart meters and electric vehicles. Still, there is a general tendency in family owned companies to be more conservative.

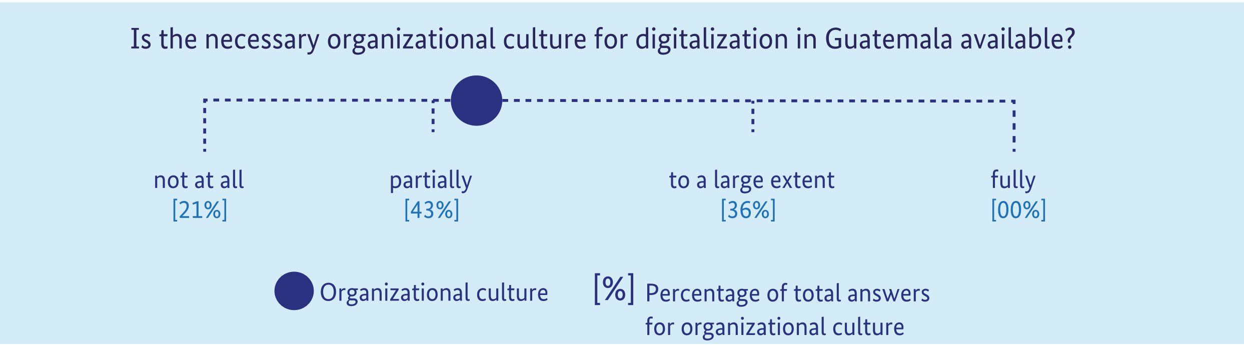


Figure 56. Organizational culture in Guatemala

The public sector does not yet embrace digitalization. State-run companies can be limited by bureaucracy, resistance to change, and weak institutional efforts towards digitalization. While there are some laws[8] promoting digitalization, adherence is not given by default.

Organizational Culture in Guatemala: Recommendations from Country Experts

- Sensitize middle and upper management and technical departments in public companies through exchange or information and ideas
- Promote pilot projects in public sector to promote cost-benefit understanding
- Identify use cases to increase tangibility and knowledge development.

[8] Law for the Recognition of Communications and Electronic Signatures (National Center for Judicial Analysis and Documentation, 2008)

Capital and Investment

Financial resources for larger corporations are generally available in Guatemala (Figure 57). Internal funds in both private and public companies are sufficient, with excess generation capacity installed allowing for regional electricity exports. External financing is provided by the financial sector, offering loans and digital payment methods.

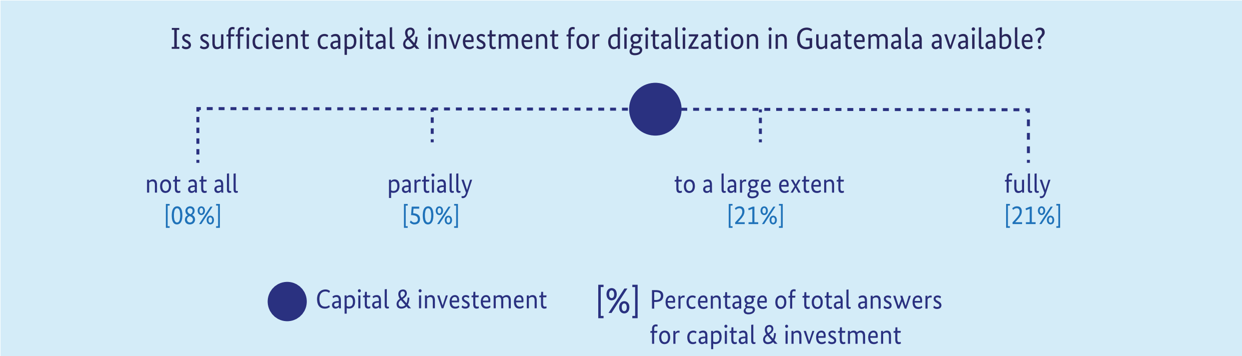


Figure 57. Capital and investment in Guatemala

However, it is important to note that financial funding for digital topics is less available. The problem is that funders have insufficient knowledge on the precise application, risk, and cost-benefit of digital technologies. Companies seeking funding have trouble articulating precise business cases, hence financial entities direct capital towards areas they understand better. In addition, startups receive little support from banks, where a conservative mindset prevails.

Capital and Investment in Guatemala: Recommendations from the Country Experts

- Standardize and institutionalize cost-benefit analyses in cooperation with financial entities
- Develop dedicated digital technology funds
- Increase recognition of startups, for example, through governmental and non-governmental organization support in financing pilot programs
- Assess other technology business models, such as leases instead of purchases.

Public Institutions and Governance

Experts suggest that enabling policies and regulatory measures are partially in place (Figure 58). Guatemala has a well-organized electricity market, with an institutionalized process for adaptations through the regulator. The ministry sets indicative rather than normative policies, the regulator provides the framework, and the market administrator represents the market players. A law on government modernization accounting for digitalization is currently under development, and it is possible to feed in privately produced energy, although only to consume it later, and not for selling purposes.

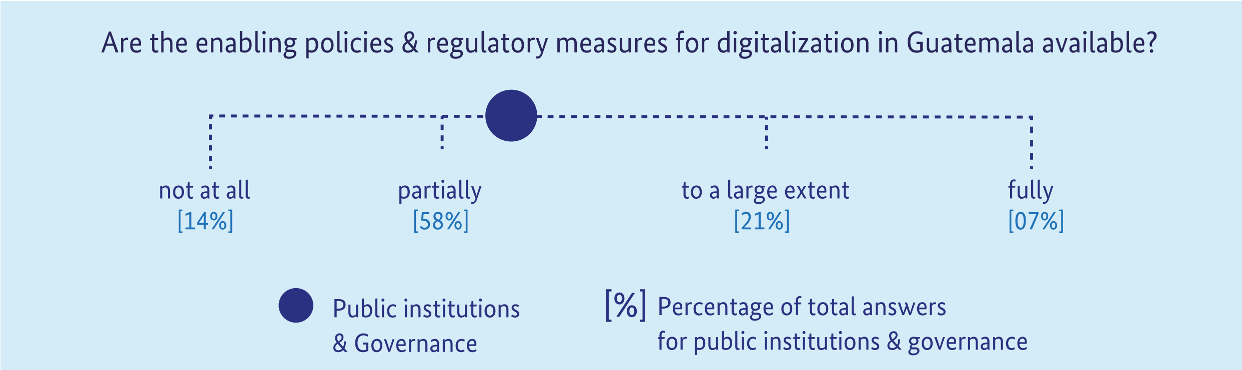


Figure 58. Public institutions and Governance in Guatemala

Still, in spite of good regulation of the electricity sector in general, there is a vacuum for regulation of digitalization. Due to a lack of knowledge, the regulator is reactive to the private sector rather than proactive and has yet to adapt to digital necessities; for example, regulator has not yet considered prepaid regulation for electricity. While the law on electricity allows for technological developments, the 2018 national plan does not consider these. This juridical lack of certainty and regulation in turn slows down investments overall.

Public Institutions and Governance in Guatemala: Recommendations from Country Experts

- Provide laws and norms on standards, security, and privacy
- Increase knowledge on digital technologies, especially within government and regulator
- Create incentive framework for deploying technology on a governental level
- Facilitate FDIs for technology companies
- Foster exchange between market participants and government.

4.3.5 Digital Technology Use Cases in Guatemala

Of the use cases identified for this study (Appendix 9), experts explicitly addressed thirteen during the interviews. The experts focused on use cases especially relevant within the *increased volatility and supply security* trend (Figure 59), estimated to be the most impactful global energy trend on the energy sector in Guatemala within the next years.

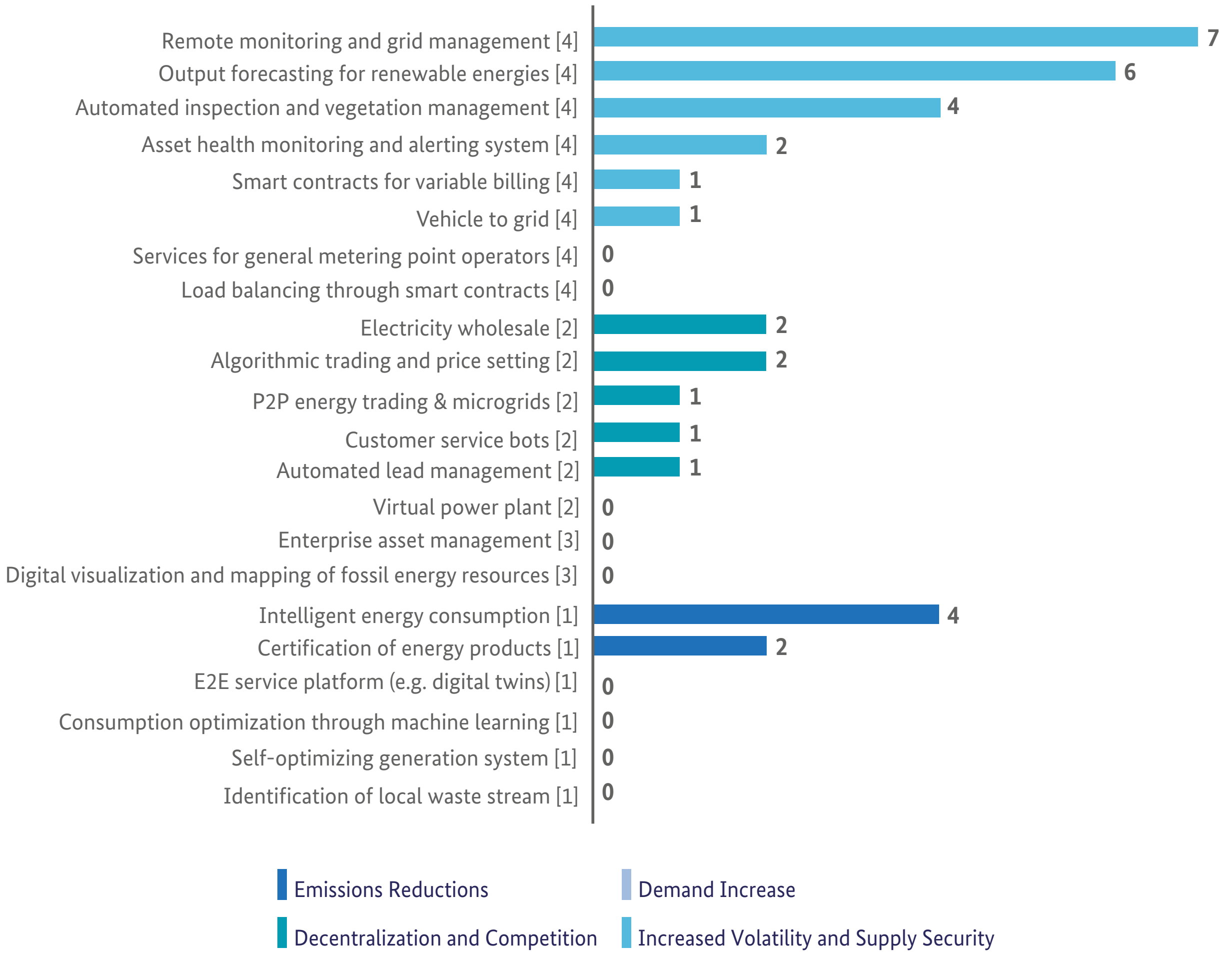


Figure 59. Addressed use cases in Guatemala

Remote monitoring and grid management was the most prominent use case that experts addressed (seven experts), followed by output forecasting for RE (addressed by six experts), automated inspection and vegetation management (addressed by four experts), and intelligent energy consumption (addressed by four experts). Experts' perceived relevance of each use case is presented in Figure 60.

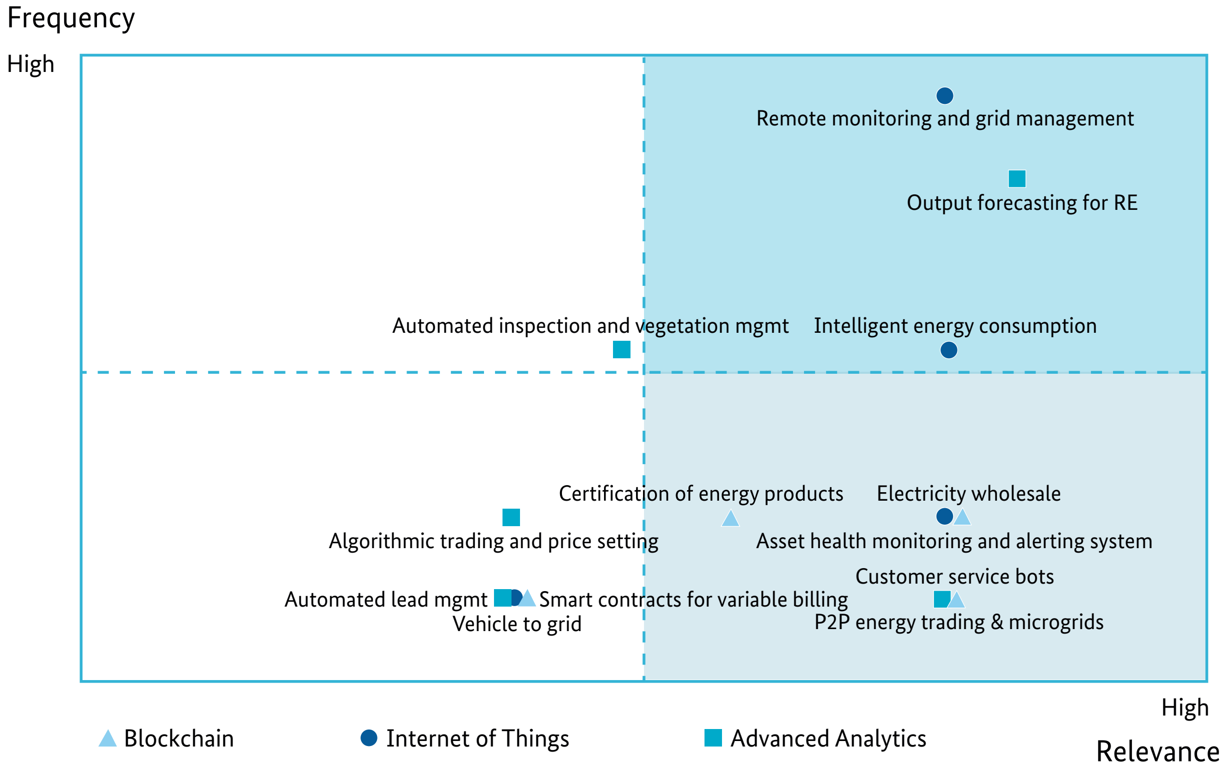


Figure 60. Use case assessment by relevance and frequency in Guatemala

Of the top ten use cases that were addressed, the top five sorted by relevance are highlighted in bold, spanning across the whole value chain as can be seen in Figure 61.

Emissions Reductions	1 Certification of energy products; 4 Self-optimizing generation system; 7 Identification of local waste streams; **17 Intelligent energy consumption**; 19 E2E service platform (e.g. digital twins); 22 Consumption optimization through ML
Decentralization and Competition	2 Virtual power plant; 8 P2P Energy trading and micrgrids; **10 Electricity wholesale**; 11 Algorithmic trading and price settings; 20 Automated lead management; 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER; 9 Enterprise asset management
Increased Volatility and Supply Security	3 Asset health monitoring and alerting system; **5 Output forecasting for RE**; 12 Load balancing through smart contracts; **13 Remote monitoring and grid management**; 14 Vehicle to grid; **15 Automated inspection and vegetation management**; 16 Smart contracts for variable billing; 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain | Internet of Things | Advanced Analytics[1]

Figure 61. Priority use cases in Guatemala

Digital Technology Use Cases in Guatemala

- **P2P energy trading & microgrids:** non-Blockchain based pilots in development
- **Intelligent energy consumption:** pilots with sensors in fast food chains in implementation
- **Automated inspection and vegetation management:** drones in use for substations, but not automated
- **Output forecasting for RE:** highly relevant as currently high mismatch between forecast and actual outcome (lack of measuring stations)
- **Remote monitoring and grid management:** SCADA systems in place.

Honduras

4.4 Honduras

Key Takeaways for Honduras

- The electricity market in Honduras is still in a transition phase. The vertical integrated government owned company ENEE is in the process of unbundling.
- For the electricity system in Honduras, experts considered the global energy trend *increased volatility and supply security* as having the greatest impact through 2030.
- This impact is reflected in the parameter estimations, including, e.g. the increase in grid interconnection to between 19.2 and 20.0 percent until 2030.
- With respect to the enabling framework conditions for digitalization:
  - Experts consider *digital infrastructure* as the most enabling, but there is a strong need for policies and regulation with respect to both digital and non-digital topics within the energy sector.
  - Due to high energy losses in transmission and distribution thereis limited financial capital within public companies.
- Concerning prospective digital technologies and use cases, experts mentioned thirteen as potentially relevant as country-specific challenges, with the top five spanning across the electricity value chain, and the top one being *electricity wholesale* based on blockchain.

4.4.1 General Information about Honduras

Honduras is located north of Nicaragua, shares a border with El Salvador in the west and Guatemala in the northwest (Figure 62). In terms of *population, society and technology,* Honduras has experienced a growth of fifteen percent in its population together with an increasing life expectancy at birth since 2009. Both changes as well as the slight decrease in income equality among Honduras' citizens have led to an overall improvement of the country's position in the Human Development Index. In addition, the internet penetration and access to electricity have increased strongly, both by around nine percent (Figure 63).

Considering *political, regulatory and legal* matters, Honduras actively implements legal incentives for RE, e.g. tax exemptions and priority dispatch, aiming to achieve 70 percent of generation from clean energy by 2020 (Figure 63).

Figure 62. Map of Honduras

With respect to Honduras's *economic and environmental* matters, gross GDP have increased by 57.5 percent and GDP per capita has increased by 16.3 percent. This development comes with an increase in CO2-emissions of 4.3 percent. Honduras inflation rate has decreased to 3.9 percent. However, unemployment has increased and reached 4.5 percent (Figure 63).

Population, Social and Technological		
- Inhabitants, 2017 (2009):	9.27 (+15.3%)	[Mn]
- Life expectancy at birth, 2017 (2009):	73.6(+1.8%)	[Years]
- GINI coefficient, 2014 (2009):	50.4 (-1.8%)	[number]
- Human dev. index, 2017 (2009):	0.62 (+4.4%)	[number]
- Internet penetration, 2016 (2009):	30 (+206%)	[%]
- Access to electricity, 2016 (2009):	87.6 (+11.9%)	[%]
- Average price of 1GB mobile data 2018:	5.02	[USD]
Political, Regulatory, and Legal		
- Government: Presidential republic		
- Democracy Index (2017): 5.72		
- Legal incentives for renewable energy production (tax exemptions, priority dispatch), by 2038 80% of generation from clean energy		
Economic and Environmental		
- GDP 2017, (2009):	22.98 (+57.5%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	4,542 (+16.3%)	[USD]
- Unemployment rate, 2017 (2009):	4.5 (+36.4%)	[%]
- Inflation, 2017 (2009):	3.9 (-28.4%)	[%]
- CO_2- emissions p.c., 2017 (2009):	1.07 (+4.3%)	[tons]

Figure 63. Profile of Honduras

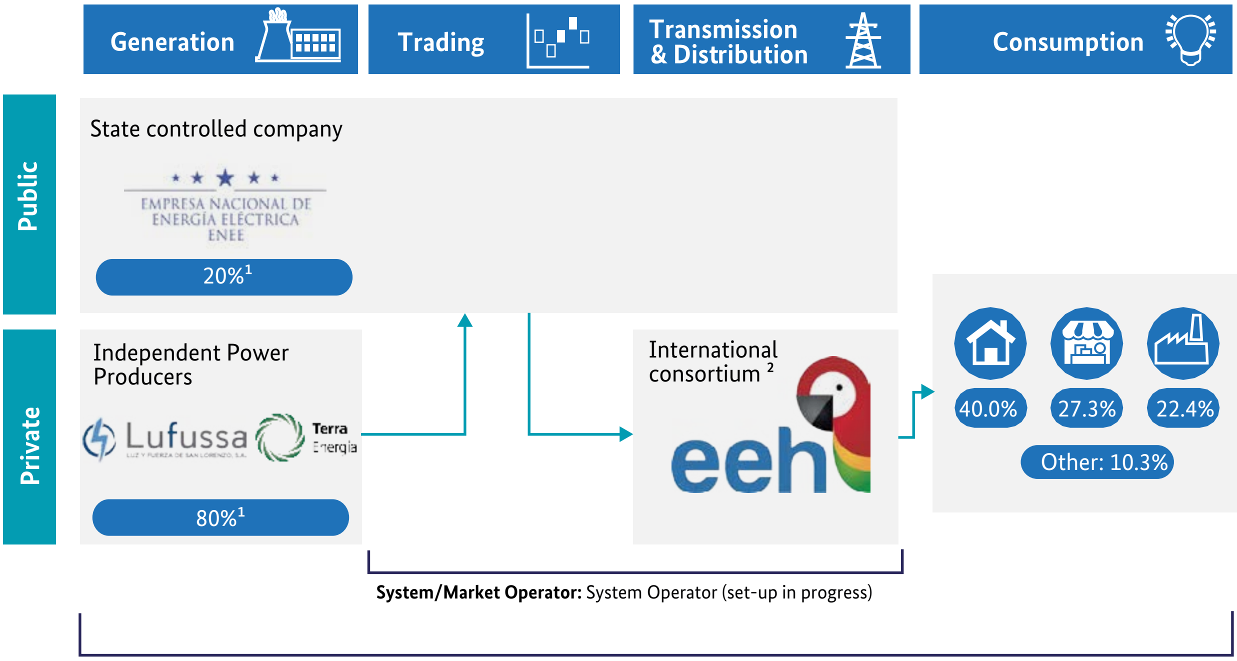
The State Secretariat in the Dispatch of Energy[9] (SEN, for its acronym in Spanish) is responsible for making energy policy (Figure 64). In 2010, Honduras published its National Vision plan 2010-2038, setting goals for the share of RES in the electricity mix of 50 percent by 2017, 60 percent by 2022 and 80 percent by 2034 (Presented for consideration by the Sovereign National Congress, 2010). These plans were made more concrete through the law for the promotion of electric power. That law aims to facilitate investment in RES, increases in the efficiency of the national grid through increased distributed generation, and increasing the number of market players (SERNA, 2007). Policy-makers extended their support for renewables through the new law of electrical industry, where they established–among others–auctions for renewable energy and net metering (SERNA, 2014).

The energy market in Honduras is currently in a transition phase (Figure 64). The electricity market is mainly controlled and led by the National Electric Energy Company (ENEE, for its acronym in Spanish). Before the reforms, ENEE was in charge of the generation, transmission, and distribution of electricity. In 1994, a law was passed allowing private companies to generate electricity and sell it to ENEE (National Congress, Republic of Honduras, 1994).[10]

Today, independent power producers provide up to 80 percent of the generation capacity in Honduras (Steward Redqueen, 2018). In 2014, a new law was passed to unbundle the electricity sector. While it states that ENEE should be split into several companies for generation, transmission, and distribution, it has yet to happen. The law created the Electric Energy Regulatory Commission (CREE, for its acronym in Spanish) in charge of the regulation of the electricity sector. In addition, the law created the System Operator (ODS, for its acronym in Spanish), who is responsible for managing the wholesale market (SERNA, 2014). Neither the wholesale market nor the ODS are fully operational yet. Since 2016, the distribution system was transferred to Hondurean Energy Company (EHH, for its acronym in Spanish) through a public-private partnership contract.

[9] SERNA was formerly in charge of energy policy in Honduras. In 2017 SEN was set to be the governing institution responsible for the national electricity sector and regional and international energy integration.

[10] There are several electricity generation companies, including San Lorenzo Light and Power Public Limited Company (LUFUSSA) with a capacity of 390 MW (LUFUSSA, 2019) as well as Terra Energia with 281.7 MW (Terra Group, 2019).



Regulator: Electric Energy Regulatory Commission (CREE)
Policy-making entity: State Secretariat in the Dispatch of Energy (SEN)

[1]Share in generation capacity
[2]EEH only covers distribution

Figure 64. Electricity market structure in Honduras

The new company is now responsible for the operation of the national distribution system, energy control, and commercialization of electrical energy (EEH, 2019). CREE sets electricity prices. The electricity price in 2017 for residential customers was approximately USD 0.138 per kWh, for commercial customers USD 0.163 per kWh and for industrial customers USD 0.118 per kWh (ECLAC, 2018). The price includes the cost incurred in generating power, transmission costs, and system operation costs.All of these components are calculated every three years with the distribution cost calculated every five years (Latin Lawyer, 2017).

Honduras is a member of the MER and is interconnected to Guatemala, El Salvador, and Nicaragua. Honduras imports 13 percent of the energy exchanged (Figure 65).

Parameter	Unit	Current[1]
Grid interconnection	[%]	10.5
Reserve margin	[%]	64.8
System average interruption duration	[hours]	257.0
Number of smart meters	[number]	90,000
Total generation	[GWh]	9,345.6
Total installed capacity	[MW]	2,571.2
Number of electric vehicles	[number]	n.a
Capacity factor	[%]	41.5
Efficiency	[$/MWh]	51.7
Net energy exports to MER	[GWh]	-318.4
Wholesale electricity market	[binary]	No
Market liquidity	[%]	-
Self-sufficiency	[%]	0.0
Market diversity	[number]	1
Energy mix	[% RE]	58.2
Carbon intensity	[tons CO2/GWh]	104.9
Energy loss	[%]	36.0
GDP energy intensity	[MWh/GDP(mn)]	406.7

[1] Sources and year for current parameters are provided in the appendices.

Figure 65. Current energy parameters in Honduras

4.4.2 Impact of Global Energy Trends on Honduras

The most impactful global energy trend in Honduras is *increased volatility and supply security.* Thirty percent of experts estimate it will have a very high and 60 percent a rather high impact on the energy system (Figure 66). Honduras faces the challenges of a high share of VRE–sixteen percent. These sources pose a challenge to the electricity system due to their fluctuation and impact on the transmission lines. Also, transmission losses prove a challenge, especially to ENEE who has to bear the majority of the cost and cannot transfer them to the end customers. The distance between the power generation units and the consumption leads to a congestion of the transmission lines.

Demand increase is the second most important trend in Honduras. Eighty percent of the experts see at least a rather high impact on the energy system. Honduras will face increased demand due to growth of the population and continuing electrification. This growth will be balanced with the increase of energy efficiency efforts, which are driven by the industry. At the moment, ENEE faces the challenge of slight overproduction.

Decentralization and competition is seen as the third most impactful trend, with 20 percent of experts assigning it a very high and another 50 percent a rather high impact on the energy system. The ongoing restructuring of the electricity industry through the unbundling of ENEE and the facilitation of a wholesale market constitutes a challenge for the country. The lack of a wholesale market hinders competition.

Emissions reductions is rated as the least impactful GET, albeit 30 percent of the experts still attribute a very high impact to it. The trend is evident in the government policy's aim to diversify the energy matrix. According to the experts, the country is highly vulnerable to climate change. In 2017, Honduras ranked as the second most affected country by climate change in the world between 1998 and 2017 (Eckstein, Hutfils, & Winges, 2018).

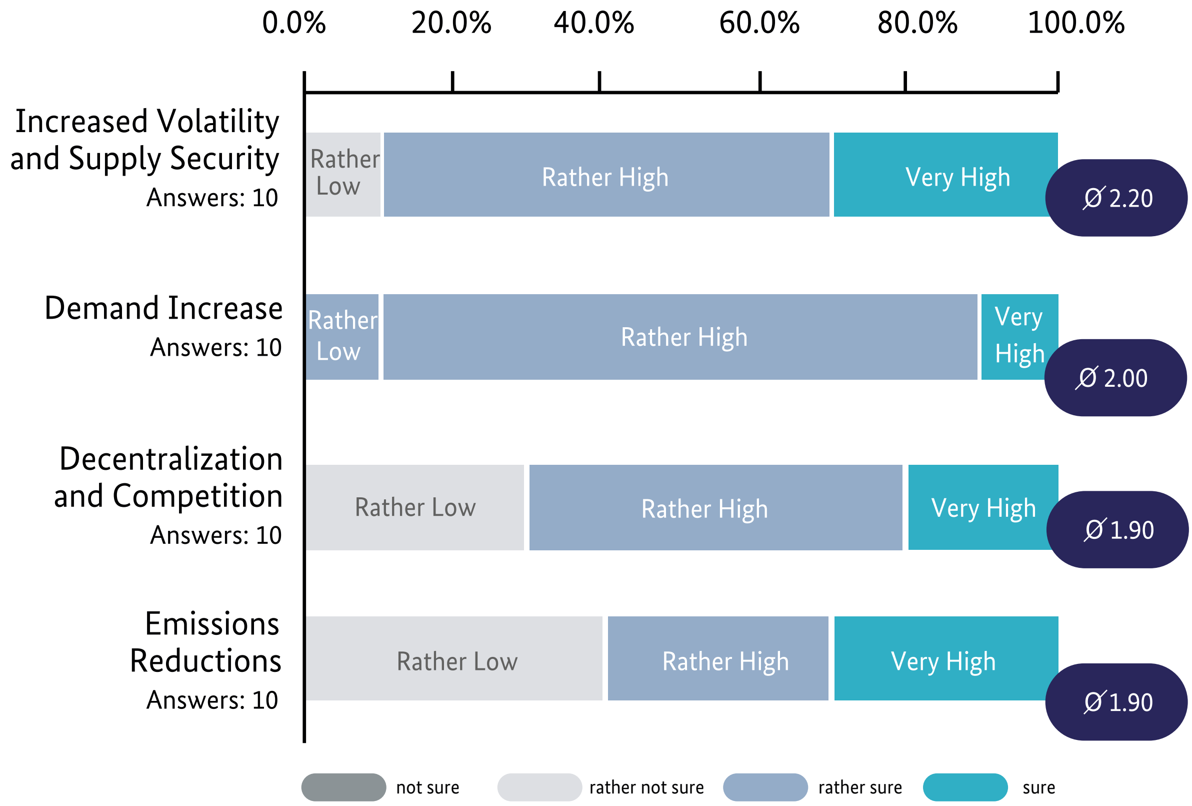


Figure 66. Global energy trends impact assessment in Honduras by 2030

4.4.3 Outlook and Improvement Areas for Honduras

Increased Volatility and Supply Security

The impact of the trend towards increased volatility and supply security can be seen in the increase of the parameter grid interconnection. Experts forecast that grid interconnection will almost double to between nineteen and 20 percent (Figure 67). The increase is due to planned investments in the second circuit of the SIEPAC network. The system average interruption duration (SAIDI) is projected to decrease to between 120 and 112 hours. According to the experts, this immense decrease will come from investments in the generation and transmission infrastructure as well as the application of new technologies (e.g., monitoring of electrical variables). In addition, it is expected that the system regulator and operator will also positively influence the system average interruption duration once fully operational. The number of smart meters is expected to increase to between 250,000 to around 400,000. This increase will come from investments and the requirement to install smart meters beyond a certain monthly energy use.

The parameters number of smart meters and SAIDI both have high levels of potential improvement through political action (Figure 68). Government regulations and programs to increase the required number of smart meters could be a strategy, as well as a focus on grid maintenance.

Demand Increase

The global energy trend can be observed in the expected increase of the total generation and installed capacity. The total generation is expected to increase to around 15,000 GWh per year and the capacity to between 3,790 MW and 3,924 MW. This increase will mainly depend on private investments, which can be seen in the already 80 percent privately owned generation capacity (Steward Redqueen, 2018). The increase of the demand will depend on the economic growth as well the structural development.

The number of electric vehicles is expected to increase to only marginally grow under current conditions. However, this parameter has a rather high level of potential to improve from political action. A reliable and broad infrastructure of EV chargers is necessary for the adoption of EVs. Here, the government could have a high impact through the implementation of regulation.

Decentralization and Competition

The parameter self-sufficiency is expected to increase to between four and ten percent. This increase stems from the recent regulations from 2014 allowing prosumption. Experts expect that projects such as the self-consumption plant near San Pedro Sula with 2 MW capacity will contribute to this increase (Molina, 2018). An increase in decentralization could also reduce energy losses as well as the SAIDI. The experts agree that in 2030 there will be a wholesale market for electricity. This depends on the implementation of the unbundling law and the execution in breaking up ENEE. The capacity factor will increase to between 45.0 and 50.1 percent. This can be explained by the better use of the current power generation facilities.

The parameter wholesale electricity market and energy efficiency both have the greatest potential to improve from political action. For the full implementation of the wholesale electricity market, the government needs to put more commitment into realizing the project.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Grid interconnection	[%]	10.5	20.0	19.2	+9.5 to +8.7	▲ 86%
Reserve margin	[%]	64.8	35.0	37.1	-29.8 to -27.6	no consensus
System average interruption duration	[hours]	257.0	120.0	112.8	-53.3% to -56.1%	▼ 100%
Number of smart meters	[number]	90,000	250,000	407,143	+160,000 to +317,143	▲ 100%
Total generation	[GWh]	9,345.6	15,000.0	15,037.6	+60.5% to +60.9%	▲ 100%
Total installed capacity	[MW]	2,571.2	3,790.0	3,924.8	+47.4% to +52.6%	▲ 90%
Number of electric vehicles	[number]	n.a	200	327	+100 to +227	no consensus
Capacity factor	[%]	41.5	45.0	50.1	+3.5 to +8.6	▲ 78%
Efficiency	[$/MWh]	51.7	60.3	61.2	+17% to +18%	▲ 75%
Net energy exports to MER	[GWh]	-318.4	-187.0	-37.4	41.3% to 88.3%	no consensus
Wholesale electricity market	[binary]	No				Yes 100%
Market liquidity	[%]	-				
Self-sufficiency	[%]	0.0	4.0	10.3	+4.0 to +10.3	▲ 100%
Market diversity	[number]	1	2	6	+1 to +5	no consensus
Energy mix	[% RE]	58.2	72.5	73.7	+14.3 to +15.5	▲ 100%
Carbon intensity	[tons CO2/GWh]	104.9	87.5	82.3	-16.6% to -21.6%	▼ 100%
Energy loss	[%]	36.0	16.5	16.2	-19.5 to -19.8	▼ 100%
GDP energy intensity	[MWh/GDP(mn)]	406.7	350.0	347.4	-13.9% to -14.6%	▼ 86%

1.Sources and year for current parameters are provided in the appendix.

2.Based on the median 2030 forecast provided by the experts.

3.Weighted average including the confidence of the assessment.

4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.

5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend

- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 67. Energy parameters in Honduras by 2030

Emissions Reductions

The trend emissions reductions is reflected in the development of the parameter share of RES in the energy mix. The share is projected to increase to between 72.5 and 73.7 percent by 2030. The experts suggest that Honduras is on track to reach 80 percent from RES by 2038. This increase comes amid a government strategy to increase share of RES with concrete goals. Government incentives for renewables have included a feed-in tariff that led to an increase of 388 MW of solar capacity in 2015[11] (López, 2017). The GDP carbon intensity is expected to decrease to between 87 and 82.3 tons CO2 per GWh. This decrease of between 16.6 and 21.6 percent comes from the addition of renewable energies in the electricity production. Additionally, the parameter energy loss is expected to be cut in half to around sixteen percent according to the experts. The Hondurean Energy Company (EEH, for its acronym in Spanish), which is commissioned by ENEE to solve the energy loss problem, targets a decrease of losses of four percent annually. This decrease will come through investments in the transmission and distribution system that challenges the technical loses. The non-technical losses need to be challenged through the prevention of energy theft and the implementation of functioning billing mechanisms.

Both energy loss and energy mix have high potential for improvement from political actions. Experts assume that legislation could decrease the non-technical energy losses. Policy-makers could promote the addition of more renewables through incentives, focusing on non-monetary incentives in order to avoid straining governmental budgets (e.g., reduction of regulatory barriers).

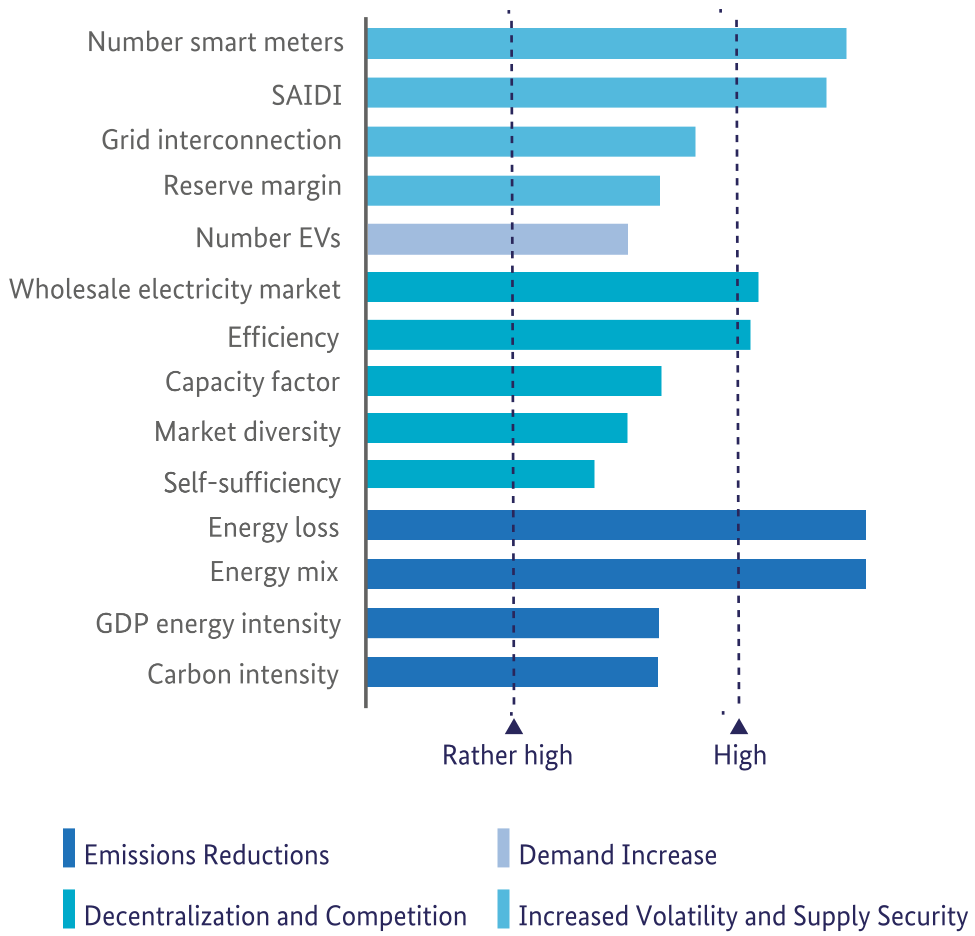


Figure 68. Improvement potential for energy parameters until 2030 in Honduras

[11]This incentive is structured as a "premium" at a rate of USD 0.03/ kwh.

4.4.4 Enabling Framework Conditions in Honduras

Digital technologies have the potential to help overcome some of the challenges that arise from global trends; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section indicates the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.

As illustrated in Figure 69, Honduras's energy sector is facing challenges that should be addressed in order to proceed with its digitalization. While in general, digital infrastructure in urban areas and human capabilities are assessed to be digitally enabling, there is a strong need for regulation not only regarding digital technologies but also to payment and measurement of energy consumption. Moreover, especially within the public sector, there is a lack of capital and investment.

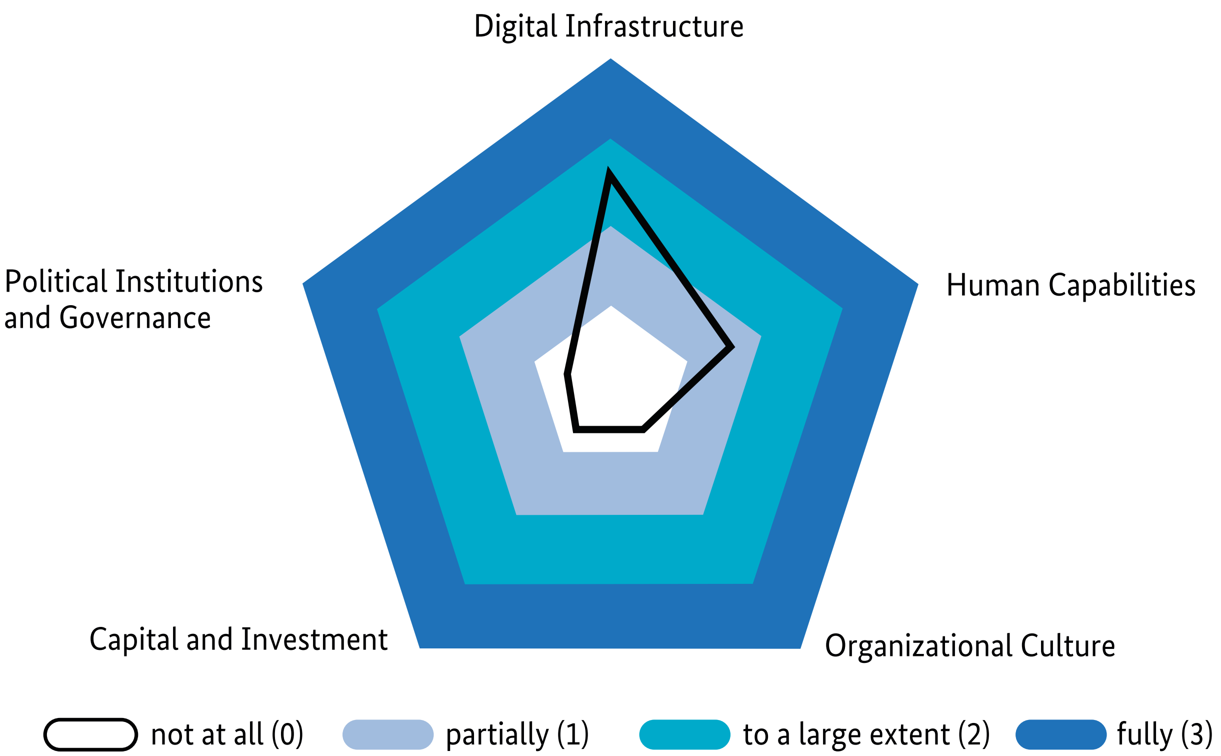


Figure 69. Availability of framework conditions in Honduras

Digital Infrastructure

Digital infrastructure in Honduras is considered to be enabling (Figure 70). Smart meters are currently being deployed, with distributed generators and large consumers already having them installed. Georeferencing of fiber optic transmission lines is targeted through a project, and the access of private companies to broadband is very good.

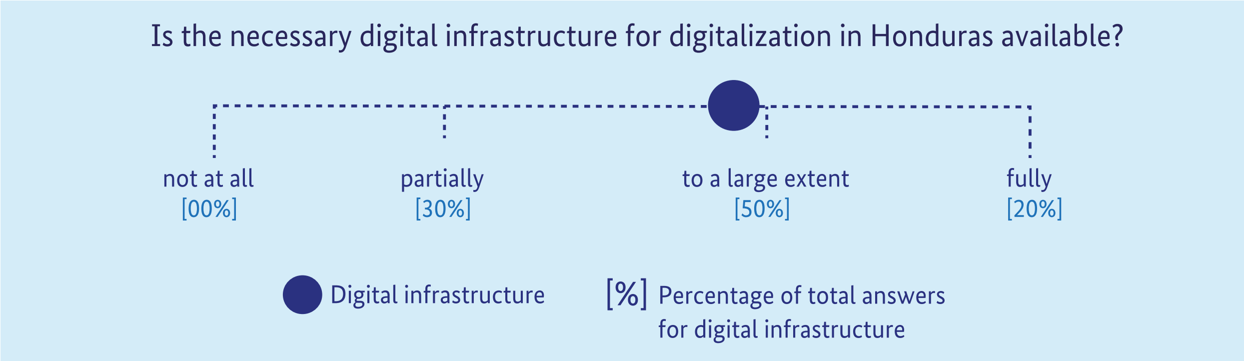


Figure 70. Digital infrastructure in Honduras

However, it is important to note that while the above mentioned applies to urban areas, rural areas are significantly less advanced - thirteen percent of the population lacks electrification. In recent decades, investments and maintenance have rarely been awarded to basic infrastructure in rural areas, resulting in weak transmission lines and robustness of the grid; for example, the injection of solar energy from prosumers and larger scale PV generation plants has already caused instability problems.

Digital Infrastructure in Honduras: Recommendations from Country Experts

- Electrify rural areas (e.g. through development of micro-grids)
- Formulate binding smart metering strategy
- Specify infrastructural requirements based on digital use cases
- Increase network speed (e.g. by supplying affordable high-speed broadband capacity)
- Establish connections throughout rural areas using innovative technologies (e.g. network providing balloons).

Human Capabilities

Human capabilities are partially in place in Honduras (Figure 71). It is generally agreed upon that basic knowledge is prevalent, with expertise on programming and databases available and sufficient capacity for further development of those national capabilities.

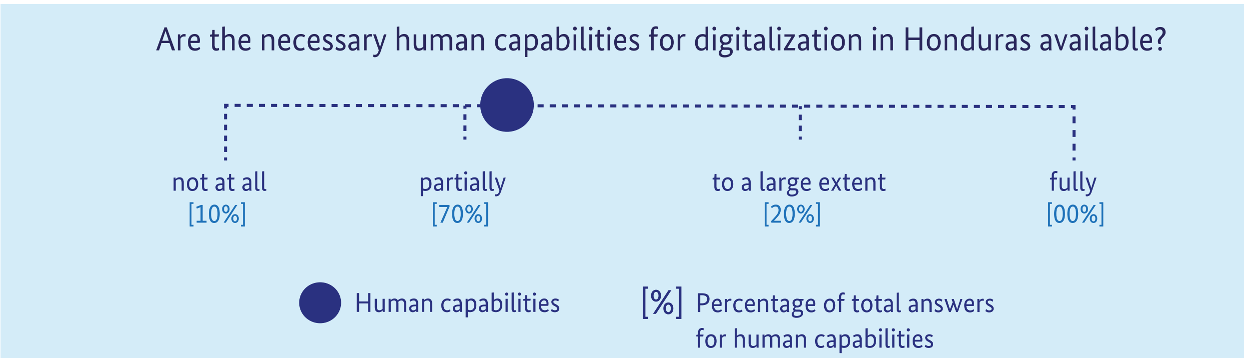


Figure 71. Human capabilities in Honduras

However, specific knowledge on digital technologies in the energy sector is missing. Companies and institutions need to advance capacity-building but face the issue of estimating the potential of respective technologies adequately.

Human Capabilities in Honduras: Recommendations from Country Experts

- Increase exchange between academia and industry
- Harmonize knowledge and data across agents within the energy sector
- Facilitate technological understanding and potential evaluation
- Implement pilot programs to raise awareness
- Adapt academic programs, e.g. business analytics.

Organizational Culture

The organizational culture in Honduras offers some potential for improvement to facilitate digitalization of the energy sector (Figure 72). Innovation processes are not institutionalized, and a perceived lack of specific knowledge on digital technologies and use cases leads to disregard of these within strategic planning. Additionally, there is strong resistance to change, with little flexibility in terms of investments especially in the public sector.

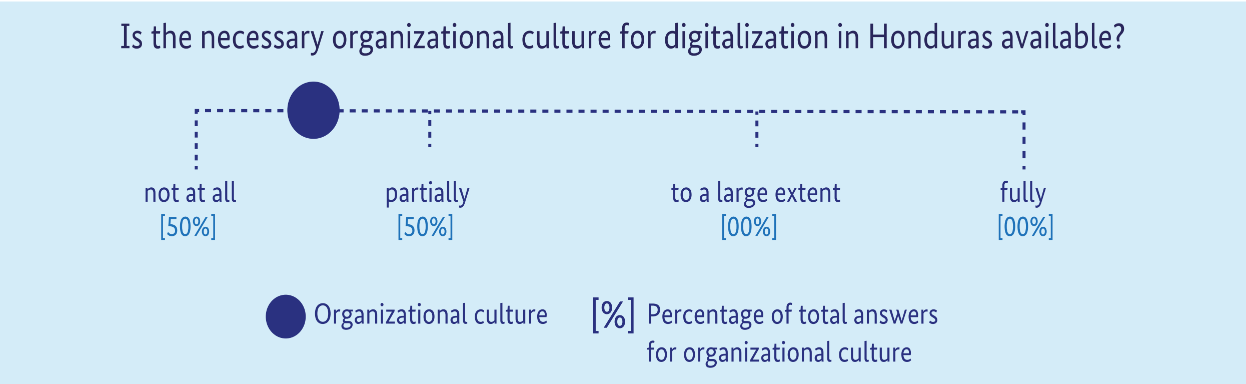


Figure 72. Organizational culture in Honduras

Still, within the private sector there is increasing awareness and motivation for pursuing digitalization.

Organizational Culture in Honduras: Recommendations from Country Experts

- Establish public innovation fund
- Institutionalize innovation processes within public and private companies
- Harmonize knowledge in order to realize importance of digitalization
- Conduct a workshop to inform and align major market players.

Capital and Investment

Securing and allowing funds for digital technology projects in the energy sector is problematic (Figure 73), especially for Honduras's public institutions. There are few resources within public companies for digitalization, as current budgeting has not accounted for these. In addition, the public vertically integrated utility is in financial distress due to overproduction and low prices, as well as very high energy losses that can only be passed on to the consumers in part through tariffs. In response, the finance ministry has cut down investments overall in the public sector.

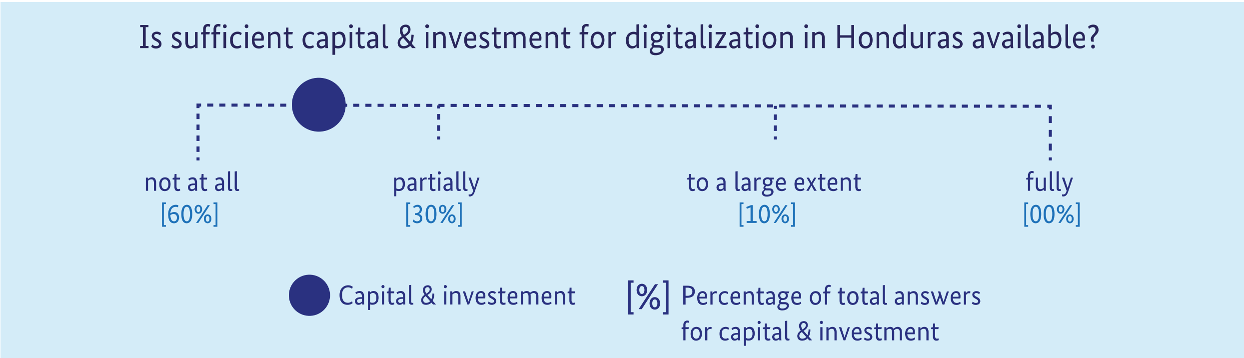


Figure 73. Capital and Investment in Honduras

Still, on the private side companies tend to have more financial leeway, especially the larger market players, and negotiations with the Inter-American Development Bank (IDB) for investments are ongoing.

Capital and Investment in Honduras: Recommendations from Country Experts

- Expand focus from operations alone to long-term, strategic projects
- Facilitate inter-institutional agreements in order to bundle resources.

Public Institutions and Governance

Regulation in Honduras's energy sector has yet to be adapted to digital topics and technologies (Figure 74). There is currently no regulation regarding digitalization in place, with issues prevalent in basic regulation that have to be addressed prior. For instance, policy-makers must establish norms concerning prepayment, as well as precise commercial measuring of energy consumption regulations.

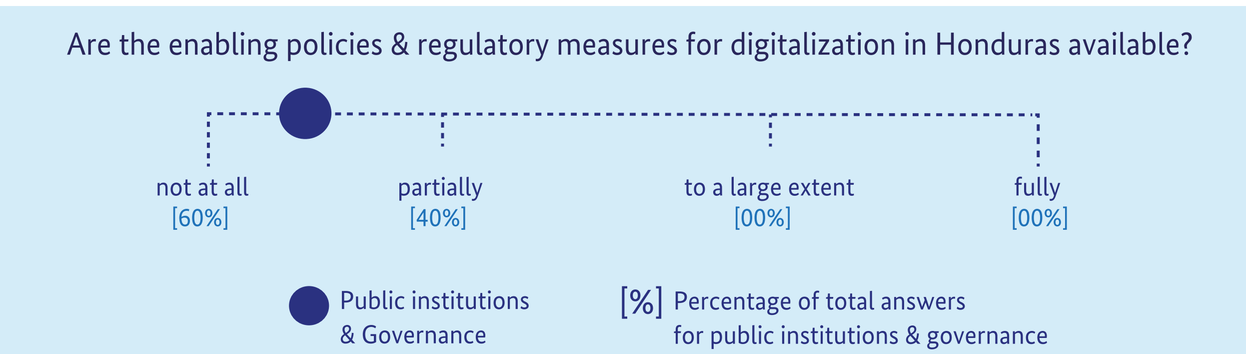


Figure 74. Public institutions and Governance in Honduras

However, the government is aware of these issues, and is passing laws and regulation regarding data transparency and unbundling. In addition, the distributor EEH is pursuing bidirectional measuring.

Public Institutions and Governance in Honduras: Recommendations from Country Experts

- Standardization of data formats to facilitate exchange between agents of the sector
- Set up regular peer-to-peer exchange between regulators
- Detail out bidirectional metering, e.g. pass feed-in tariff
- Pursue smart meter deployment to enable digital use cases
- Incentivize innovation through proactive regulation
- Install national and cross-national data transmission system
- Establish norms that require digital technologies to be addressed efficiently.

4.4.5 Digital Technology Use Cases in Honduras

Of the use cases identified for this study (Appendix 9), experts explicitly mentioned thirteen within the interviews. The experts focused on use cases especially relevant within the *increased volatility and supply security* trend (Figure 75), which they estimated will be the most impactful global energy trend affecting the energy sector in Honduras within the next years.

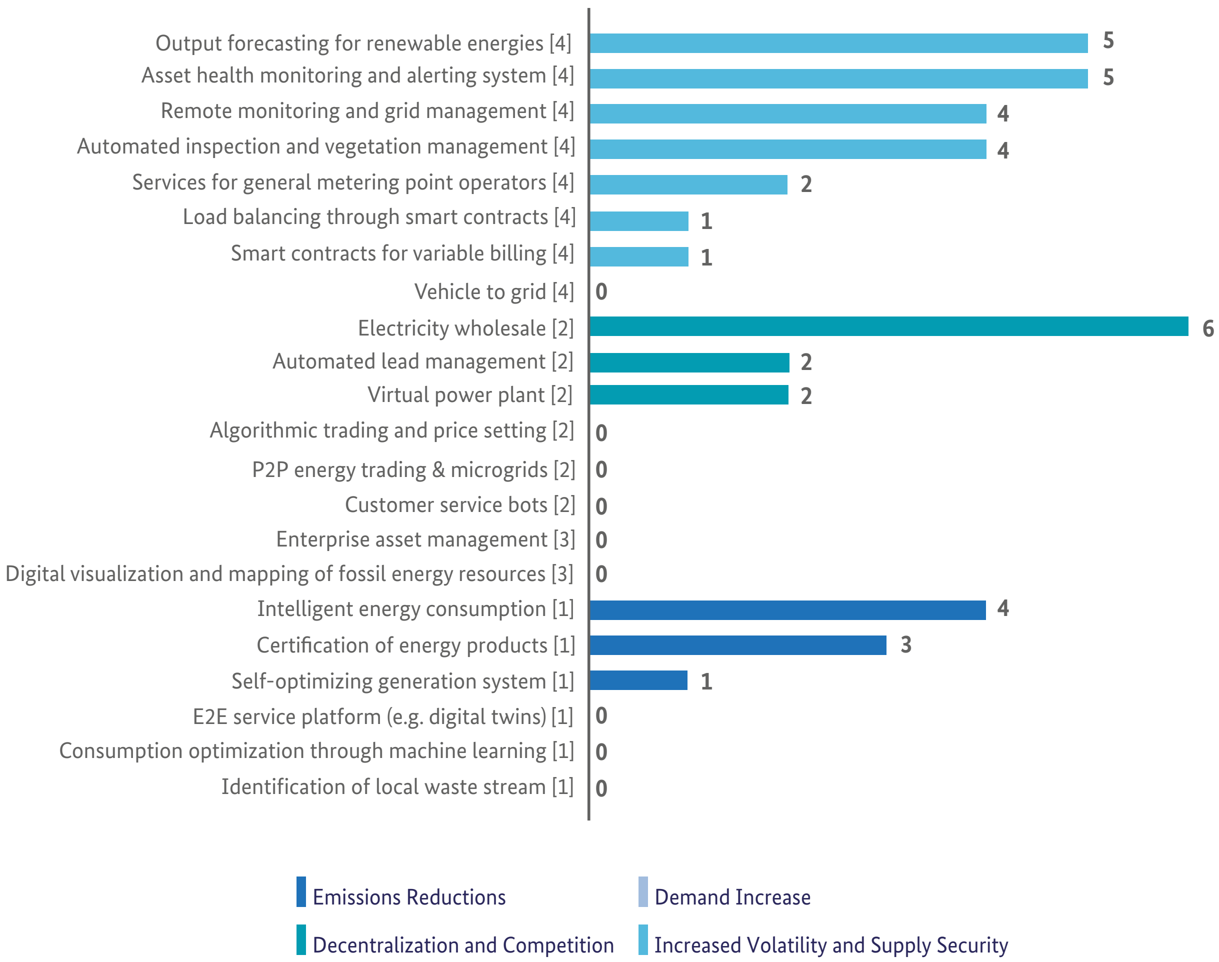


Figure 75. Addressed use cases in Honduras

Experts mentioned electricity wholesale more often than any other use case (addressed by six experts), followed by output forecasting for RE (addressed by five experts), asset health monitoring and alerting system (addressed by five experts), remote monitoring and grid management (addressed by four experts), and automated inspection and vegetation management (addressed by four experts). We present experts' perceptions of the relevance of each use case in Figure 76.

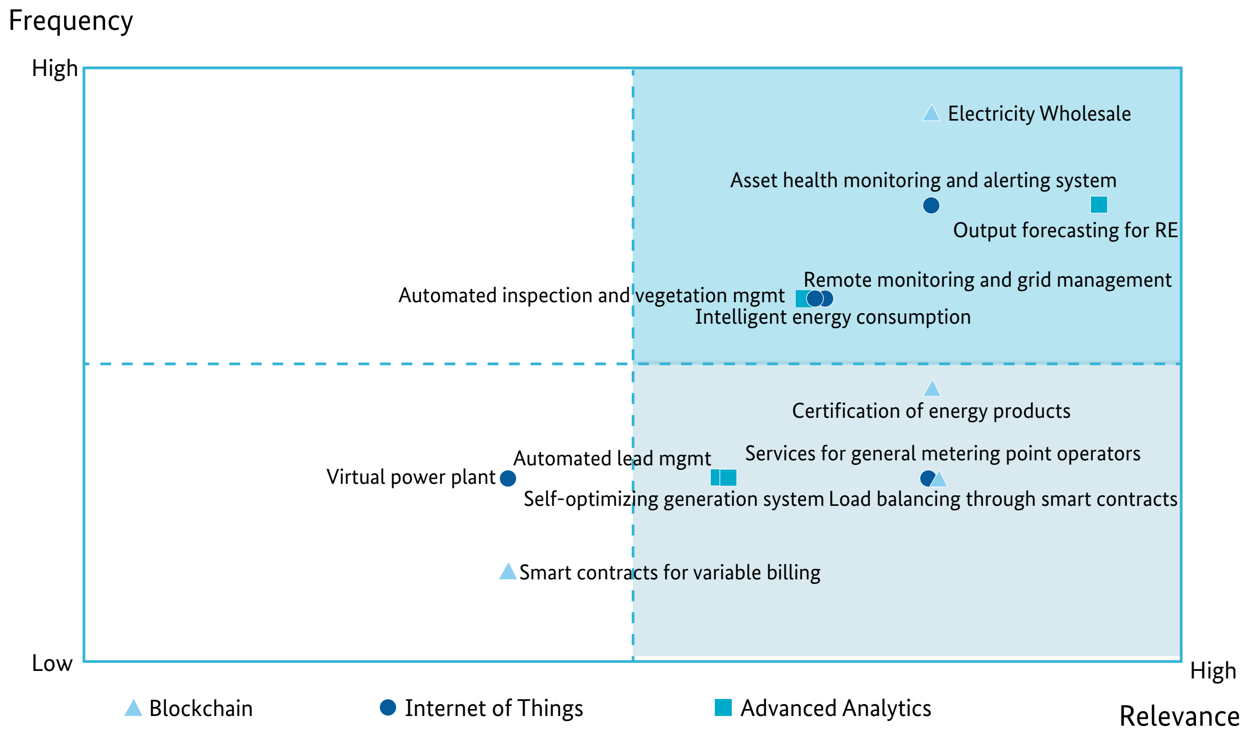


Figure 76. Use case assessment by relevance and frequency in Honduras

Of the top ten use cases that were addressed, the top five sorted by relevance are highlighted in bold, spanning across the whole value chain as can be seen in Figure 77.

	Generation	Trading	Transmission and Distribution	Consumption[2]
Emissions Reductions	1 Certification of energy products 4 Self-optimizing generation system 7 Identification of local waste streams			17 **Intelligent energy consumption** 19 E2E service platform (e.g. digital twins) 22 Consumption optimization through ML
Decentralization and Competition	2 Virtual power plant	8 P2P Energy trading and microgrids 10 **Electricity wholesale** 11 Algorithmic trading and price settings		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 **Asset health monitoring and alerting system** 5 **Output forecasting for RE**		12 Load balancing through smart contracts 13 **Remote monitoring and grid management** 14 Vehicle to grid 15 Automated inspection and vegetation management	16 Smart contracts for variable billing 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain | Internet of Things | Advanced Analytics[1]

Figure 77. Priority use cases in Honduras

Digital Technology Use Cases in Honduras

- **Output forecasting of RE:** implementation considered to be of low complexity
- **AI-based energy loss control:** first ideas are being developed to increase transmission efficiency
- Blockchain-based automatization of data capturing, transmission and centralization*
- AI-based energy loss control*
- Predictive maintenance of networks*

*Non-specific use cases.

Panama

4.5 Panama

Key Takeaways for Panama

- The electricity market in Panama has undergone privatization and is now liberalized, today, most of the investments come from the private sector.
- For the electricity system in Panama, experts indicated that the global energy trend *increased volatility and supply security* would have the greatest impact through 2030.
- This impact is reflected within parameter estimations, including the increase of the number of smart meters to over 100,000.
- With respect to the framework of conditions enabling digitalization,
  - Panama has sufficient *digital infrastructure,* adapting *human capabilities,* a supportive *organizational culture*, and access to financial *capital.*
  - On the limiting side there is potential for improvement to *regulation,* with a need to build up digital understanding to adjust regulative measures accordingly.
- Concerning prospective digital technologies and use cases,
  - Experts mentioned fourteen as potentially relevant as country-specific challenges, with the top five spanning across the energy value chain.
  - The top use cases were *intelligent energy* consumption based on the internet of things and *electricity wholesale* through blockchain technology.

4.5.1 General Information about Panama

Panama shares a border with Costa Rica to the west and Colombia to the east (Figure 78). Regarding *population, society and technology,* Panama has experienced both a population growth of fifteen percent and an increase of life expectancy at birth to 78 years. The GINI coefficient has decreased by 1.3 points indicating a more equal distribution of income. More than half of Panama's population has access to internet.

Main *economic and environmental* developments in Panama are reflected in the high growth of the economy with an increase in GDP of 130 percent since 2009. At the same time, the unemployment rate fell to 4.5 percent and the inflation rate decreased. Furthermore, Panama has a sustainable carbon footprint per inhabitant, achieving 2.25 tons per capita per year.

Figure 78. Map of Panama

In terms of *political, regulatory and legal* matters, Panama has stipulated ambitious targets of 70 percent of generation from RES by 2050. Panama currently implements its National Energy Plan that was launched in 2016.

Population, Social and Technological		
- Inhabitants, 2017 (2009):	4.1 (+14.5%)	[Mn]
- Life expectancy at birth, 2017 (2009):	78.0 (+1.8%)	[Years]
- GINI coefficient, 2014 (2009):	50.6 (-2.5%)	[number]
- Human dev. index, 2017 (2009):	0.79 (+4.4%)	[number]
- Internet penetration, 2016 (2009):	54 (+38.2%)	[%]
- Access to electricity, 2016 (2009):	93.4 (+6.8%)	[%]
- Average price of 1GB mobile data 2018:	5.56	[USD]
Political, Regulatory, and Legal		
- Government: Unitary presidential constitutional republic		
- Democracy Index (2017): 7.08		
- At least nine energy auctions conducted since 2011. National Energy Plan was launched in 2016. 70% of generation from RES by 2050		
Economic and Environmental		
- GDP 2017, (2009):	62.28 (+129.7%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2011):	15,196 (+100.6%)	[USD]
- Unemployment rate, 2017 (2009):	4.5 (-31.6%)	[%]
- Inflation, 2017 (2009):	0.88 (-63.7%)	[%]
- CO_2- emissions p.c., 2017 (2014):	2.25 (-10.6%)	[tons]

Figure 79. Profile of Panama

In Panama the Ministry of Environment formulates the environmental strategy. In 2015, it published the national climate change strategy of Panama. This plan includes strategies for adapting to climate change and for reducing greenhouse gases (Ministry of Environment, 2015). In addition, the National Energy Secretariat (SNE, for its acronym in Spanish) conducted the formulation of the national energy plan (2015-2050) in 2016. This plan lays out a strategy to diversify the energy sector with plans to decarbonize the energy system and promote energy efficiency and energy access (SNE, 2015).

The electricity market in Panama is liberalized. The formerly government owned vertically integrated electricity company Institute of Hydraulic Resources and Electrification (IRHE, for its acronym in Spanish) was unbundled in 1997. The company was split up into four companies for electricity generation, one transmission company, and three distribution companies. The generation and distribution companies where partly privatized while the transmission company remains under complete government ownership. There are distributors covering different areas of the country, respectively Electric Northeast Limited Company (ENSA, for its acronym in Spanish), Chiriqui Electric Distribution Company (EDECHI, for its acronym in Spanish) and Metro-West Electric Distribution Company (EDEMET, for its acronym in Spanish). Electric Transmission Company (ETESA, for its acronym in Spanish) is the operator of the transmission system responsible for connecting new actors and arranging auctions for power capacity. The National Dispatch Center (CND, for its acronym in Spanish), a dependency of ETESA, is responsible for the system operation and market. National Authority of Public Services (ASEP, for its acronym in Spanish) is the regulator of the power sector and in charge of granting generation licenses and distribution concessions as well as setting the tariffs for distribution and transmission service (IRENA, 2018).

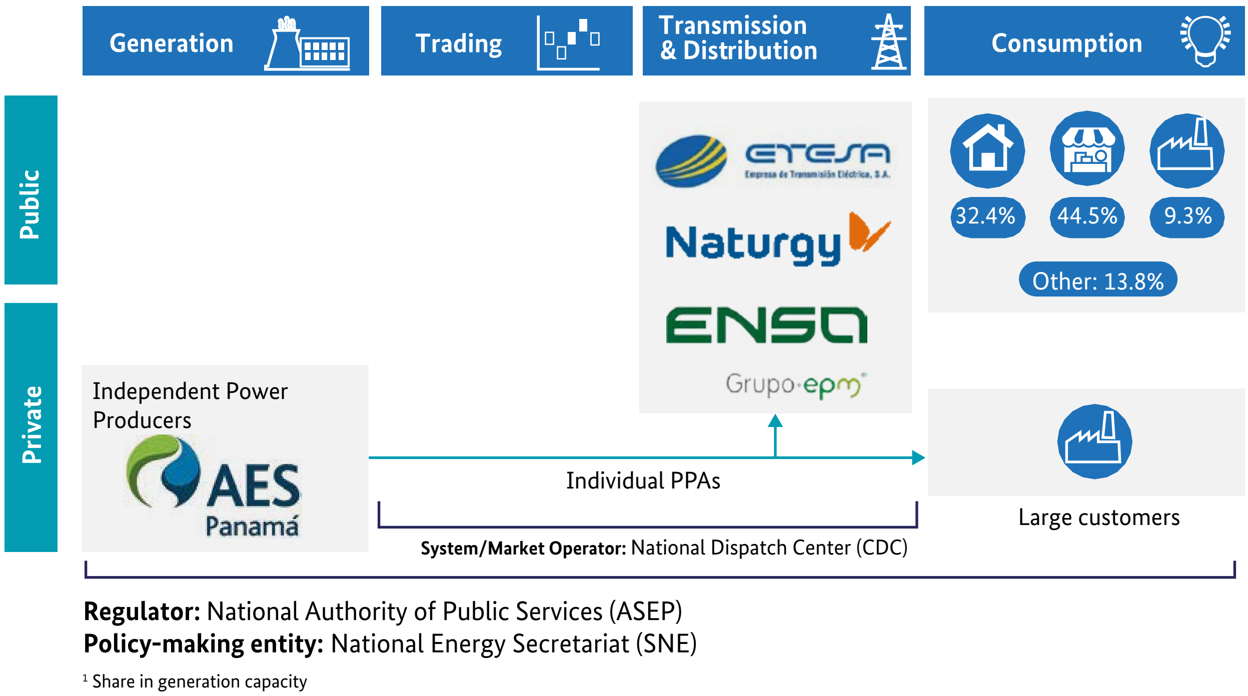


Figure 80. Electricity market structure in Panama

The prices for electricity in Panama in 2017 ranged from USD 0.15 (EDECHI) to 0.18 (ENSA) per kWh (ECLAC, 2018). The prices include tariffs for transmission and distribution costs that are structured by ASEP. The generation costs are determined on the wholesale market through power purchase agreements (PPA) and direct purchases of electricity on the spot market (IRENA, 2018).

Panama is a member of the MER and is an energy exporter with a net energy export value of 311.6 GWh or 13 percent of total exchanged energy (Figure 81), which is transmitted through the Regional Transmission Network (RTR) to Costa Rica. In addition, Panama and Colombia are currently planning an interconnection of their transmission lines (IRENA, 2018).

Parameter	Unit	Current[1]
Grid interconnection	[%]	8.5
Reserve margin	[%]	105.3
System average interruption duration	[hours]	0.9
Number of smart meters	[number]	n.a
Capacity factor	[%]	36.7
Efficiency	[$/MWh]	51.4
Net energyexports to MER	[Gwh]	311.6
Wholesale electricity market	[binary]	Yes
Market liquidity	[%]	4.7
Self-sufficiency	[%]	3.7
Market diversity	[number]	1
Total generation	[GWh]	10,937.8
Total installed capacity	[MW]	3,401.6
Number of electric vehicles	[number]	n.a
Energy mix	[% RE]	65.3
Carbon intensity	[tons CO2/GWh]	91.7
Energy loss	[%]	13.6
GDP energy intensity	[MWh/GDP(mn)]	176.9

[1] Sources and year for current parameters are provided in the appendix.

Figure 81. Current energy parameters in Panama

4.5.2 Impact of Global Energy Trends on Panama

Experts forecast that *increased volatility and supply security* will be the most impactful trend in Panama (Figure 82). Forty percent of the experts estimate a very high and 60 percent of the experts a rather high impact on the energy system in Panama. Panama is affected by dry and rainy season changes that influence water resources, which leaves them vulnerable to a system collapse. In addition, the transmission lines are insufficient and electricity generation capacities are located far from the consumers. Recently, lack of investment has created problems in the transmission system that has led to an increase in grid blackouts. In addition, social conflicts are hindering the expansion of the transmission network.

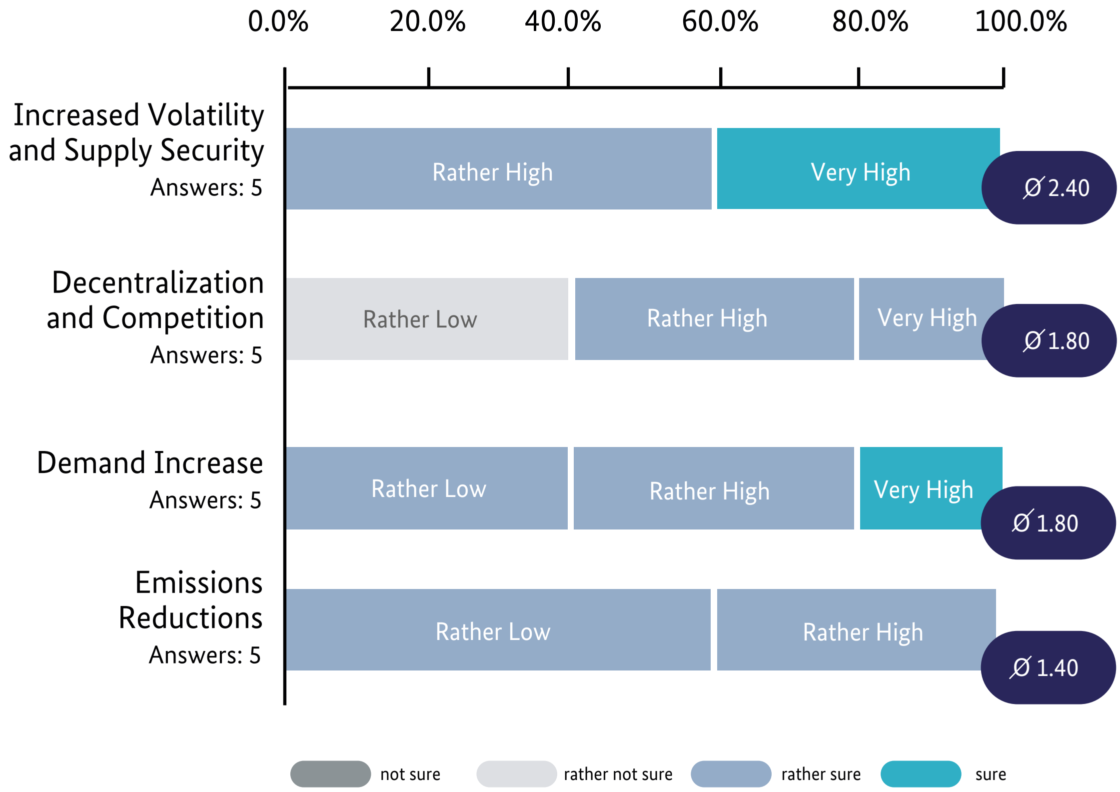


Figure 82. Global energy trends impact assessment in Panama by 2030

Decentralization and competition is rated as having a very high impact by 20 percent and as a rather high impact by 40 percent of the experts. The recent increase in decentralized production provides several challenges to the energy system. There is a lack of information on prosumers and the regulator does not know where and when generation capacity will be added to the grid. The prosumers are also destabilizing the grid. Furthermore, there are limitations on the commercialization of variable renewable energy.

Sixty percent of the experts rated demand increase as a trend with at least a rather high impact. Uncertainty of development demand in upcoming years is prevalent: while economic downturn and energy efficiency measures are expected to reduce demand, other factors such as e-mobility and growth in rural areas are likely to increase the demand.

Forty percent of experts rate the trend *emissions reductions* as having a rather high impact on Panama. While diesel and bunker generators are being phased out and replaced with gas, there is no dedicated price mechanism for renewables in place, thereby posing a challenge to decarbonization.

Other challenges in Panama include the planned addition of gas power plants, which could lead to an increase in overcapacity of electricity.

4.5.3 Outlook and Improvement Areas for Panama

Increased Volatility and Supply Security

The impact of the increased *volatility and supply security* can be observed in the increased number of smart meters ranging between 110,000 and 130,000 for 2030 according to the experts (Figure 83). This increase will partly come from regulation, as smart meters will be required for large customers. In addition, the system average interruption duration will decrease slightly to around 0.6 hours.

All parameters reflecting this trend have a rather high amount of potential for improvement through political action (Figure 84). The government could launch additional requirements for smart meter deployment to accelerate their spread.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Grid interconnection	[%]	8.5	5.4	13.0	-3.1 to +4.4	no consensus
Reserve margin	[%]	105.3	98.5	86.6	-6.8 to -18.7	no consensus
System average interruption duration	[hours]	0.9	0.6	0.6	-33.3% to -30.2%	▼ 80%
Number of smart meters	[number]	n.a	130,000	110,067	+130,000 to +110,067	▲ 100%
Capacity factor	[%]	36.7	40.0	41.9	+3.3 to +5.2	▲ 80%
Efficiency	[$/MWh]	51.4	70.0	73.7	+36% to +43%	▲ 80%
Net energy exports to MER	[GWh]	311.6	600.0	867.7	+92.5% to +178.4%	▲ 100%
Wholesale electricity market	[binary]	Yes				
Market liquidity	[%]	4.7	20.0	20.0	+15.3 to +15.3	▲ 100%
Self-sufficiency	[%]	3.7	10.0	9.7	+6.3 to +6.0	▲ 100%
Market diversity	[number]	1	1	1	+-0 to +-0	no consensus
Total generation	[GWh]	10,937.8	19,744.0	19,229.2	+80.5% to +75.8%	▲ 100%
Total installed capacity	[MW]	3,401.6	5,500.0	5,069.1	+61.7% to +49.0%	▲ 80%
Number of electric vehicles	[number]	n.a	10,000	88,629	+9,900 to +8,8529	▲ 100%
Energy mix	[% RE]	65.3	70.0	65.9	+4.7 to +0.6	no consensus
Carbon intensity	[tons CO2/GWh]	91.7	50.0	65.0	-45.5% to -29.1%	▼ 100%
Energy loss	[%]	13.6	10.0	11.1	-3.6 to -2.5	▼ 80%
GDP energy intensity	[MWh/GDP(mn)]	176.9	170.0	201.9	-3.9% to +14.1%	no consensus

1.Sources and year for current parameters are provided in the appendix.
2.Based on the median 2030 forecast provided by the experts.
3.Weighted average including the confidence of the assessment.
4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.
5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend
- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 83. Energy parameters in Panama by 2030

Decentralization and competition

The impact of *decentralization and competition* can be observed in the development of the capacity factor (Figure 83). This parameter indicates the profitability of installed capacity. A higher capacity factor reflects potentially higher profits from installed capacity, which leads to more competition. Experts expect this parameter to increase to between 40 and 42 percent. The addition of natural gas power plants will support this increase through more effective use of resources. However, gas power plants may lead to an overcapacity of generation. The market liquidity is expected to increase to around 20 percent, as more large customers will move to the wholesale market and more competition between generators becomes likely. Self-sufficiency is expected to increase to around ten percent, coming amid recently implemented policy measures. Energy exports are expected to grow between 600 GWh and 867 GWh. This increase will partially depend on the expansion of the SIEPAC line and could be served by new natural gas plants. In terms of market diversity there are no plans to expand the market and the number of distributors who have the sole responsibility of the commercialization to the clients is unlikely to increase. The parameter market liquidity has a very high level of potential to improve if additional action is taken (Figure 84).

Demand Increase

Experts predict that electricity generation will increase to between 19,229 GWh and 19,744 GWh and that total capacity will increase to between 5069 MW to 5500 MW. They expect the increase in demand to come from economic growth. There are also plans to electrify the transportation sector through increasing the number of electric vehicles as well as through the expansion of the metro system. There are, however, uncertainties regarding the increase in energy demand. Energy efficiency measures and the use of solar power to heat water could decrease the growth rate of electricity consumption.

Concerning the number of *electric vehicles* there is high potential to improve if political measures are taken (Figure 84). Moreover, government involvement is needed to set up the necessary infrastructure that will enable e-mobility, such as charging stations.

Emissions Reductions

The trend *emissions reductions* can be observed in the reduction of carbon intensity, which is expected to decrease to 65 to 50 tons of CO2 per GWh. This decrease will come from the substitution of inefficient coal plants by natural gas power plants or renewable energy sources. Energy losses are forecasted to decrease to between 11 and 10 percent. This decrease would be a follow up on the large decreases in energy loss after privatization. Also, the increase in smart metering could help reduce the impact of energy losses. There is no conclusive answer from the experts regarding the future development of the energy mix. Nevertheless, the recent addition of natural gas power plants could impact this value.

Still, the parameter energy mix is considered to have the highest amount of potential to improve from additional action. Here, financial incentives or auctions could increase the attractiveness of private sector investments to increase the share of RES (Figure 84).

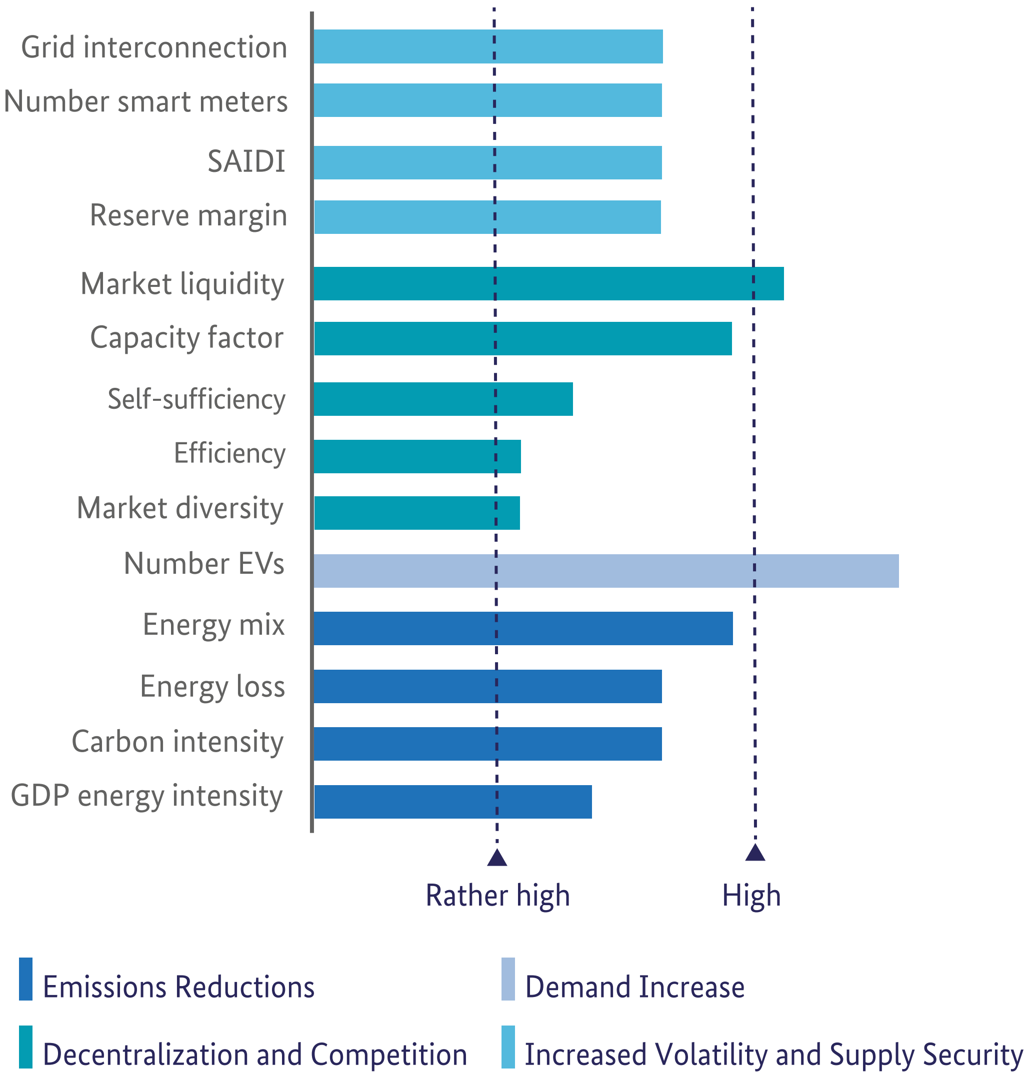


Figure 84. Improvement potential for energy parameters until 2030 in Panama

4.5.4 Enabling Framework Conditions in Panama

Digital technologies have the potential to help overcome some of the challenges that arise from global trends; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section indicates the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.

As illustrated in Figure 85, Panama's energy sector is ready to undergo digitalization. There are supporting digital infrastructure, adapting human capabilities, an innovation-embracing culture among companies, and good access to funding. However, Panama falls short in terms of regulation, with the regulator facing the challenges of limited knowledge and capacity.

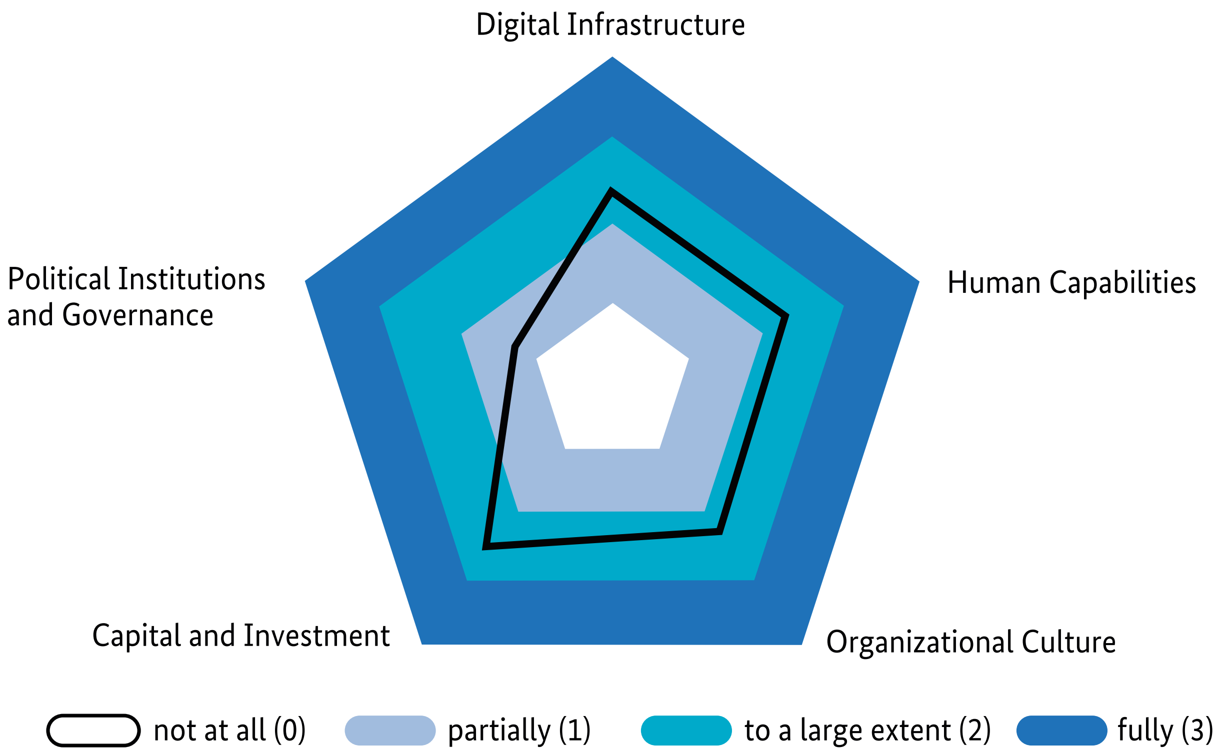


Figure 85. Availability of framework conditions in Panama

Digital Infrastructure

The experts consider the digital infrastructure in Panama as enabling digitalization (Figure 86). After consolidating the telecommunication providers to four, the market is operating efficiently and offering high coverage and a few data centers. Fiber optics are deployed along the transmission lines, and the operator is completely connected through these. Regarding smart meter deployment, there is a norm that requires installation after a certain threshold.

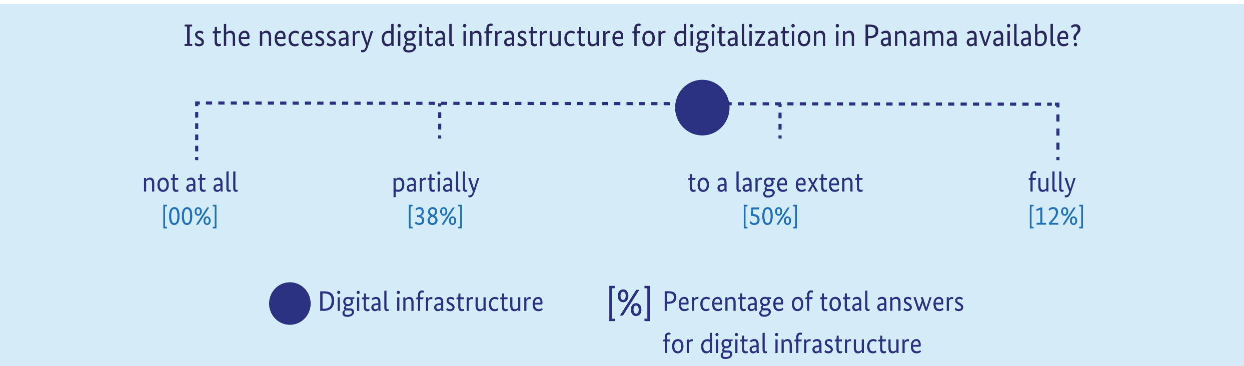


Figure 86. Digital infrastructure in Panama

Still, there are differences between areas because robust infrastructure is not widely available, and specific requirements for some digital applications may not be met.

Digital Infrastructure in Panama: Recommendations from Country Experts

- Specify needs from industry to guide telecommunication providers
- Illustrate concepts on how to use technology applications to increase tangibility (e.g. type of sensors, intelligent devises, etc).

Human Capabilities

Human capabilities in Panama are generally available (Figure 87). Panama has a large services sector, with technology centers building up. While historically higher education was a limiting factor, recent changes have raised the standards: the Technological University of Panama offers dedicated technology careers, and there is a new community college specializing in technology–the High Specialized Technical Institute–admitting its first students in 2019.

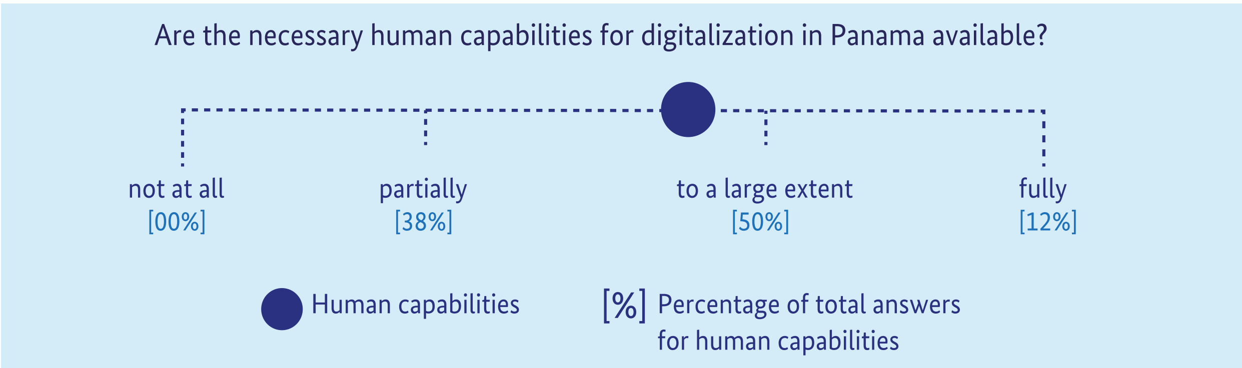


Figure 87. Human capabilities in Panama

However, precise application knowledge on digital technologies and applications is missing. Thus, many firms rely on external consultants. For example, the operator currently buys services for demand forecasting from a private company.

Human Capabilities in Panama: Recommendations from Country Experts

- Develop internal capacity and know-how, e.g. through pilot projects
- Facilitate interaction and exchange between industry and academia
- Facilitate exchange on digital technologies across sectors
- Include subject matter experts in discussions and planning
- Create interdisciplinary, interinstitutional, and intergenerational teams.

Organizational Culture

The organizational culture in Panama is generally considered to be digitally oriented (Figure 88). Some companies have introduced innovation plans, currently working on the centralization of data flows via the web. In addition, ENSA created a subsidy (ENSA Services) to facilitate disruptive business services, demonstrates that companies actively embrace innovation.

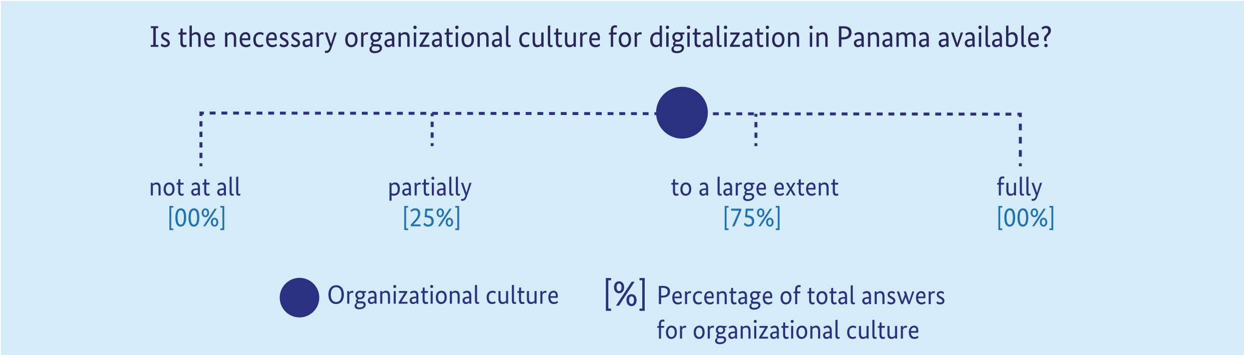


Figure 88. Organizational culture in Panama

Although the organizational culture fosters innovation, there are some organizations, especially in the public sector, with potential to improve.

Organizational Culture in Panama: Recommendations from Country Experts

- Facilitate exchange among private, public, and academic agents
- Create understanding of potential of technologies, especially among decision-makers
- Public companies should act as role models.

Capital and Investment

Experts consistently estimate that capital and investment are largely available in Panama (Figure 89). There is very good access to loans, venture capital, and financial services. The regulator ASEP is generally perceived as supportive for technological investments, with transmission companies having an edge over distribution companies. These investments are then considered as marginal costs.

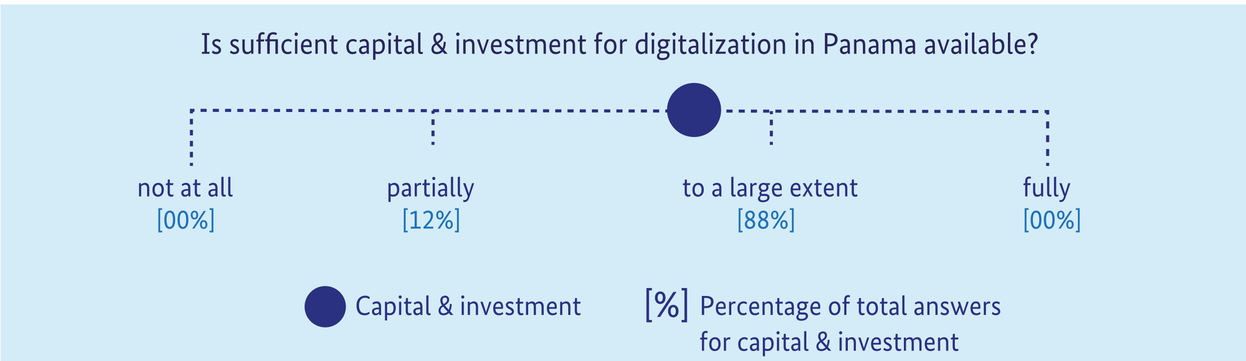


Figure 89. Capital and investment in Panama

However, investment plans are set on a five-year basis, with the current one prioritizing other areas for investments and offering low flexibility to introduce digital technologies.

Capital and Investment in Panama: Recommendations from Country Experts

- Create robust business cases to facilitate investments
- Make CND and ETESA independent so they can manage own budgets

Public Institutions and Governance

Policies and regulatory measures are considered to be lacking (Figure 90). The current regulatory framework does not incentivize technology investments, as distributors only receive remuneration for assets and not for additional technology investments. There are ambivalent signals towards technologies, such as partial follow-through on digitalization projects, such as a limited number of smart meters being installed. It is estimated that this is in part due to lack of knowledge by the regulator and in part due to lack of personnel.

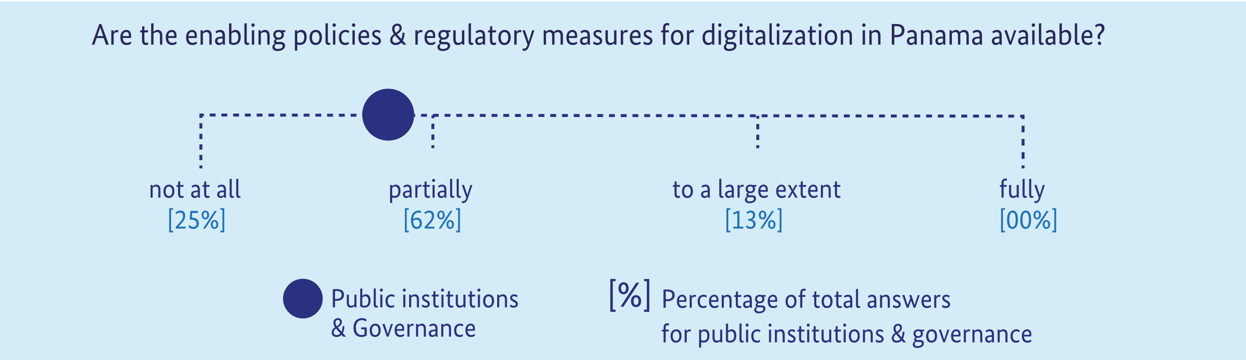


Figure 90. Public institutions and Governance in Panama

Still, on the governmental side there is strong engagement in smart city initiatives. Since 2009 with the creation of the Authority for Governmental Innovation (AIG, for its acronym in Spanish) there is specific support of other governmental entities in the process of digitalization.

Public Institutions and Governance in Panama: Recommendations from Country Experts

- Implement proactive regulation
- Enable prepayment services.

4.5.5 Digital Technology Use Cases in Panama

Of the use cases identified for this study (Appendix 9), experts explicitly addressed fourteen in the interviews. The experts focused on use cases especially relevant to *increased volatility and supply security* (Figure 91), which they estimated as the trend with the greatest impact on Panama's energy sector in upcoming years.

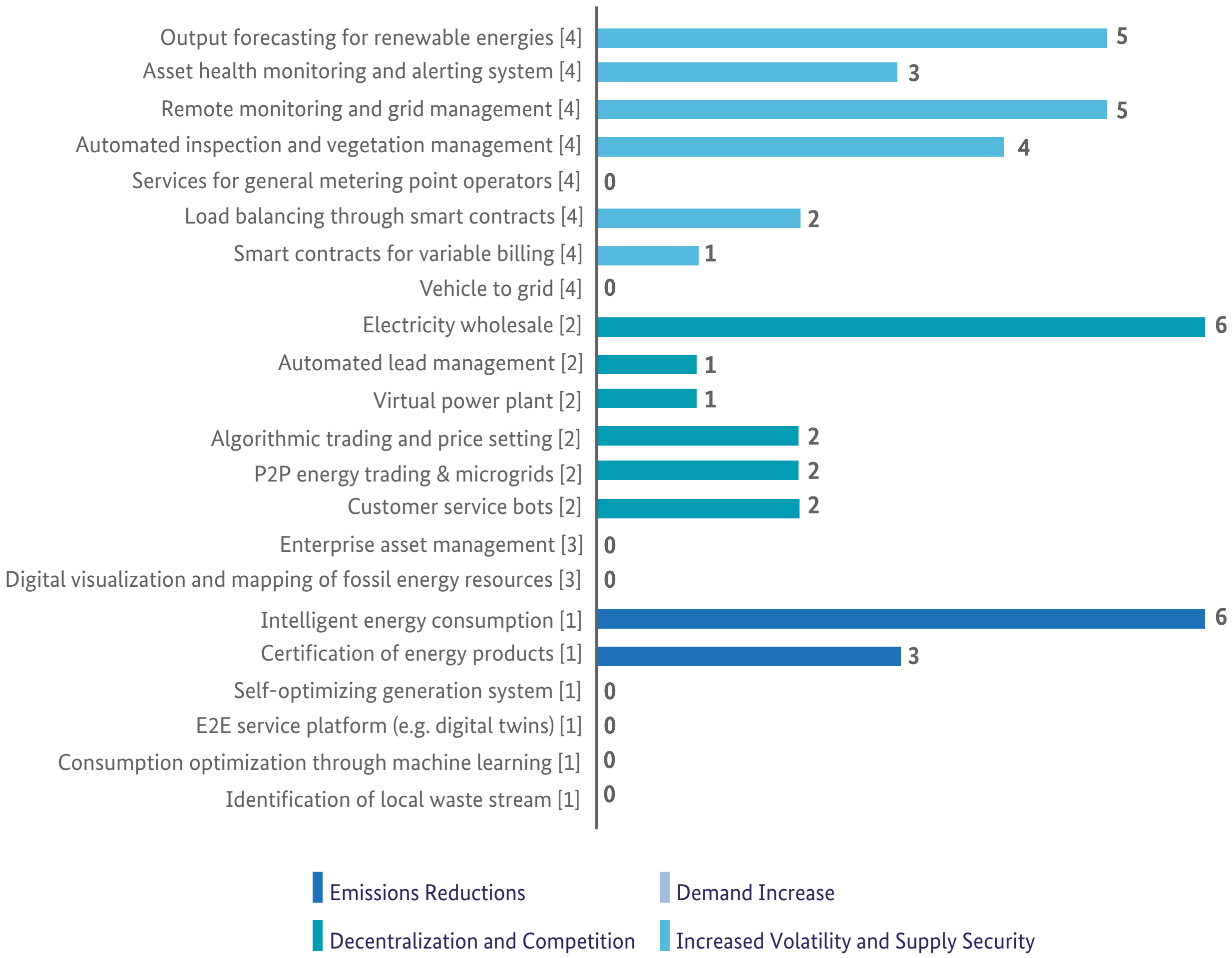


Figure 91. Addressed use cases in Panama

Electricity wholesale and intelligent energy consumption were the most-mentioned use cases (six experts addressed each of these), followed by output forecasting for RE (addressed by five experts), remote monitoring and grid management (addressed by five experts), and automated inspection and vegetation management (addressed by four experts).The perceived relevance of each use case can be seen in Figure 92.

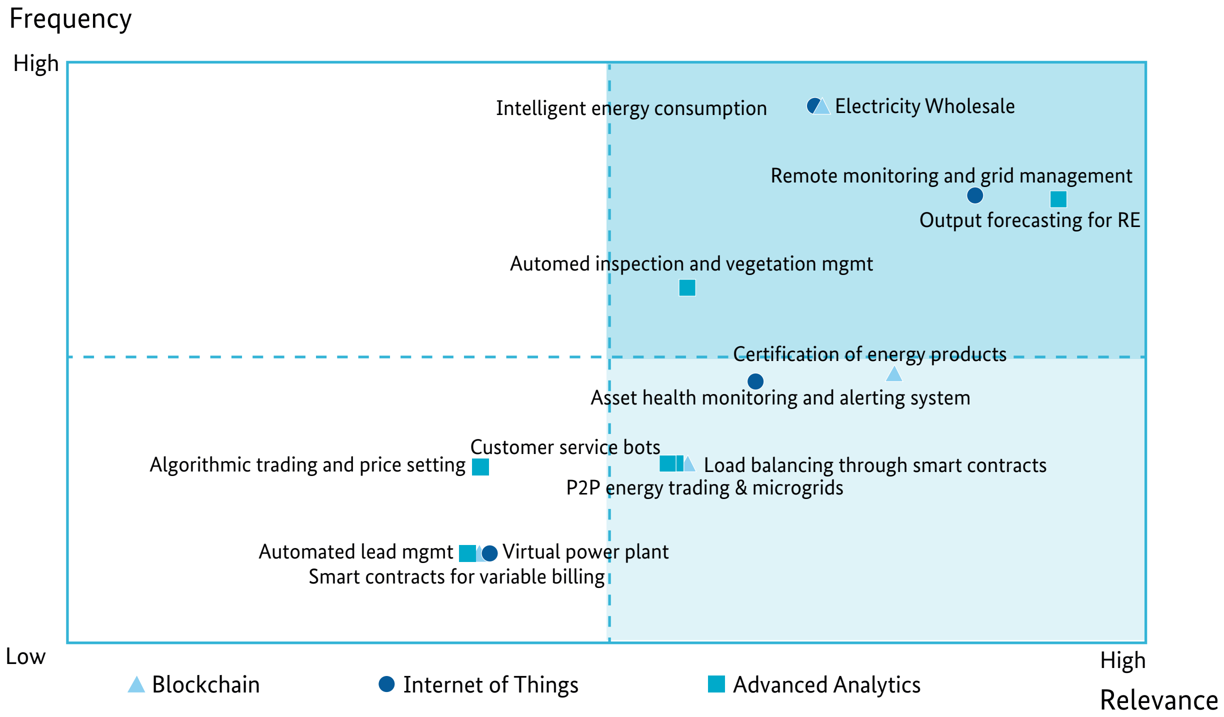


Figure 92. Use case assessment by relevance and frequency in Panama

Of the top ten use cases addressed, the top five sorted by relevance are highlighted in bold, spanning across the whole value chain as can be seen in Figure 93.

	Generation	Trading	Transmission and Distribution	Consumption[2]
Emissions Redcutions	1 **Certification of energy products** 4 Self-optimizing generation system 7 Identification of local waste streams			17 **Intelligent energy consumption** 19 E2E service platform (e.g. digital twins) 22 Consumption optimization through ML
Decentralization and Competition	2 Virtual power plant	8 P2P Energy trading and microgrids 10 **Electricity wholesale** 11 Algorithmic trading and price settings		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 Asset health monitoring and alerting system 5 **Output forecasting for RE**		12 Load balancing through smart contracts 13 **Remote monitoring and grid management** 14 Vehicle to grid 15 Automated inspection and vegetation management	16 Smart contracts for variable billing 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain Internet of Things Advanced Analytics[1]

Figure 93. Priority use cases in Panama

Digital Technology Use Cases in Panama

- **Certification of energy products:** certification based on current analyses, Blockchain to automate
- **Asset health monitoring and alerting system:** SCADA systems for monitoring in place
- **Output forecasting for RE:** pilots in development, low complexity of implementation
- **Remote monitoring and grid management:** Pilots and SCADA systems in place
- **Automated inspection and vegetation management:** Drones used for specific works by ETESA, but not yet for automated inspection of transmission lines
- **Intelligent energy consumption:** Pilots and services being offered (ENSA)
- **Customer service bots:** initiative planned due to increase of market participants.

Nicaragua

4.6 Nicaragua

Key Takeaways for Nicaragua

- The electricity market in Nicaragua is partly liberalized and is heavily influenced by ongoing social and political conflict.
- For the electricity system in Nicaragua, the *emissions reductions* trend was considered the most impactful global energy trend until 2030.
- This impact is reflected within the parameter estimations, including the increase of the share of renewables in the energy mix to between 68.5 and 70.0 percent.
- With respect to the enabling framework conditions for digitalization,
  - *Digital infrastructure and capital and investment* seem available, while *policies and regulation* are lacking.
  - There are strong differences within the respective framework conditions.
- Regarding prospective digital technologies and use cases,
  - Experts mentioned thirteen as potentially relevant for the country-specific challenges.
  - The top five span across the electricity value chain, and the top one is r*emote monitoring and grid management* based on the internet of things.

4.6.1 General Information about Nicaragua

Nicaragua is located to the north of Costa Rica and shares a border with Honduras in the north. In terms of *population, society, and technology,* Nicaragua has experienced a moderate population growth of 9.7 percent. The life expectancy as well as the GINI coefficient both have improved since 2009. While internet penetration and access to electricity have increased by 24.6 percent and 81.8 percent respectively, there is still room for improvement.

Considering *economic and environmental* matters, Nicaragua increased its GDP by 66.5 percent since 2009 in nominal terms as well as 51.7 percent on a per capita basis. Moreover, the unemployment rate in Nicaragua has increased to 4.4 percent. Nicaragua has the lowest level of CO2-emissions per capita among the countries analyzed, accounting for 0.8 tons p.c. (World Bank, 2014)

Figure 94. Map of Nicaragua

Regarding *political, regulatory and legal* matters, there is an electric generation expansion plan fostering the development of renewable energy sources for generation until 2050.

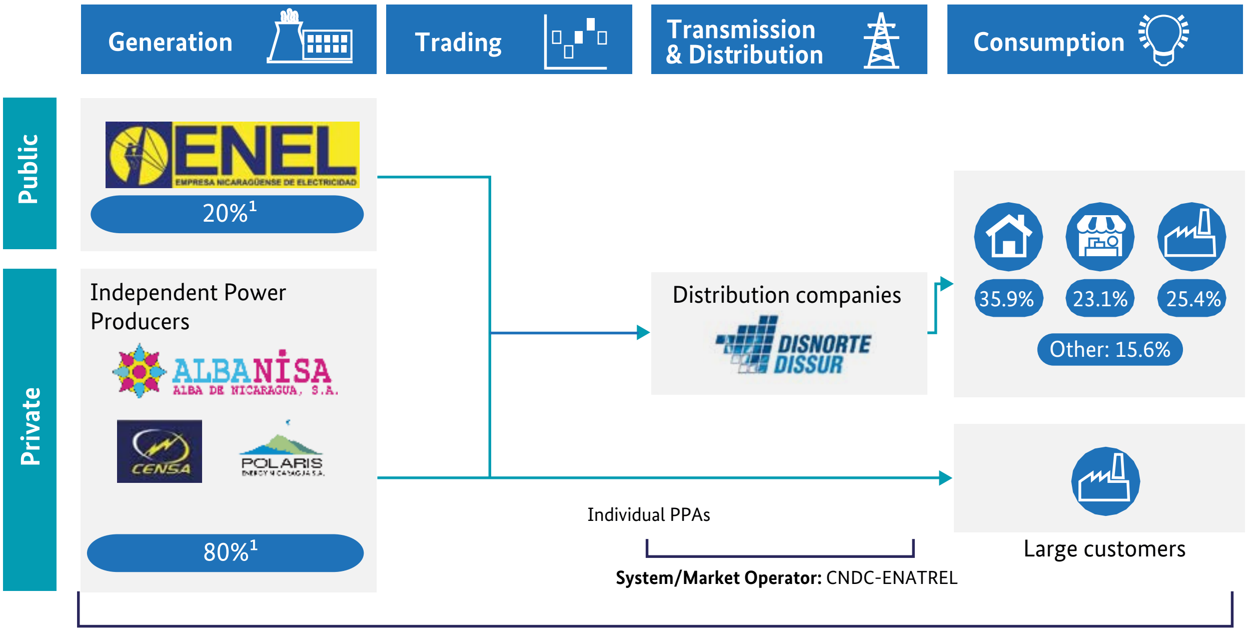
In Nicaragua, the Ministry of Energy and Mines (MEM, for its acronym in Spanish) is responsible for creating the energy policy as well as for granting authorization for electricity generation, transmission, and distribution. While Nicaragua relies on fuel oil for electricity generation, it plans to increase the share of renewable energy in the electricity mix. The initial goal of 90 percent share of renewables in electricity generation has been revised to 75 percent (IDB, 2015).

Population, Social and Technological		
- Inhabitants, 2017 (2009):	6.22 (+9.7%)	[Mn]
- Life expectancy at birth, 2017 (2009):	75.4 (+2.8%)	[Years]
- GINI coefficient, 2014 (2009):	46.2 (5.2%)	[number]
- Human dev. index, 2017 (2009):	0.66 (+7%)	[number]
- Internet penetration, 2016 (2009):	24.6 (+236%)	[%]
- Access to electricity, 2016 (2009):	81.8 (+5%)	[%]
- Average price of 1GB mobile data 2018:	6.04	[USD]
Political, Regulatory, and Legal		
- Government: Unitary dominant-party presidential constitutional rep.		
- Democracy Index (2017): 4.66		
- The Electric Generation expansion plan includes tax benefits for developers and 73% (64%) of generation from RES until 2050 (2023)		
Economic and Environmental		
- GDP 2017, (2009):	13.81 (+66.5%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	2,221 (+51.7%)	[USD]
-Unemployment rate, 2017 (2009):	4.4 (-45.6%)	[%]
- Inflation, 2017 (2009):	3.85 (+4.4%)	[%]
- CO_2- emissions p.c., 2017 (2009):	0.8 (-1.4%)	[tons]

Figure 95. Profile of Nicaragua

The electricity market in Nicaragua is partly liberalized. In 1997 the law to unbundle the sector, the *Ley de la Industria Eléctrica* (Electric Industry Law), split Nicaraguan Electricity Company (ENEL, for its acronym in Spanish), the state-owned electricity company (National Congress of the Republic of Nicaragua, 1997). Before that, ENEL was responsible for electricity generation, transmission, and distribution, setting energy policies and managing the energy resources. Today, the generation companies include, among others, Central Generating Power, Western Electric Generating, and Hydroelectric Generating. The transmission is carried out by National Electricity Transmission Company (ENATREL, for its acronym in Spanish). The private company Disnorte-Dissur is responsible for 97 percent of the distribution. There is no retail company, so the distributor also acts as the retailer. The Nicaraguan Institute of Energy (INE, for its acronym in Spanish) is the regulator for the power sector. It approves the tariffs and adopts technical norms (IDB, 2015).

The electricity prices in Nicaragua were USD 0.143 per kWh for residential customers, USD 0.193 per kWh for industrial customers and USD 0.253 for general (ECLAC, 2018). The tariff for electricity is calculated based on the energy consumption level: the higher the consumption level, the higher the prices. The high prices come from high dependency on imported fuel sources (IDB, 2015).



Regulator: Nicaraguan Institute of Energy (INE)
Policy-making entity: Ministry of Energy and Mines (MEM)
[1] Share in generation capacity

Figure 96. Electricity market structure in Nicaragua

Nicaragua is part of the MER and has a negative net energy export balance (Figure 97). Nicaragua is connected to Honduras and Costa Rica through the SIEPAC transmission network.

Parameter	Unit	Current[1]
Energy mix	[% RE]	53.8
Carbon intensity	[tons CO2/GWh]	115.1
Energy loss	[%]	21.6
GDP energy intensity	[MWh/GDP(mn)]	295.2
Grid interconnection	[%]	14.3
Reserve margin	[%]	115.8
System average interruption duration	[hours]	73.7
Number of smart meters	[number]	0
Capacity factor	[%]	31.7
Efficiency	[$/MWh]	93.4
Net energy exports to MER	[GWh]	-325.6
Wholesale electricity market	[binary]	Yes
Market liquidity	[%]	-
Self-sufficiency	[%]	3.7
Market diversity	[number]	1
Total generation	[GWh]	4,077.0
Total installed capacity	[MW]	1,467.3
Number of electric vehicles	[number]	n.a

[1] Sources and year for current parameters are provided in the appendix.

Figure 97. Current energy parameters in Nicaragua

4.6.2 Impact of Global Energy Trends on Nicaragua

Emissions reductions is the most impactful global energy trend in Nicaragua. Twenty percent of the experts predict it will have a very high impact and 80 percent a rather high impact on the energy system in Nicaragua (Figure 98). Due to changing the initial ambitious goal of reaching a share of 90 percent RES in electricity generation to 75 percent, persistence of policies is creating uncertainty among market participants. In addition, some RES, such as wind turbines, have been shut down in favor of fossil fuel plants, adding more uncertainty for electricity producers.

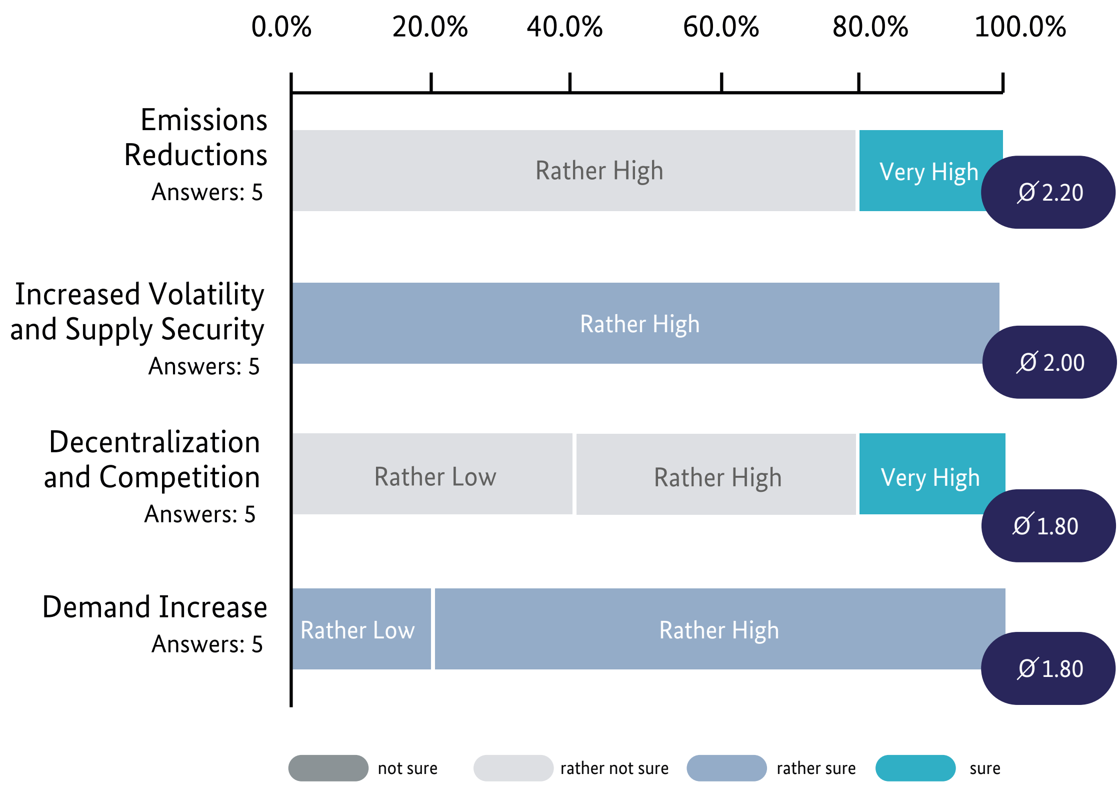


Figure 98. Global energy trends impact assessment in Nicaragua by 2030

The second most impactful trend is *increased volatility and supply security.* All experts expect this trend to have a rather high impact on the energy system in Nicaragua. High electricity losses are a challenge for Nicaragua. They can be partly attributed to energy theft. In addition, experts suggest that because installed capacity of wind energy is located in a zone other than where main consumption occurs, it poses challenges to the grid. Further, the increase of volatile renewable energy sources also poses a challenge to the electricity grid. There is also a lack of coordination on RES generation capacity.

Decentralization and competition is rated as having a very high impact by 20 percent of experts and as having a rather high impact by 40 percent. Low energy access levels pose a challenge for Nicaragua, especially in areas where low-density electrification is limited. There is also an insufficient number of skilled people operating small power generation plants and their regulation does not go far enough. In terms of competition, the distributors do not buy in the market as it is over-contracted. In addition, the experts mentioned the high prices for electricity.

Eighty percent of experts forecasted that *demand increase* will have a rather high impact. The future demand increase highly depends on the development of the political situation. The current uncertainty will affect future development of demand.

4.6.3 Outlook and Improvement Areas for Nicaragua

Emissions Reductions

The impact of the trend emissions reductions is observed in the parameters energy mix, carbon intensity, and energy loss. According to the experts, the share of renewable energies will increase to between 68.5 to 70 percent by 2030 (Figure 99). This is in line with the government policy. However, private investors are worried about a lack of commitment to the plan. They complain about the government putting a halt on initiatives (e.g. the government reducing the goal for the share of renewables from 90 to 75 percent). Energy losses are expected to decrease to around fifteen percent. This decrease will follow up on the recent successes of the huge loss reductions since the unbundling of the electricity market. However, an increase of energy theft related to the ongoing urbanization could complicate the targeted decrease of energy losses. Carbon intensity is expected to decrease by around 20.8 percent. This decrease can be achieved by switching the current electricity generation from fossil fuels to renewable energy.

The parameter energy mix has rather high potential to improve from political action (Figure 100). This shows the importance of government commitment to the reduction of fossil fuels. The government could take action by implementing favorable regulation (e.g., financial incentives) or giving RES priority grid access.

Increased Volatility and Supply Security

The parameter grid interconnection is expected to increase to between 18.8 to 22.5 percent. This increase will come amid the planned expansion of the SIEPAC line. The system average interruption duration is expected to decrease to between 50 to 55.8 hours by 2030. This decrease will come amid further improvements to the grid. There is no reliable consensus among the experts regarding the forecast of the smart meters. According to the experts, parameters system average interruption duration and reserve margin have a rather high potential for improvement.

Parameter	Unit	Current[1]	2030F Median[2]	2030F Average[3]	Change[4]	Trend and Support[5]
Energy mix	[% RE]	53.8	70.0	68.5	+16.2 to +14.7	100%
Carbon intensity	[tons CO2/GWh]	115.1	90.0	90.0	-21.8% to -21.8%	▼ 100%
Energy loss	[%]	21.6	15.0	15.3	-6.6 to -6.4	▼ 100%
GDP energy intensity	[MWh/GDP(mn)]	295.2	320.0	337.1	+8.4% to +14.2%	▲ 100%
Grid interconnection	[%]	14.3	22.5	18.8	+8.2 to +4.5	▲ 75%
Reserve margin	[%]	115.8	88.0	73.5	-27.8 to -42.3	▼ 80%
System average interruption duration	[hours]	73.7	50.0	55.8	-32.2% to -24.3%	▼ 80%
Number of smart meters	[number]	0	20,250	41,927	+20,250 to +41,927	▲ 100%
Capacity factor	[%]	31.7	39.0	41.6	+7.3 to +9.9	▲ 80%
Efficiency	[$/MWh]	93.4	100.0	98.8	+7% to +6%	▲ 80%
Net energy exports to MER	[GWh]	-325.6	-300.0	-71.4	7.9% to 78.1%	▲ 100%
Wholesale electricity market	[binary]	Yes				
Market liquidity	[%]	-	-	-		
Self-sufficiency	[%]	3.7	10.0	10.4	+6.3 to +6.7	▲ 100%
Market diversity	[number]	1	2	2	+1 to +1	no consensus
Total generation	[GWh]	4,077.0	8,066.5	7,776.4	+97.9% to +90.7%	▲ 100%
Total installed capacity	[MW]	1,467.3	1,776.0	1,906.0	+21.0% to +29.9%	no consensus
Number of electric vehicles	[number]	n.a	50	72	-50 to -28	no consensus

1.Sources and year for current parameters are provided in the appendix.

2.Based on the median 2030 forecast provided by the experts.

3.Weighted average including the confidence of the assessment.

4.Change without the % sign as absolute change in the parameter units. Range based on median to average value.

5.Trend arrows (up and down) represent the trend most common in expert answers, with the support in % indicating the share of experts who agreed with the most common trend.

Global Energy Trend
- Emissions Reductions
- Decentralization and Competition
- Increased Volatility and Supply Security
- Demand Increase

Figure 99 . Energy parameters in Nicaragua by 2030

Decentralization and Competition

The parameter self-sufficiency is expected to increase to around ten percent. The governmental rural electrification project in isolated areas will contribute to this increase. Through the program, rural areas are supported in the set-up of small-scale solar projects. However, import taxes on batteries and panels could negatively impact growth. The net energy exports to MER are expected to decrease to between -300 GWh and -71.4 GWh. The decrease could partly come from an increase in installed capacity inside Nicaragua. Experts also expect that a wholesale market will be in place in 2030. According to the experts, this highly depends on finding a resolution to the political crisis.

The parameter self-sufficiency has the highest potential for improvement from additional action taken. The government could improve the development of self-sufficiency by introducing further programs for self-generation that simultaneously aim to increase the electrification rate. Also, a measure such as this could lead to decreasing the taxes on importing the required equipment.

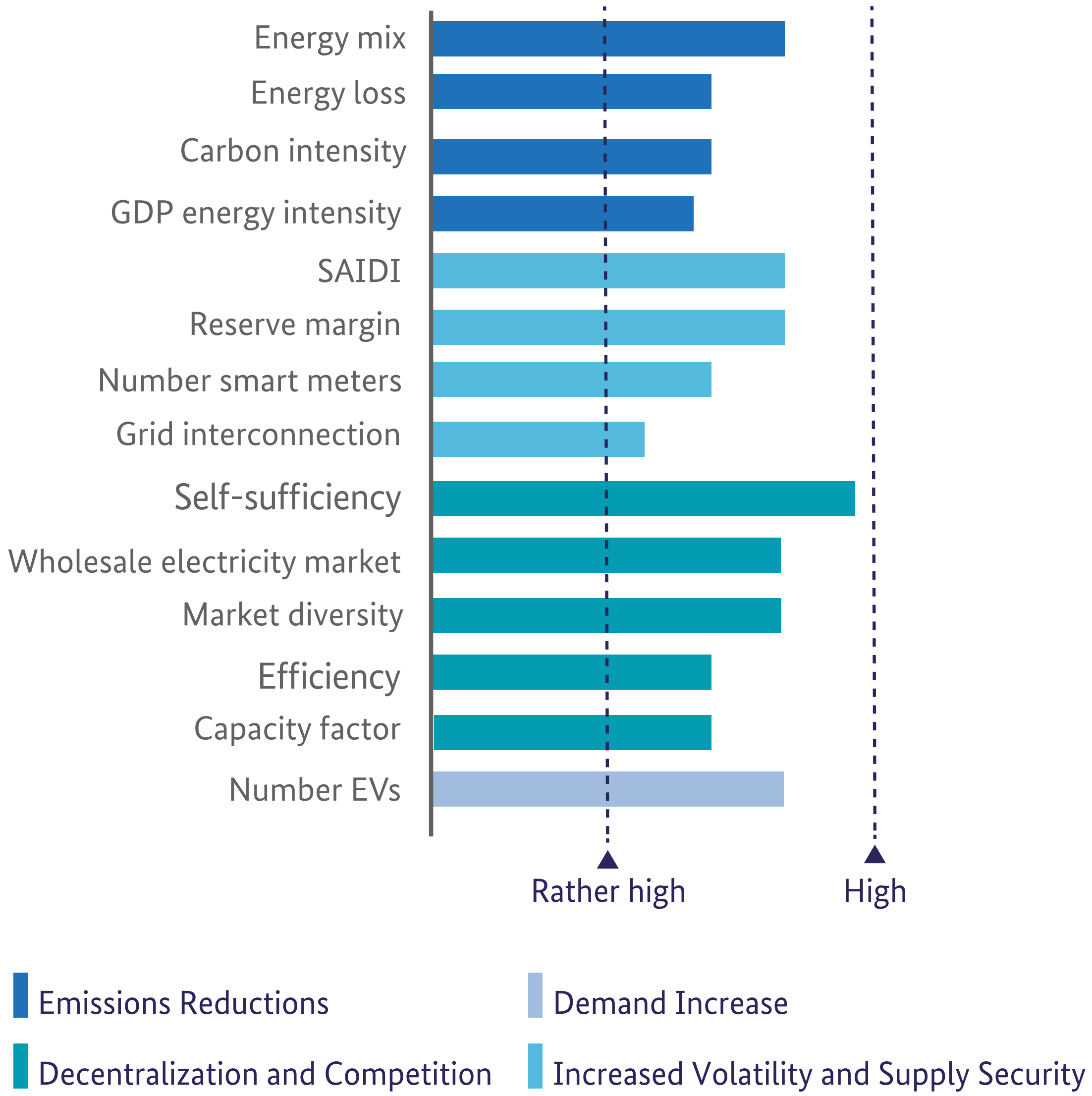


Figure 100. Improvement potential of energy parameters until 2030 in Nicaragua

Demand Increase

The parameter demand increase will grow to between around 7,776 GWh to 8066 GWh according to the experts. The increase comes amid a higher electrification rate as well as urbanization. The increase in total generation will presumably come from better use of the current capacity, which is also reflected in the expected increase of the capacity factor. There is no consensus among the experts for the forecast of the parameters total installed capacity and number of electric vehicles. This could be influenced by the current political situation that creates a lot of uncertainty for investors. Many current projects have not been put out for tender or have been denied licenses, according to the experts.

The experts see, however, a rather high amount of potential to improve from political action for the parameter number of electric vehicles. Political support is needed for the required infrastructure of electrical vehicles (e.g., charging stations).

4.6.4 Enabling Framework Conditions in Nicaragua

Digital technologies have the potential to help overcome some of the challenges presented above; nevertheless, their implementation requires the presence of certain framework conditions. As outlined within the assessment framework, the following section indicates the current state with respect to the five framework conditions that enable the development and implementation of supportive digital technologies within the energy sector.

As illustrated in Figure 101, digital infrastructure and human capabilities are selectively in place. However, within organizational culture there is a strong focus on day-to-day operations, limiting the will to change due to prioritizing short term gains over long term benefits. Availability of capital and investment as well as policies and regulations are both affected by the current unstable political situation, which is causing risk and uncertainty.

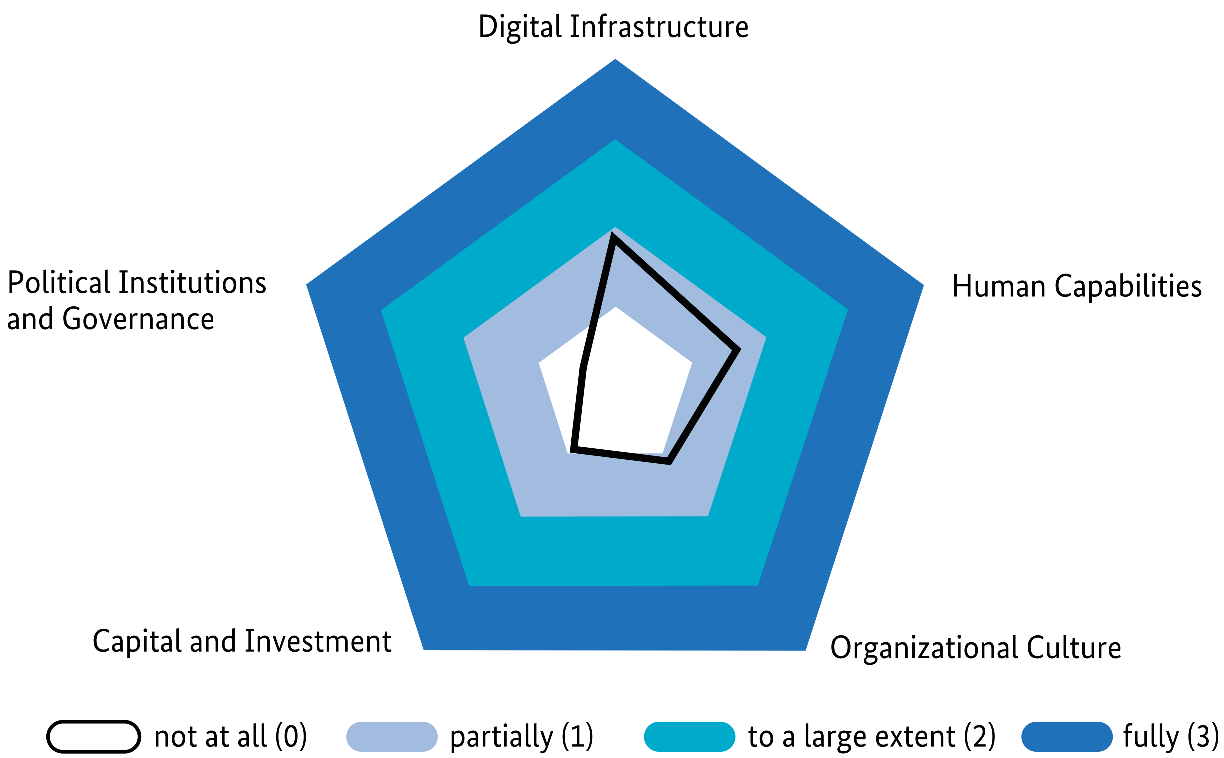


Figure 101: Availability of framework conditions in Nicaragua

Digital Infrastructure

In Nicaragua, the experts' opinions reflect the discrepancy between urban and rural areas, but overall, the estimate the digital infrastructure to be partially enabling (Figure 102). The government is involved in a broadband project on the Atlantic coast, private telco companies have installed advanced fiber optics and transmission lines, and smart meter deployment is ongoing. In rural areas, however, even basic electrification is sometimes missing, although the national energy plan addresses this as a major goal. In addition, due to fiber optics being privatized, prices are quite high. High prices are also a problem for new technologies because they slow down acquisition and installation of digital equipment.

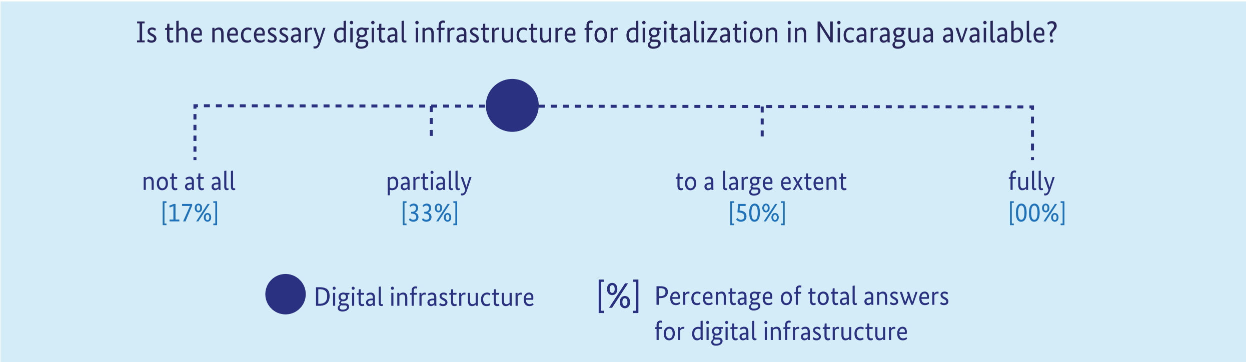


Figure 102. Digital infrastructure in Nicaragua

Digital infrastructure in Nicaragua: Recommendations from Country Experts

- Provide broadband connection for electrification of rural areas
- Liberalize telecommunications market to increase competition
- Regulate prices on fiber optics usage.

Human Capabilities

The experts agreed that *human capabilities* are partially available for digitalization (Figure 103). Nicaragua has access to individuals with rudimentary knowledge on technologies as well as a few experts. Nevertheless, specific training for applying technologies in the energy sector is needed, as the connection between theory and praxis has not yet been established. In addition, stakeholders see capacity-building with a short-term view as “cost,” as opposed to long-term “investment,” which impedes development. Thus, few experts remain in Nicaragua, resulting in a dependency on foreign knowledge.

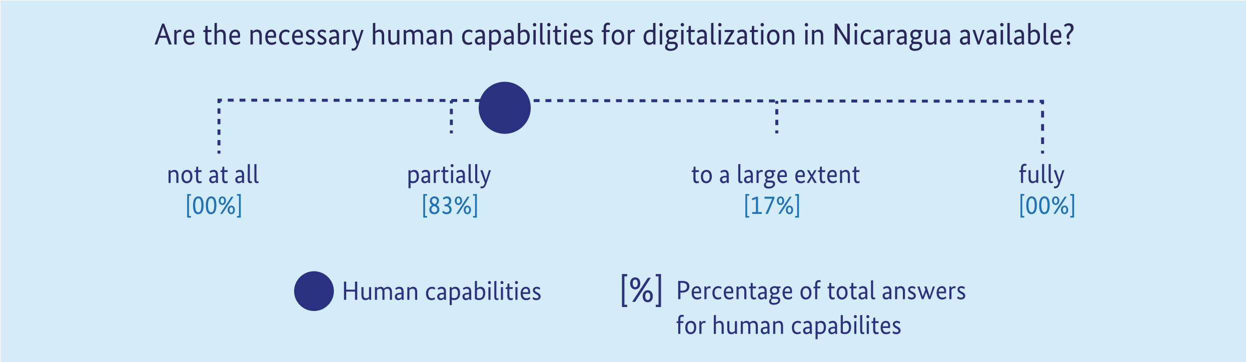


Figure 103. Human capabilities in Nicaragua

Human Capabilities in Nicaragua: Recommendations from Country Experts

- Facilitate exchange between academia and companies
- Establish dialogue among companies within the whole region
- Develop technology-centered degrees and training programs
- Encourage capacity-building and change of view, in both private and public organizations
- Incentivize experts to stay in Nicaragua
- Develop interdisciplinary digital pilots in the energy sector.

Organizational Culture

Experts consider the *organizational culture* in Nicaragua to be partially enabling (Figure 104). Some companies implement pilot programs in Nicaragua as a small test market, with the aim to implement these in larger countries if successful. In addition, *Disnorte-Dissur*, which is almost solely responsible for distribution in the country, has established a department to monitor energy losses and explore innovative ways to cut losses to protect the secondary network, following a Chilean example.

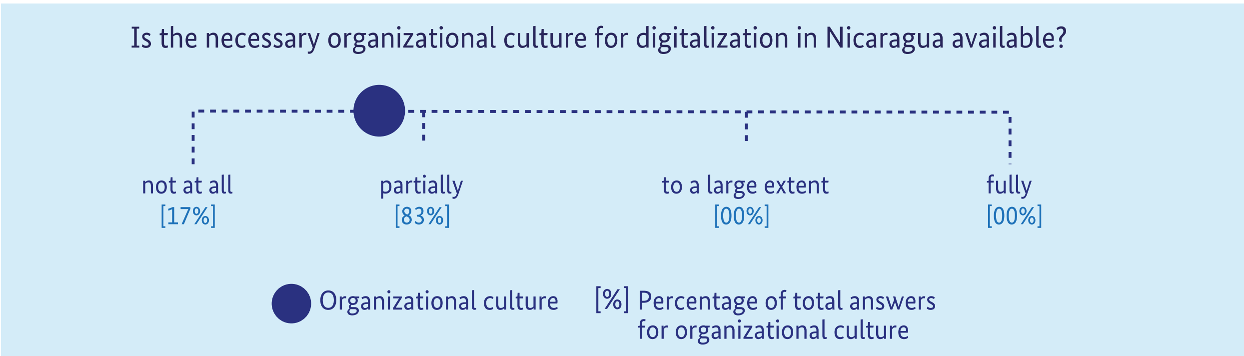


Figure 104. Organizational culture in Nicaragua

Despite progress on some fronts, in both private and public organizations, Nicaragua lacks a culture that supports digitalization. The focus lies on day-to-day operations, with a resistance to change and a corresponding lack of investment in technologies that do not impact cost reduction short-term. In the current system, the decision-making process is highly centralized, with little recognition of potential due to a lack of understanding.

Organizational Culture in Nicaragua: Recommendations from Country Experts

- Facilitate exchange between academia and companies
- Establish political norms to foster digitalization
- Address digitalization in national strategy plans.

Capital and Investment

National capital and investment is considered hardly available (Figure 105). Funds are selectively available from international lenders, including the KfW development bank and the Central American Bank for Economic Integration, which supports AMI and smart grid infrastructure.

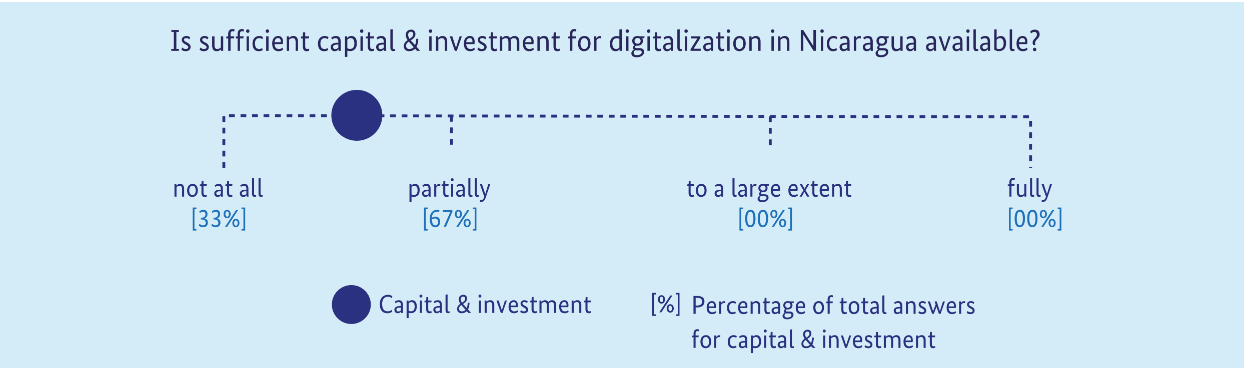


Figure 105. Capital and investment in Nicaragua

But under the current socio-economic situation, there is high market uncertainty and risk, resulting in reluctance to lend, and thus, limited access to capital. If capital is provided, it is generally expensive to compensate for the associated risk.

Capital and Investment in Nicaragua: Recommendations from Country Experts

- Increase presence of multilateral lenders
- Facilitate access through transparency, e.g. create institution for information on potential funding sources.

Public Institutions and Governance

Policies and regulatory measures that enable digitalization show significant potential for improvement in Nicaragua (Figure 106), because they are not a focal point for the regulator. There is government pressure to concentrate on tariff reduction and, therefore, little capacity to build digital expertise. In addition, the current political instability creates ongoing uncertainty.

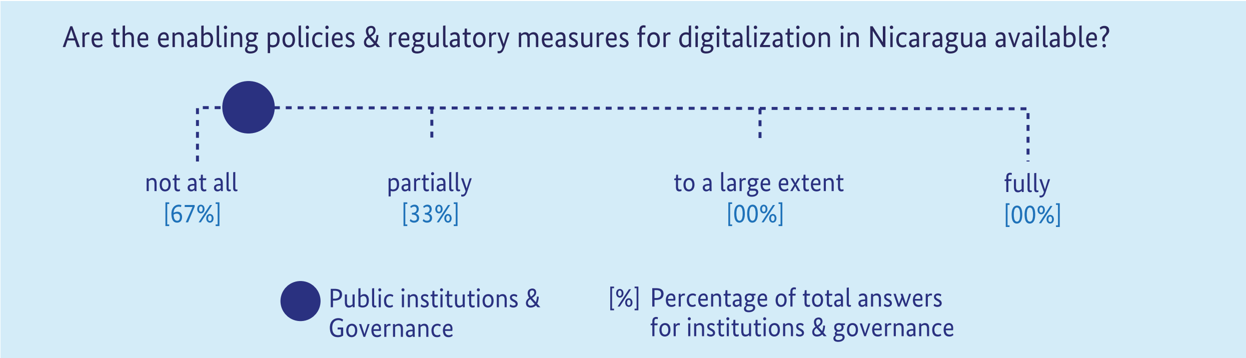


Figure 106. Public institutions and Governance in Nicaragua

Still, while the regulator does not act proactively, there is reactive adaption to advances by the private sector, such as companies that proactively install smart meters, with regulation following.

Public Institutions and Governance in Nicaragua: Recommendations from Country Experts

- Recognize and reflect digitalization within laws and regulation
- Increase proactiveness by public organizations
- Increase pace of regulatory adaptations to match needs.

4.6.5 Digital Technology Use Cases in Nicaragua

Of the use cases identified for this study (Appendix 9), experts explicitly addressed twelve during the interviews. The experts focused on use cases especially relevant within the increased volatility and supply security trend (Figure 107), which ranked as the second most impactful global energy trend for Nicaragua's energy sector in the upcoming years.

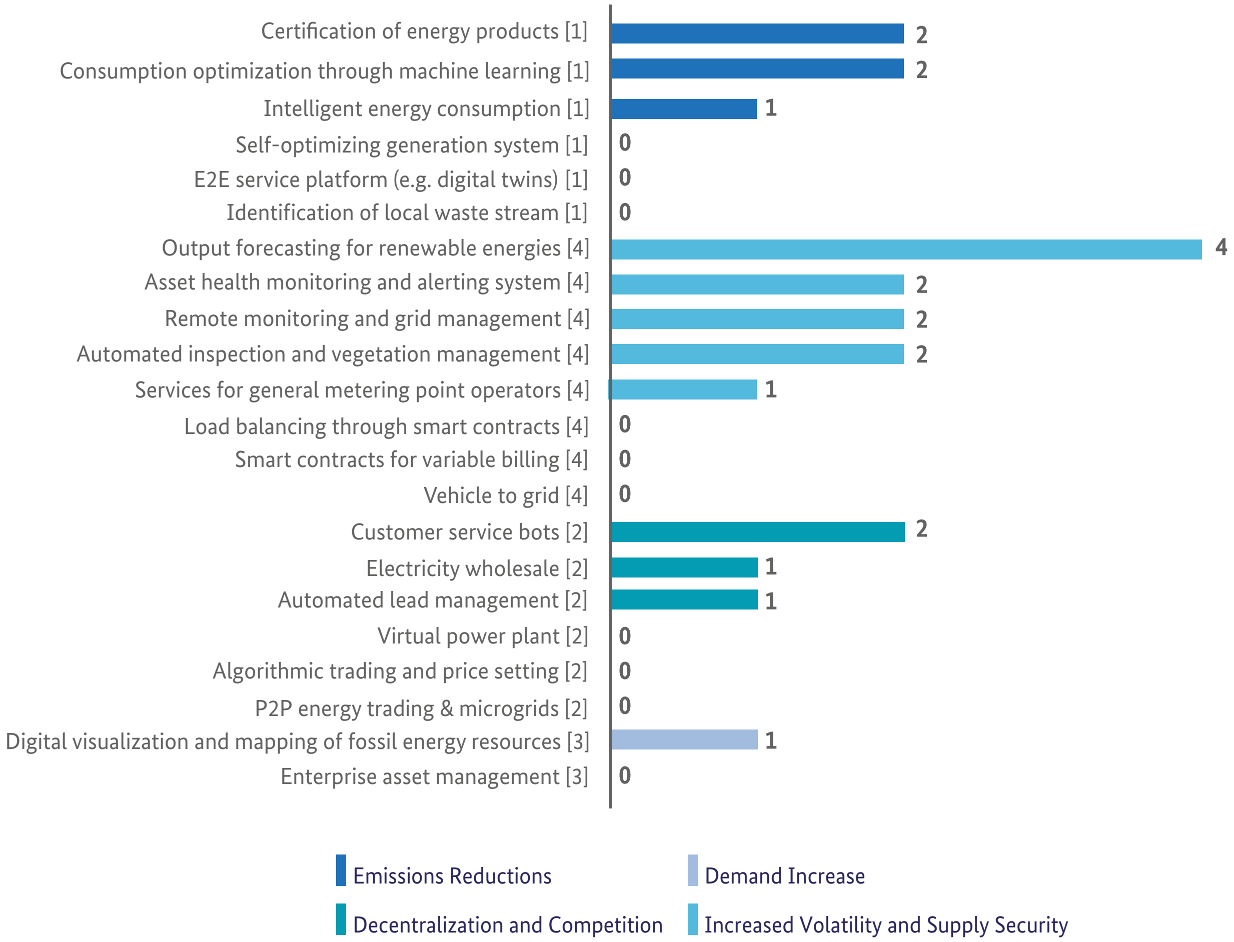


Figure 107. Addressed use cases in Nicaragua

Experts mentioned output forecasting for renewable energies in four different interviews, making it the most prominent use case, followed by remote monitoring and grid management, automated inspection and vegetation management, asset health monitoring and alerting system, and consumption optimization through machine learning, which were all mentioned by two experts each. The perceived relevance of each use case can be seen in Figure 108.

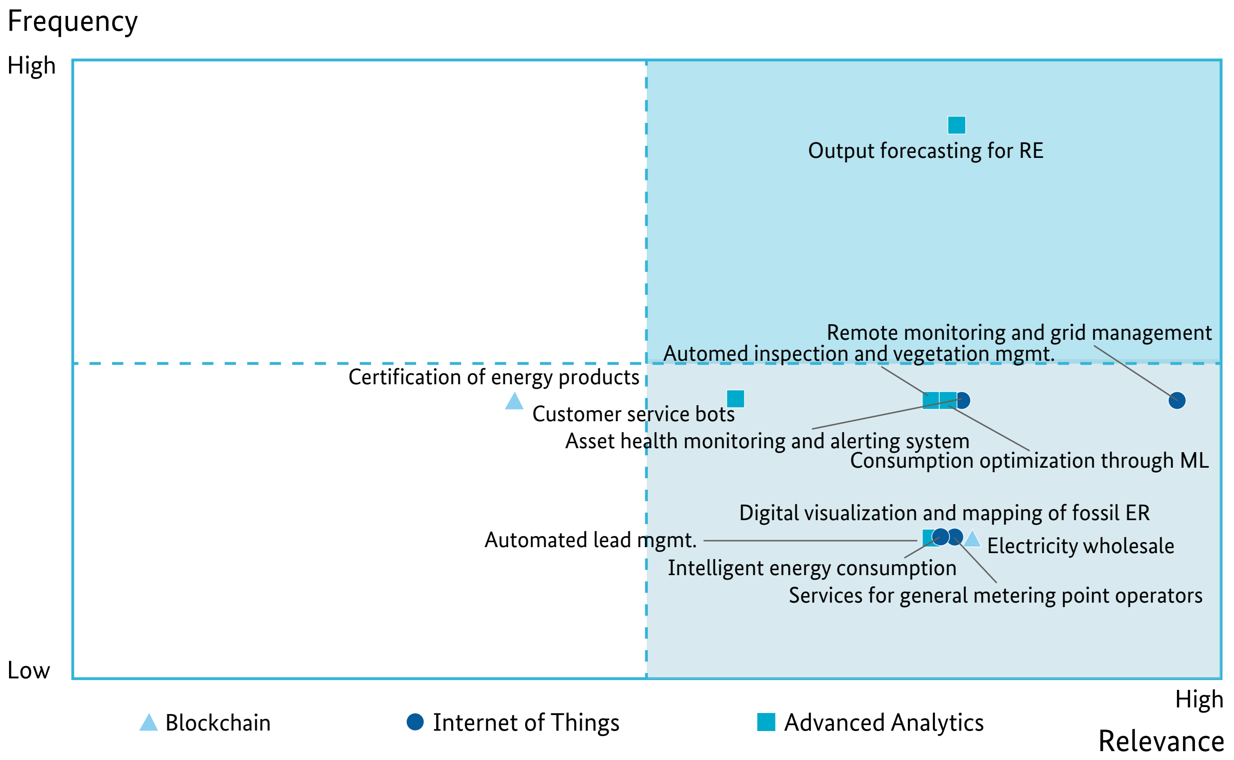


Figure 108. Use case assessment by relevance and frequency in Nicaragua

Of the top ten use cases that were addressed, the top five are sorted by relevance and are highlighted in bold, concentrating on generation and transmission and distribution (Figure 118).

	Generation	Trading	Transmission and Distribution	Consumption²
Emissions Reductions	1 Certification of energy products 4 Self-optimizing generation system 7 Identification of local waste streams			17 Intelligent energy consumption 19 E2E service platform (e.g. digital twins) 22 **Consumption optimization through ML**
Decentralization and Competition	2 Virtual power plant	8 P2P Energy trading and microgrids 10 Electricity wholesale 11 Algorithmic trading and price settings		20 Automated lead management 21 Customer service bots
Demand Increase	6 Digital visualization and mapping of fossil ER	9 Enterprise asset management		
Increased Volatility and Supply Security	3 **Asset health monitoring and alerting system** 5 **Output forecasting for RE**		12 Load balancing through smart contracts 13 **Remote monitoring and grid management** 14 Vehicle to grid 15 **Automated inspection and vegetation management**	16 Smart contracts for variable billing 18 Services for general metering point operators

[1]Including Artificial Intelligence
[2]Including Services

Blockchain | Internet of Things | Advanced Analytics[1]

Figure 109. Priority use cases in Nicaragua

Digital Technology Use Cases in Nicaragua

- **Asset health monitoring and alerting system:** concept and SCADA systems in tests
- **Output forecasting for RE:** pilot program in cooperation with German company (Energy & Meteo Systems, ANSCHI, 2019).
- **Electricity wholesale:** in consideration for MER
- **Automated inspection and vegetation management:** law forbids usage of drones.

Germany

4.7 Germany (Comparator)

General Information

Germany is in Central Europe and is surrounded by several European countries (Figure 110). In terms of *population, social, and technological indicators,* Germany has a significantly higher population than the Central American countries with 83 million people. During the same time, the population has barely grown, increasing by just one percent from 2009 until 2017. Life expectancy at birth has continued to increase and reached 81 years in 2017. The HDI showed a slight increase of 0.02 points and reached 0.94 points in 2017.

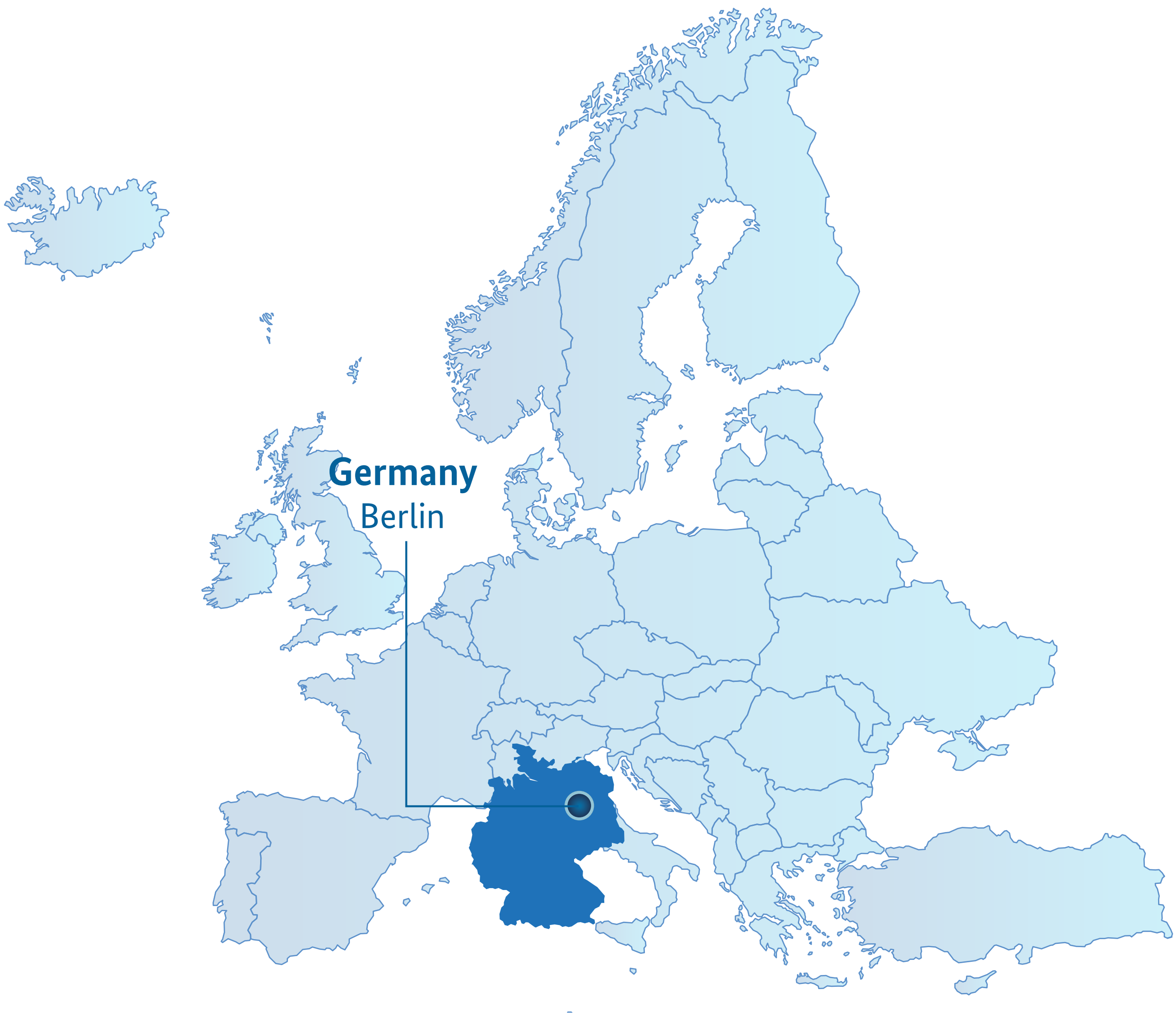


Figure 110. Map of Germany

Regarding *political, regulatory, and legal matters,* Germany has attained 8.61 points in its Democracy Index. In the National Renewable Energy Action Plan, Germany has the ambitious target to achieve 18 percent share of energy from renewable sources in gross final consumption of energy by 2020.

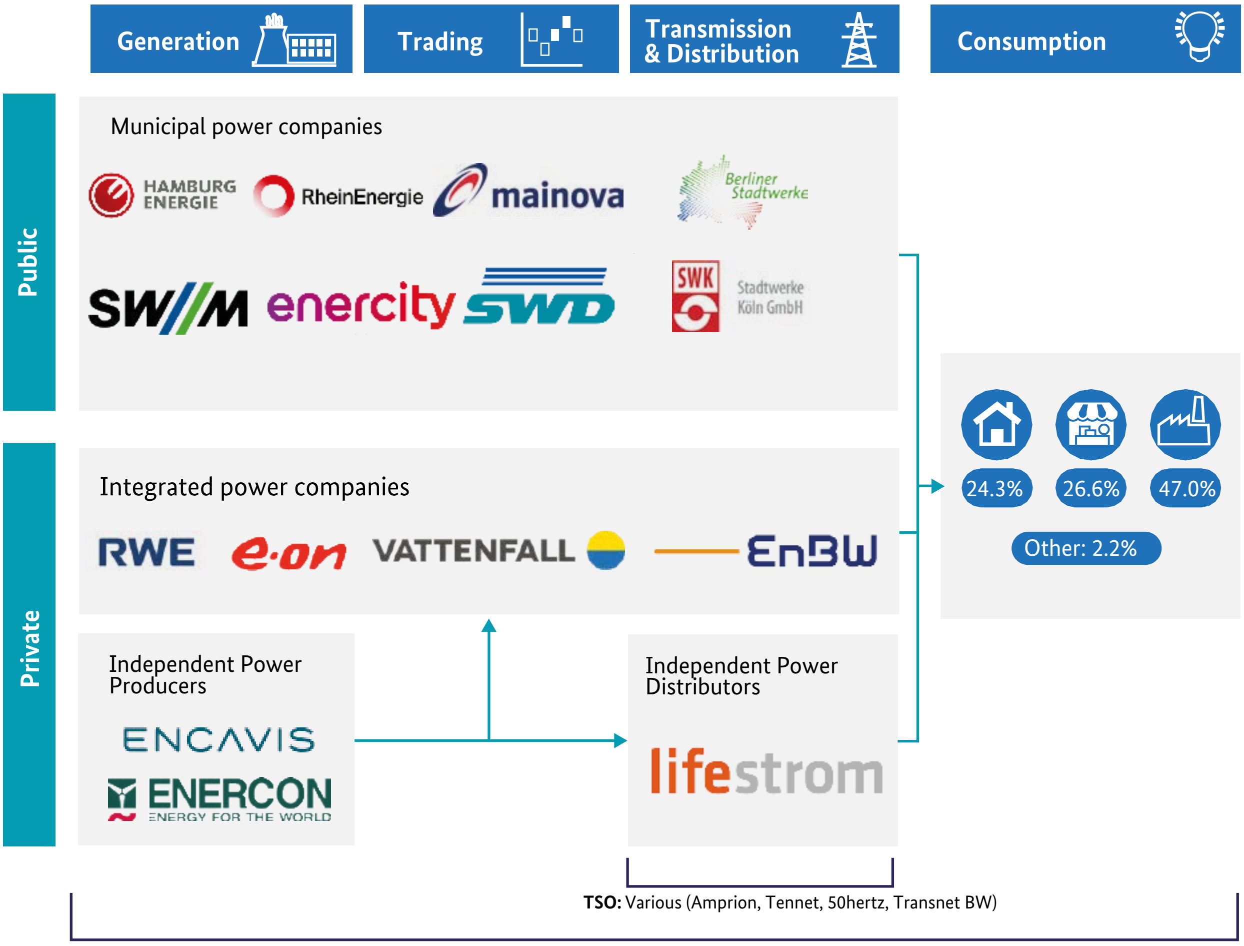
Population, Social and Technological		
- Inhabitants, 2017 (2009):	82.7 (+1)	[Mn]
- Life expectancy at birth, 2017 (2009):	80.6 (+1%)	[Years]
- GINI coefficient, 2014 (2006):	31.7 (+1.3%)	[number]
- Human dev. index, 2017 (2009):	0.94 (+2.1%)	[number]
- Internet penetration, 2016 (2009):	89.6 (+13.5%)	[%]
- Access to electricity, 2016 (2009):	100 (+/-0%)	[%]
- Average price of 1GB mobile data 2018:	6.96	[USD]
Political, Regulatory and Legal		
- Government: Federal democratic parliamentary republic		
- Democracy Index (2017): 8.61		
- According to the National Renewable Energy Action Plan, Germany plans to archieve 18% of energy from renewable sources by 2020		
Economic and Environmental		
- GDP 2017, (2009):	3,677 (+7.6%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	45, 229 (+16.6%)	[USD]
- Unemployment rate, 2017 (2009):	3.8 (+51.6%)	[%]
- Inflation, 2017 (2009):	1.51 (+382%)	[%]
- CO_2- emissions p.c., 2017 (2009):	8.17 (-12.7%)	[tons]

Figure 111. Profile of Germany

On *economic and environmental* matters, the German GDP grew by 7.6 percent from 2009 to 2017. The GDP per capita has increased by 16.6 percent while the unemployment rate decreased by 50 percent during the same period. Also, inflation has increased by 1.20 percentage points and reached 1.51 percent from 2009 to 2017. Compared to Central American peers, Germany shows a significantly higher rate of CO2 emissions per capita–8.71 tons in 2017.

Both the Federal Ministry for the Economy, Affairs, and Energy and the Federal Ministry for the Environment (BMWi, for its acronym in German), Nature Conservation, and Nuclear Safety (BMU, for its acronym in German) are responsible for making energy policy in Germany. In recent years, energy policy in Germany has been shaped by the "Energiewende" (energy transition), a strategy to shift to renewable energy for electricity. In 1991, Germany released its first feed-in tariffs to incentivize renewable energy. This was expanded through the renewable energy act in 2000 that made the feed-in tariffs more attractive and gave grid priority for renewables (Federal Ministry of Economic Affairs and Energy, 2017). More legislation followed in 2011. In 2016, the German government developed the Climate Action Plan 2050, a framework for decarbonizing the German economy. This plan envisions a further increase of RES in electricity generation and emissions reductions in the building and transportation sector (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2016).

Germany's electricity market has been fully liberalized since 1998. There are several vertical integrated suppliers that operate in the areas of transmission, generation, and distribution (Figure 112). There are four Transmission System Operators (TSOs): TransnetBW, 50 Hz, Tennet, and Amprion. The power lines transmit electricity with a maximum voltage of 220 kV or 380 kV. There are four major Distribution System Operators (ODS)—EnBW, E.ON, RWE, and Vattenfall—and a regional and municipal market with over 900 public-sector-owned suppliers. There is a wholesale market for electricity in the form of the European Energy Exchange. The transmission network is owned by four companies (Germany Trade & Invest, 2019).



Regulator: Federal Network Agency (BNetzA)
Policy-making entities: Federal Ministry for Economic Affairs and Energy (BMWi)
Federal Ministry for Environment, Nature Conservation
Building and Nuclear Safety (BMU)

Figure 112. Electricity market structure in Germany

Chile

4.8 Chile (Comparator)

General Information

Chile is located in South America and is adjacent to Argentina and Bolivia along its eastern border, with Peru along the northern border (Figure 113). In terms of population, social, and technological indicators, Chile has experienced a population growth of 7.3 percent since 2009 and today has 18.1 million inhabitants. Both life expectancy and human development have increased since 2009.

Figure 113. Map of Chile

Regarding *political, regulatory, and legal matters,* Chile has attained 7.84 points in the Democracy Index. In its National Energy Policy 2050, Chile describes an increase of its share of renewable energy to 70 percent.

On economic and environmental matters, compared to Central American countries, Chile's GDP showed a comparable growth rate of the GDP, but on a partially higher base value. GDP per capita in Chile has increased by 22.7 percent since 2009. At the same time, the unemployment rate decreased to seven percent and the inflation rate increased by 1.83 percentage points.

The Ministry of Energy is responsible of shaping Chile's energy policy (Figure 114). In 2015 it published its new national energy policy. In this strategy, Chile laid out its plan to advance in the field of energy efficiency and to increase its share of renewable energy in electricity generation to 70 percent by 2050 (Ministry of Energy, 2016).

Population, Social and Technological		
- Inhabitants, 2017 (2009):	18.1 (+7.3%)	[Mn]
- Life expectancy at birth, 2017 (2009):	79.5 (+1.5%)	[Years]
- GINI coefficient, 2015 (2009):	47.7 (-1%)	[number]
- Human dev. index, 2017 (2009):	0.84 (+4.9%)	[number]
- Internet penetration, 2016 (2009):	83.6 (+100%)	[%]
- Access to electricity, 2016 (2009):	100 (+0.4%)	[%]
- Average price of 1GB mobile data 2018:	1.87	[USD]
Political, Regulatory and Legal		
- Government: Representative Democracy		
- Democracy Index (2017): 7.84		
- According to the National Energy Policy 2050, Chile plans to achieve 70% of energy from renewable sources by 2050		
Economic and Environmental		
- GDP 2017, (2009):	277 (+60.7%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	22,767 (+22.7%)	[USD]
- Unemployment rate, 2017 (2009):	7.0 (-28.2%)	[%]
- Inflation, 2017 (2009):	2.18 (+518%)	[%]
- CO_2- emissions p.c., 2017 (2009):	4.57 (+18.7%)	[tons]

Figure 114. Profile of Chile

The electricity market in Chile is fully liberalized (Figure 115). The unbundling of the electricity market started back in 1981. Through dedicated laws, especially the 1982 Electricity Act, the sector was broken up vertically and horizontally. The former state company National Electricity Company (ENDESA, for its acronym in Spanish), was split into several companies for electricity generation, transmission, and distribution. The National Energy Comission (CNE, for its acronym in Spanish) is responsible for analyzing and setting the tariffs and technical norms. The Electricity and Fuels Superintendence (SEC, for its acronym in Spanish) oversees the proper operation of the market. In addition, there is a contracts market where you can freely negotiate prices.

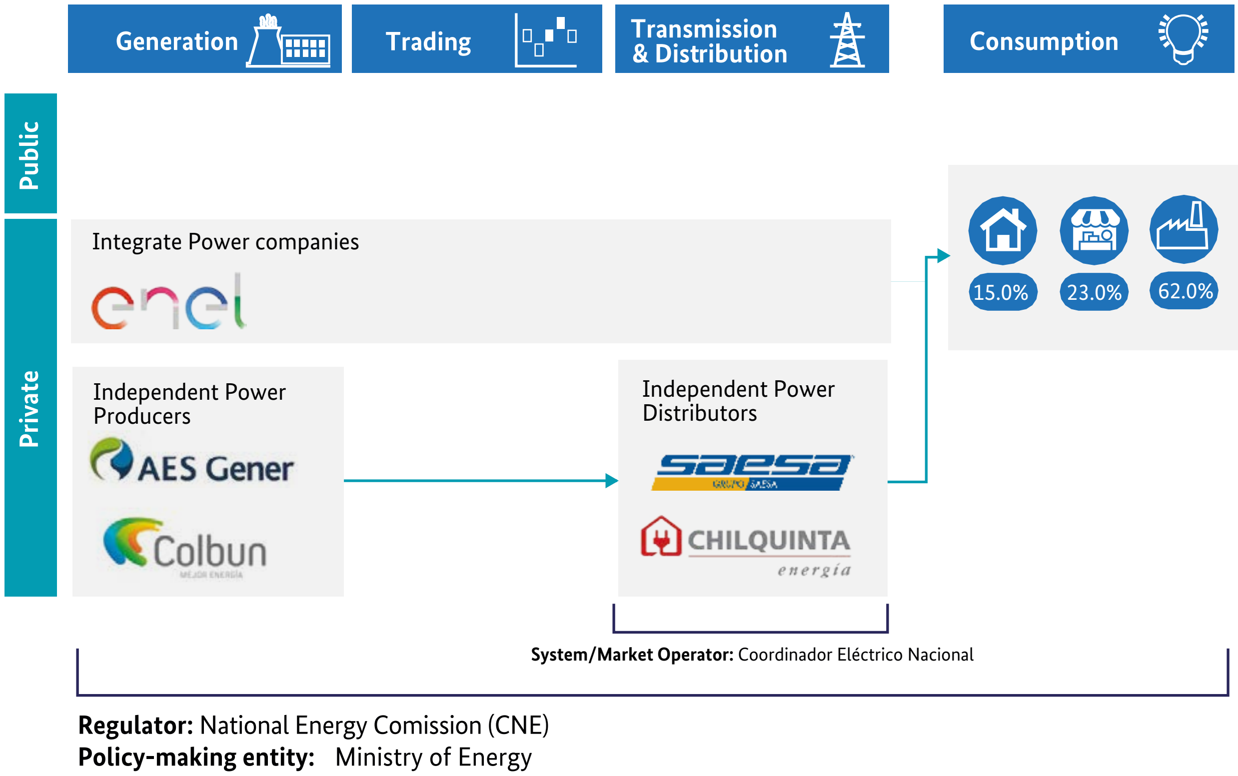


Figure 115. Electricity market structure in Chile

4.9 Central America

General Information

The countries of study include Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. Together with Belize, these countries make up the region Central America (Figure 116).

Figure 116. Map of Central America (countries under consideration)

From a *population, social, and technological* perspective, between 2009 and 2017 the region's population grew by 13 percent (Figure 117), an increase that is partly due to increasing life expectancy at birth. Concerning equality and development, there has been a reduction of the GINI coefficient. In addition, the Human Development Index (HDI) increased and internet penetration rate rose, with 37 percent of the population now having internet access. The higher prosperity of the region is reflected in a higher gross domestic product (GDP) per capita, up by 26 percent between 2009 and 2017.

In recent decades, Central America has strived to come together under a common, regional cooperation framework. Therefore, in 1991 SICA was founded by Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. The main aim was to integrate Central America to constitute a region of peace, liberty, democracy, and development. Belize and the Dominican Republic joined as full members in 2000 and 2013, respectively (SICA, 2019). In 2007 the region launched its common *Sustainable Energy Strategy* 2020, setting targets to reduce fossil fuel dependency, increase the share of renewable energy, reduce GHG-emissions, and increase efficiency in energy supply and demand.

Through SICA's framework treaty for the electricity market in Central America, agreed by the governments of the countries of study, the Regional Electricity Market (MER) was created in 2000 and is considered as a 7th market, on top of existing national markets and systems. Currently, the market includes 232 participants, including generators, distributors, retailers, and large consumers (ECLAC, 2018). The physical infrastructure is the Regional Transmission Network (RTR, for its acronym in Spanish). Since 2014, all six countries are covered from Guatemala to Panama through the SIEPAC network, which includes a 300 MW and 230 kV transmission line (E&N, 2014).

Population, Social and Technological		
- Inhabitants, 2017 (2009):	47.8 (+13.2%)	[Mn]
- Life expectancy at birth, 2017 (2009):	74.8 (+2.3%)	[Years]
- GINI coefficient, 2014 (2009):	47.6 (-4.2%)	[number]
- Human dev. index, 2017 (2009):	0.70 (+5.2%)	[number]
- Internet penetration, 2016 (2009):	37 (+112.7%)	[%]
- Access to electricity, 2016 (2009):	92.2 (+7%)	[%]
- Average price of 1GB mobile data 2018:	5.12	[USD]
Political, Regulatory and Legal		
- In 1991, the six countries found the SICA, whit the objetive to constitute a region of peace, liberty, democracy and development		
- The Sustainable Energy Strategy 2020 was launched in 2007, with a focus on the promotion of a sustainable dvelopment of the regional energy sector, especially through energy efficiency		
Economic and Environmental		
- GDP 2017, (2009):	256.8 (+89%)	[Bn USD]
- GDP p.c. 2017, (PPP, 2009):	7,672 (+26%)	[USD]
- Unemployment rate, 2017 (2009):	4.23 (-20.4%)	[%]
- Inflation, 2017 (2009):	2.5 (29.7%)	[%]
- CO_2- emissions p.c., 2014 (2009):	1.16 (+4.5%)	[tons]

Figure 117. Profile of Central America

While the Network Owner Company (EPR) is the owner and operator of the SIEPAC line, the EOR is responsible for the dispatch and electricity exchanges between the countries. The Regional Commission for Electricity Interconnection (CRIE, for its acronym in Spanish) is responsible for regulation of trade relationships between the public and private entities connected to the system and for sets the tariffs (CRIE, 2019). The governing body that facilitates compliance with the commitments of the parties and coordinates relationships among regional MER institutions is the MER's Steering Committee (CDMER; CRIE, 2017). CDMER promotes the development of the MER and takes steps to achieve the objectives and goals of the treaty. In addition, regulators and market participants cooperate with each other through CECACIER (Regional Committee of CIER for Central America and the Caribbean), a member of the Regional Commission of Energetic Integration (CIER).

4.9.1 Enabling Framework Conditions for the MER

Digital Infrastructure

The experts view the digital infrastructure as a limiting factor in digitalization. Nevertheless, the countries are exchanging ideas to implement a robust telecommunications infrastructure that includes using fiber optic lines operated by SIEPAC (REDCA, Central American Telecommunications Network).

Human Capabilities

Across the region, institutions like the EOR experience a shortage of digitally skilled specialists. This is particularly relevant within cyber-security, causing network-related reliability concerns.

Regional Regulation

Some of the regional institutions work on partially outdated regulation. This holds true for the EOR, which is operating on regulation implemented from 2002–2005. Hence these regulatory statutes only partially contain digitalization-specific regulation, if they contain any at all (e.g. on privacy and data management). Lack of regulation hinders the implementation of technology-based solutions. Still, strong national, but not regional, regulation initiatives exist that include topics specific to digitalization.

4.9.2 Regional Challenges

Each country in the region faces a set of specific challenges stemming from its unique energy system and experience with global energy trends. Figure 118 illustrates a clustered selection of 107 challenges suggested by the experts. Based on relevance (calculated by frequency), the graphic below displays the local and regional geopolitical scope of these challenges by color.

Challenges range throughout the energy value chain from generation to consumption. Additionally, there is a specific set of regional challenges: data *quality insufficiency, financial straits, institutional, energy losses,* and *demand forecasting.*

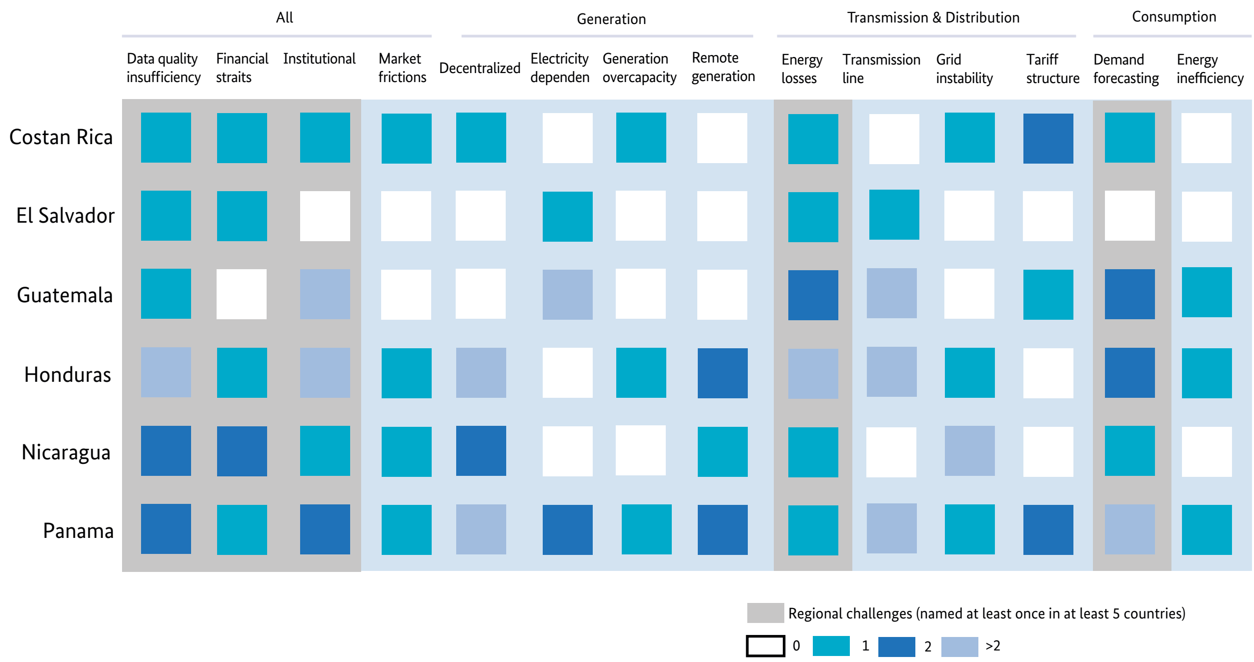


Figure 118. Selection of clustered regional challenges

4.9.3 Recommendations and Digital Technology Use Cases for MER

Central America: Recommendations from the Regional Experts

- Create a centralized, cross-border data base
- Update regional SCADA systems and enhance national ones
- Develop regional smart meter deployment strategy.

Digital Technology Use Cases for Central America

- **Customer service bots**: AI-based providing direct answers
- **Output forecasting for RE**: prediction of generation
- **Data integrity**: Blockchain-based centralization of data
- **Intelligent energy consumption**: IoT and AI-based energy, e.g. for prospective office buildings, including the new headquarters for EOR.

5. Digital Readiness Benchmark

In this chapter we introduce methods for two basic benchmark analyses for estimating digital readiness among the six Central American countries we investigated. These methods include the self-assessed benchmark analysis, which is the Central American experts' assessments, and parameter-based benchmark analysis, which considers world rankings for Germany and Chile.

5.1 Self-Assessed Digital Readiness Benchmark

In this section we compare the results from the analysis of the five framework conditions across the six Central American countries based on information we gathered from experts[12] to establish a regional benchmark. Taking a closer look at the regional benchmark, as illustrated in Figure 119, on average, the most favorable framework conditions within Central America can be found in Panama, followed by Costa Rica and Guatemala. In contrast, Nicaragua and Honduras, show the largest potential for improvement in digital readiness and ability to implement digital technologies and use cases.

The experts commonly agree that the framework condition *digital infrastructure* has a basic level of availability. This assessment is reflected in internet penetration, already present with ongoing efforts to develop it further, such as deployment of smart meter and fiber optic networks.

Considering *human capabilities,* Costa Rica stands out by having this framework condition in place to a large extent. This difference relative to regional peer countries is reflected in the high regional literacy rate (97.8%) and a strong awareness of digitalization and digital technologies within academia (Appendix 7).

[12] Please note that this assessment is primarily based on expert opinions–i.e. they represent subjective opinions, which we complemented with data from desk research.

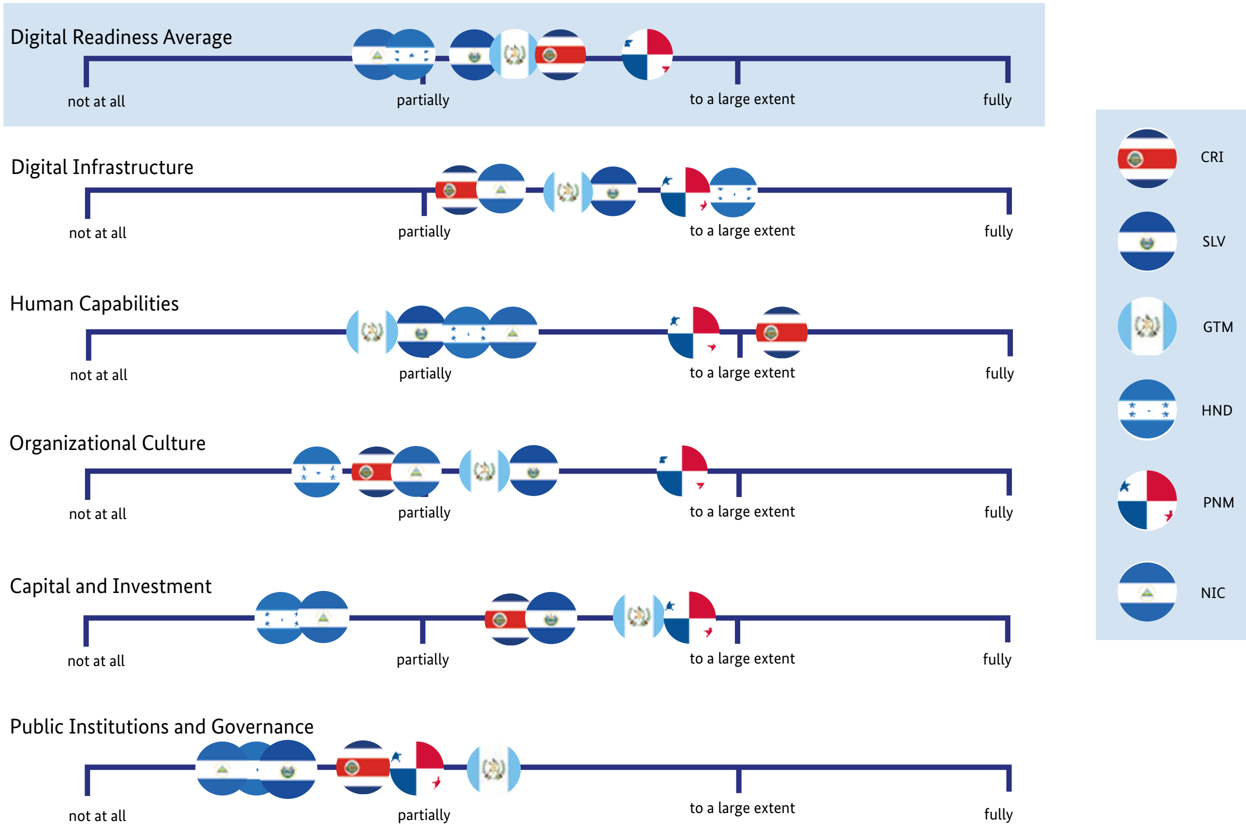


Figure 119. Digital readiness benchmark

The most enabling *organizational culture*, reflected in the institutionalization of innovation and digital tech, can be found in Panama. In contrast, in Honduras this condition appears to limit implementation of digital use cases. This difference can be partly attributed to the diverging market structure, as liberal markets with private agents usually display higher innovative capacities.

The framework condition *capital and investment* is a strong facilitator of digitalization in Panama and Guatemala. This is based on the relatively stable political and economic situations, liquid capital markets, access to loans, and venture capital institutions that finance technological innovations. However, in Nicaragua, *capital and investment* limits digitalization, partially induced by the unstable socio-economic situation. Also, in the Central American countries we reviewed, capital is interconnected with the regulator, as financing must be recouped through tariffs.

The digital enabler public *institutions and governance* appears to be a strong facilitator in Guatemala. This assessment is based on the well-organized electricity market and government modernization policies. This condition is a strong limiter in Nicaragua and Honduras, influenced by the socio-economic instability in Nicaragua and the partially uncertain market structures in Honduras.

5.2 Parameter-Based Digital Readiness Benchmark

In the non-regional benchmark analysis, comparing the digital readiness of Central America with Germany and Chile indicates there is potential for improvement in Central America throughout the digital framework conditions. Nevertheless, there are substantial differences with respect to the level of divergence (Figure 120).

Taking into consideration regional benchmarks, the most beneficial digital framework conditions among the countries of Central America are Costa Rica, Panama and Guatemala.

5.2.1 Digital Infrastructure

In general, with respect to this *digital infrastructure,* differences are minor, as Germany and Chile are both also in the process of large-scale smart meter rollout. Nevertheless, indicators like overall internet penetration, being 90 percent in Germany and 83.6 percent in Chile, partially explain the remaining gap. Germany is a leader in terms of the quantity of broadband fixed subscriptions–fourth in the world; internet users–eighth in the world; and cellular mobile network–fifteenth in the world. At the same time, Guatemala is the regional leader in digital infrastructure, holding the 81st place in the world in terms of the quantity of broadband fixed subscriptions, 74th place for internet users, and 57th for cellular mobile network (CIA, 2018).

5.2.2 Human Capabilities

Regarding *human capabilities,* according to the Global Competitiveness Report, both non-regional benchmark countries show a high tertiary education enrollment rate. Chile holds seventh place in the world, and Germany holds 32nd, while Central America's leader, Costa Rica, is in 52nd place. Germany is the leader in comparison group in terms of the quality of education system ranking ninth in the world. Costa Rica's education system ranks 27th and Chile's ranks 86th. In terms of availability of scientists, Germany is performing the best and holds eleventh place in the ranking, Chile is in 22nd place and Costa Rica is at 27th place (WEF, 2018). Considering the Human Development Index ranking, which reflects multiple human capability indicators, Germany is sixth in the world, Chile is 41st, and Costa Rica is 68th (UNDP, 2016).

Considering the non-regional benchmark, 83 percent of Germany's population (25+) has at least completed upper secondary education, in comparison to 38 percent in Costa Rica. Germany has seen a strong rise in the number of university programs specializing in digital technologies (e.g. degrees offered by technical universities like RWTH Aachen in Data Analytics and Decision Science). Additionally, there are strong institutional ties between business and academia, which leverages research synergies and enhances spillover effects (WB, 2016).

5.2.3 Organizational Culture

We compared Central America to its comparators in terms of business culture. Indicators like the Global Competitiveness Report have ranked Germany as fourth in the world in terms of its company spending on research and development, whereas Panama is 59th and Honduras is 102nd. In addition, Germany shows a high level of business sophistication, an index of global competitiveness. It is ranked fifth in the world, whereas Panama is 68th and Honduras is 88th (WEF, 2018).

In the non-regional benchmark, in Germany and Chile, due to the market structure, companies in the energy value chain have increased market pressure to engage in research and development as well as innovation and digital technology deployment. This situation is reflected in the widespread installation of in-house-incubators and venture capital funds (e.g. Innogy Venture Capital by Innogy and Green:field by Vattenfall). Due to the local market structures, including public, vertically integrated companies, these incentives are less available in Central America.

5.2.4 Capital and Investment

In terms of financial market development through *capital and investment,* Germany is placed twelfth in the world according to the Global Competitiveness Report ranking, while the best performing Central American country, Panama, is fourteenth and Guatemala is eighteenth. In terms of venture capital development, Germany is sixth, Panama is 26th and Guatemala is 60th (WEF, 2018). Chile and Germany both have multiple public funding schemes in place enhancing the implementation of digital technologies and use cases. This includes schemes offered by CORFO in Chile, KfW in Germany (High-Tech Gründerfonds), and the EIB (InnovFin) in Europe.

5.2. 5 Public Institutions and Governance

We reviewed different sources to compare *public institutions and governance.* The World Justice Project, an initiative that measures how the rule of law is experienced and perceived by the public in 126 countries, ranked Germany sixth in the world while Chile ranked 27th and Costa Rica 24th (WJP, 2018). At the same time, the Global Competitiveness Report ranked Germany eighteenth in terms of transparency of government policymaking, 29th in irregular payments and bribes, and seventh in burden of government regulation. Costa Rica, the Central American leader in public institutions and governance, was ranked 38th in terms of transparency of government policymaking, 55th in irregular payments and bribes, and 125th in burden of government regulation (WEF, 2018). Germany holds eleventh place in the word in terms of corruption perception, Chile holds 27th and Costa Rica holds 48th (Transparency International, 2018).

Within the non-regional benchmark, Chile and Germany have more proactive regulations in place, setting policy agendas with a focus on digitalization and modernization of the energy sector and acting as role models. Examples include initiatives like the Blockchain-based energy data certification as developed by the Chilean energy commission CNE.

Detailed information on all parameters used in this digital readiness benchmarks is described in Appendix 12.

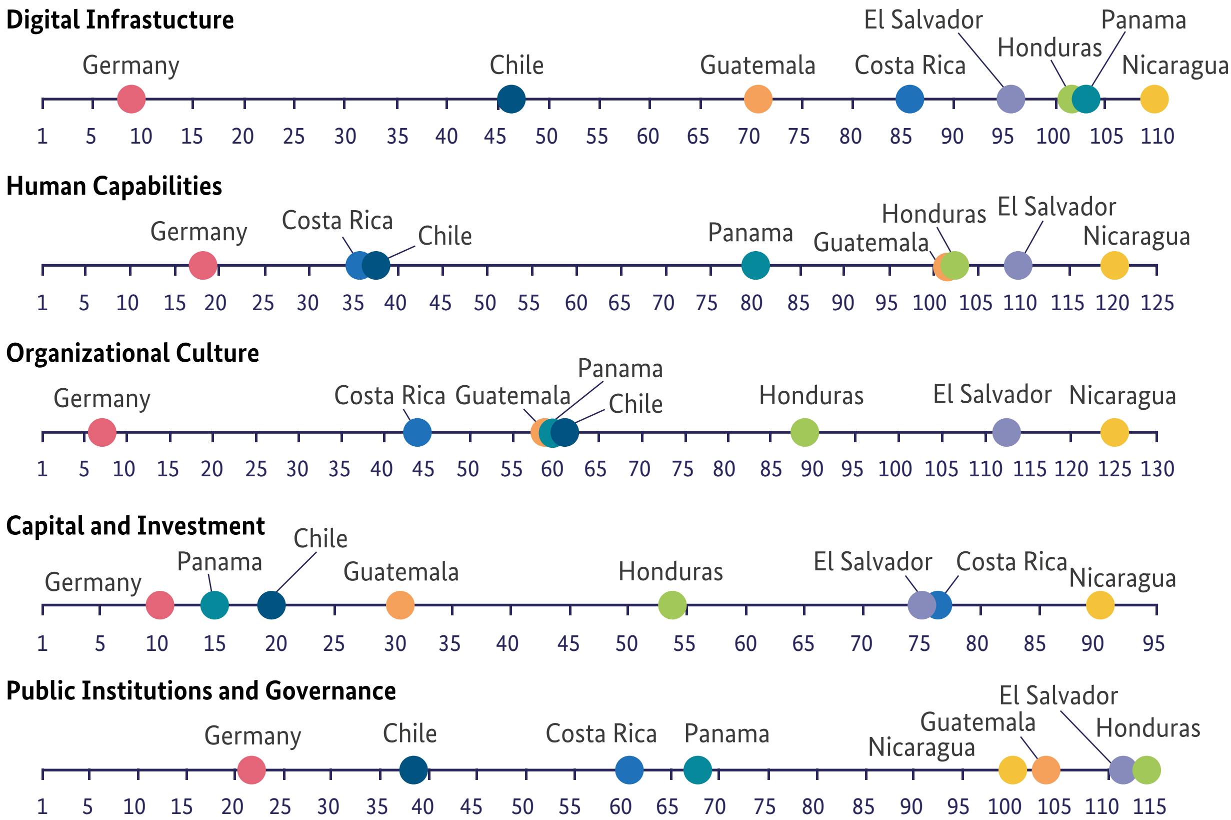


Figure 120. Parameter-based ranking of digital readiness

5.3 Benchmarks' Comparison

In this section we discuss the results of the two digital readiness benchmarks, self-assessed and parameter-based.

5.3.1 Digital Infrastructure

Benchmarks differ for *digital infrastructure* conditions. Honduras, the region leader in terms of digital infrastructure under self-assessed benchmark, holds 102nd place according to the parameter-based benchmark. Also, a great difference is observed for Costa Rica, which holds 86th place under CIA ranking and takes the second place in this region, while under self-assessed benchmark it takes the worst position. At the same time, both digital readiness benchmarks confirmed that Germany and Chile take leading positions in terms of digital infrastructure.

5.3.2 Human Capabilities

To a large extent, both benchmarks show similar results in the *human capabilities* framework, but there are still some differences. Taking the last position under the self-assessed benchmark, Guatemala is third in the region according to parameter-based benchmarking. In addition, Nicaragua holds 120th place and is last among Central American countries according to the parameter- based benchmark, while self-assessed benchmark states that it takes the third place in Central American region. Under both methods, Germany and Chile hold leading positions in human capabilities, and Costa Rica holds the dominant role among Central American countries.

5.3.3 Organizational Culture

The results from these benchmark analyses regarding the *organizational culture* framework look much different. Therefore, Costa Rica holds 44th place in terms of the organizational culture framework according to the parameter-based benchmark analysis in comparison to the worst position in the Central American region based on experts' estimation. In the regional benchmark analysis, Panama is the leader in Central America, as observed in both benchmarking methods.

5.3.4 Capital and Investment

The results of benchmarking in the *capital and investment* framework are quite similar, but still there are some distinctions. Holding the last position in the Central American region under self-assessed benchmark, Honduras is among the top three countries under parameter-based benchmark as it holds 38th place in terms of financial market development (WEF, 2018). On the other hand, the results on leading positions of Panama and Guatemala among Central American countries are similar in both benchmarks.

5.3.5 Public Institutions and Governance

Self-assessed as well as parameter-based benchmark shows almost identical results in *public institutions and governance.* Guatemala, however, is the leader in the Central American region under self-assessed benchmark. Benchmark analyses for Germany, Chile, Costa Rica and Panama, show similar results in the *public institution and governance* framework.

6. Risk Analysis

Based on experts' opinions on digital framework conditions, this chapter elaborates on risks that inhibit digitalization and risks posed by the digitalization of the energy sector in Central America. Furthermore, based on the identified set of risks, respective mitigation measures are presented (Figure 121). Therefore, this section is subdivided into two sections:

1. First, we conducted the pre-digital risks and respective mitigation measures that result from the absence of framework conditions. This part is based on results from Survey B. We illustrate the risks with selected examples.
2. Subsequently, the second part presents post-digital risks that result from the implementation of digital technologies and use cases and their respective mitigation measures. This part is based on the results from Survey B and complemented by additional desk research.

For both types of risks, we give an overview of the potential impact and provide country-specific examples. For the *pre-digital risks*, we also provide the likelihood of the risk in form of a risk assessment from the experts.

1 **Pre-digital** risks: that result from the absence of the framework conditions

- **Legacy systems risk**
- **Labor & skills risk**
- **Organizational transformation risk**
- **Economic risk**
- **Legal & regulatory risk**

2 **Post-digital** risks: that result from the implementation of digital technologies and use cases

- **Technology failure**
- **Privacy loss**
- **Unauthorized access & data loss**
- **Technological employment transition**
- **Environmental harm**

Figure 121. Identified risks

6.1 Pre-Digital Risks

Based on experts' estimations of the five framework conditions in the countries we investigated, we have derived the following pre-digital risks[13]:

6.1.1 Legacy Systems Risk

The legacy systems risk is related to the *digital Infrastructure* framework condition and reflects all the possible threats that may arise from outdated/ rigid infrastructure. Companies need to leverage modern technologies to introduce digital solutions across the energy value chain. Outdated equipment may weaken company operations and obstruct the installation of new technologies. Therefore, neglected or underperforming digital infrastructure may be the biggest bottleneck in the process of digitalization of the energy sector.

[13]The risks are based on expert-based, country specific subjective assessments. This means that even if infrastructure is available in a specific country, depending on individual expectations, the perceived availability might be lower than in a country without the specific infrastructure.

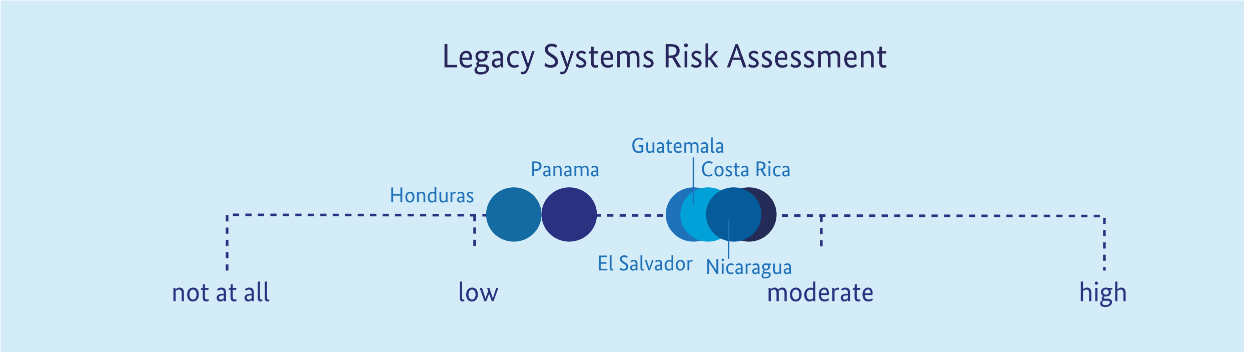


Figure 122. Legacy systems risk assessment

All Central American countries show low-to-moderate legacy systems risk, while Costa Rica has the highest score (Figure 122). Concerning Nicaragua, the experts mentioned grid stability issues, which can potentially disrupt the data network.

Mitigation Measures

- Update old equipment and invest in smart grid infrastructure (smart transformer stations, sensors, etc.)
- Improve the internet penetration in rural areas
- Increase the data availability by introducing smart meters
- Increase bandwidth and network speed
- Invest in software solutions and AI to leverage available data.

6.1.2 Labor and Skills Risk

The labor and skills risk is linked to the *human capabilities* enabler, which is defined as the availability of skilled labor with specialized knowledge of the digital industry necessary to support the energy digitalization. The absence of the skilled workforce may restrain the ability to implement technological innovations.

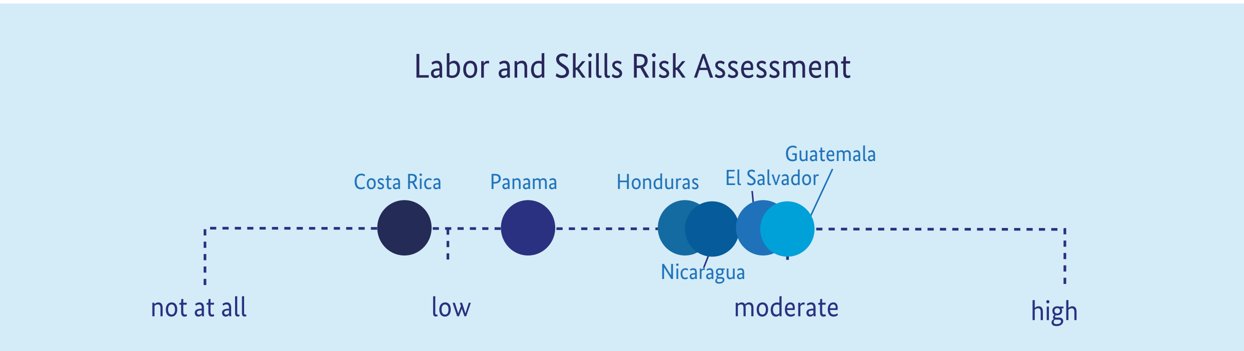


Figure 123. Labor and skills risk assessment

Across Central America, Costa Rica has the lowest labor and skills risk (Figure 123). At the same time, experts suggested that Guatemala and El Salvador experience the highest risk of having a skilled labor force shortage, which in turn poses a risk to the digitalization process.

Mitigation Measures

- Establish collaboration among companies, academia, and the public sector to evaluate the supply of skilled workers
- Identify future competence and skill needs to shape the educational policy agenda
- Increase investment in digital skills development and promote ICT education in universities and schools
- Train the workforce for changing business requirements.

6.1.3 Organizational Transformation Risk

The organizational transformation risk is directly linked to the *organizational culture* enabler, which defines the corporate attitude towards digital innovations and new technology solutions. Management and workforce tend to be risk-averse. They prefer systems they are familiar with instead of pursuing innovation (anchoring). They typically associate the introduction of new technologies with high costs, changes in job roles and possible job loss, and the need for extensive training. Resistance to change may significantly affect the digitalization process, hinder acceptance of new technologies, and dampen motivation to pursue new ideas.

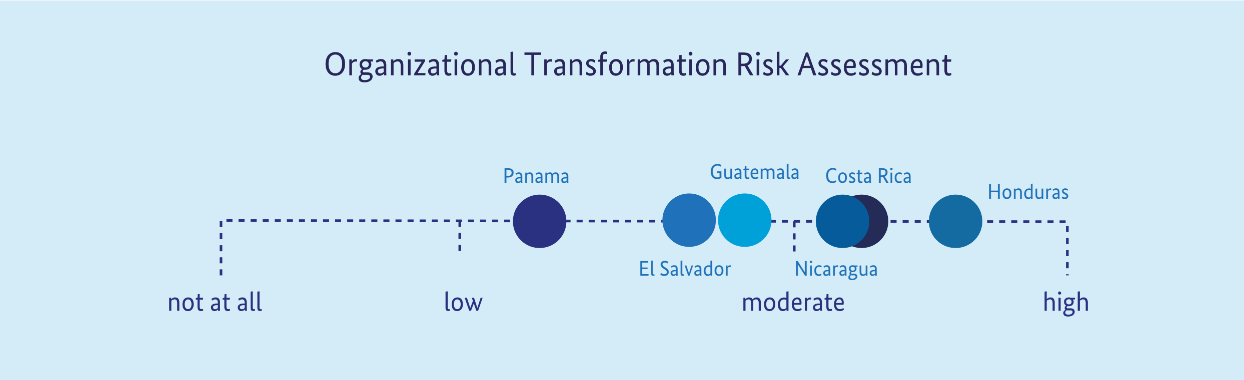


Figure 124. Organizational transformation risk assessment

Honduras has the highest organizational transformation risk, followed by Costa Rica and Nicaragua. Guatemala and El Salvador have a moderate score while Panama has a rather low score (Figure 124). At the same time, private and public companies in all six Central American countries face the risk of resistance to adapt new digital technologies. Organizations are not eager to procure the digital solutions and prefer outdated but familiar equipment. In Guatemala, Honduras, and Panama the experts have emphasized strong social resistance in implementing basic digital infrastructure. This frame of mind possibly stems from a negative attitude towards technology.

Mitigation Measures

- Design and implement the digitalization strategies and targets within the companies
- Involve interested parties in the planning of digitalization strategies, promote interorganizational information exchange (best practices, etc.)
- Promote the digital acceptance among employees by creating motivation schemes
- Communicate the benefits of the digitalization initiative to the affected workers
- Train employees (and the population) on usage of digital technologies and innovative solutions
- Foster the entrepreneurship culture that allows experimentation
- Implement the technology through the lens of user adoption to enhance consumer experience.

6.1.4 Economic Risk

Economic risk arises from the *capital and investment* enabler, which reflects both the availability of capital and the viability of the investments in digital technologies. Public and private investments are essential to building network infrastructure. At the same time, proper investment analysis is necessary to ensure that technology installation will lead to efficiency gains. The absence of respective risk assessment and investment analysis of digital solutions can lead to underutilization and failure to implement the innovation within the existent system and can create a negative attitude towards digitalization in society.

More than a half of the region's countries have a low-to- moderate economic risk: Panama, Guatemala, El Salvador, and Costa Rica. Only two countries, Honduras and Nicaragua, show high economic risk (Figure 125). In Costa Rica, Guatemala, and El Salvador, the main economic risk stems from the inability of policymakers and company management to target the right technology, identify the most efficient solution to the problem, and provide solid investment analyses. In Guatemala and Honduras, it is challenging to keep a permanent level of investment in innovative technology, as digitalization is not the key focus of policy agenda.

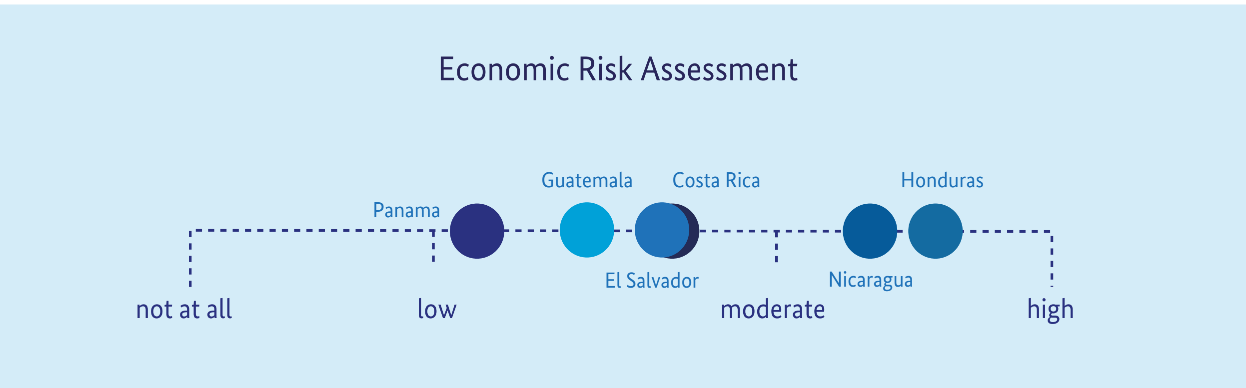


Figure 125. Economic risk assessment

Mitigation Measures

- Provide target analysis of digital technology to focus on the most relevant issues
- Conduct investment analysis to ensure financial viability (and profitability of digital solutions)
- Establish a government investment plan to accelerate the move towards digitalization
- Create digital awareness among financial institutions
- Develop new financial instruments and promote innovative funding opportunities (angel investors, venture capitalists).

6.1.5 Legal and Regulatory Risk

Legal and regulatory risk is linked to the *institutions and governance* enabler and underlies the inefficiency and burden of government regulation that may inhibit the digitalization of the energy sector. In the first place, the absence of regulatory stability can pose a risk to digitalization processes. Next, the government may negatively influence the cost-structure of the companies by changing the "rules of the game," such as by introducing encumbering legislative procedures (increasing the compliance costs), setting the fixed rates that companies should charge (intervene in price-setting process), or by changing the competitive landscape.

Finally, often the extant bureaucracy hinders efficient decision-making and deters investments by increasing the costs and time that are needed to adopt new technology solutions.

At the same time, the absence of regulatory standards for the digital infrastructure may inhibit the compatibility of systems across the value chain, increase the number of low-quality installations, and deteriorate consumer experience. Thereafter, a balanced regulatory mix is necessary to both protect consumer interests and support the efficient implementation of digital solutions.

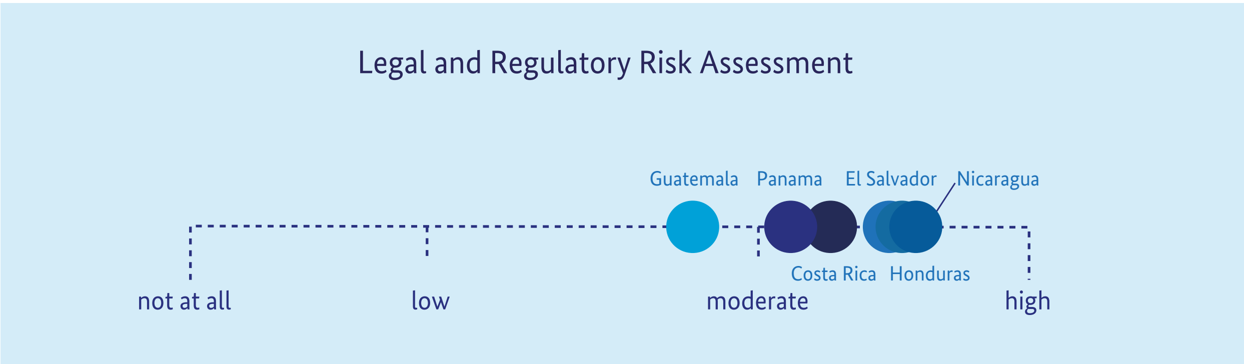


Figure 126. Legal and regulatory risk assessment

All Central American countries except Guatemala have high legal and regulatory risk (Figure 126). In El Salvador and Honduras, the legal and regulatory risk partially rises from missing regulatory initiative and lack of establishing a proactive policy. In Nicaragua, the risk arises from the unstable political situation, which might interfere with existing policy initiatives. In Costa Rica, El Salvador, and Guatemala the lack of standards and energy efficiency norms is perceived as a significant risk to energy digitalization. In El Salvador and Honduras, we observed that the lack of well-functioning institutions significantly hinders digitalization (namely lack of property rights and transparency). In Costa Rica legal and regulatory risk lies within possible changes in market competition, namely deregulation.

Mitigation Measures

- Establish a comprehensive digital policy with clear targets through policies that are supplemented by international agreements/commitments
- Establish a range of quality standards necessary to maximize interoperability
- Encourage data sharing among the incumbents if such measures promote digitalization targets
- Create a stable regulatory environment: regulation of energy sector must be robust; changes in rules need to be as predictable as possible.

6.2 Post-Digital Risks

Digital transformation makes the energy systems more efficient, intelligent, and sustainable. At the same time, digital technologies significantly transform the risk landscape once they are implemented. We identified the following *post-digital* risks.

6.2.1 Technology Failure

Over time, energy systems become more reliant on digital infrastructure. Like any technology, digital infrastructure can fail, which may result in the interruption of the energy supply chain, black-outs, and subsequent disruption of business activity in the whole country. Experts from El Salvador, Honduras, and Panama have expressed their concern over the possible technology failure in the energy sector. Experts mentioned that there is a need to ensure a proper level of human-machine interaction. The possible technology accidents may lead to reputational risks and increasing resistance to implement digital solutions in the society.

Mitigation Measures

- Establish technology quality standards
- Conduct regular hardware and software checks
- Provide back-up options
- Provide technology recovery plan
- Educate employees on how to handle a technology breakdown.

6.2.2 Privacy Loss

Daily usage of smart devices that monitor and gather consumer data (such as smart meters) may lead to privacy loss. The collected data could be transferred to third parties where it can be used for various purposes, including criminal activity. In addition, criminals might access companies' intellectual property or use the customers' and employees' personal information for identity theft. Thus, it is crucial to ensure a responsible use of customer data by utilities and other market players.

The risk of privacy loss is present in all Central American countries that are in the scope of our study. In El Salvador and Guatemala, the threat of privacy loss is related to the absence of regulation such as a data protection law. In Costa Rica, Honduras, and Panama the privacy risks arise from the low level of data awareness among the population. Namely in Honduras, companies and households are strongly unwilling to disclose energy production/consumption figures, whereas in Costa Rica consumers are not aware of the threats that may arise from data misuse. In Panama the experts have highlighted that there is a high risk of unintentional release of secure or private/confidential information to the public.

Mitigation Measures

- Introduce data protection and information privacy regulation
- Introduce internal company rules related to handling consumer data
- Collect only necessary data and only on a 'need to know' basis
- Use up-to-date security solutions
- Restrict data transfer and data download.

6.2.3 Unauthorized Access and Data Loss

While modern technology systems evolve and become more sophisticated, various risks related to unauthorized use of information prosper. Unauthorized access and control occurs when a server, program, or system is accessed without the permission of the owner or administrator. The term relates to access that is unlawful, criminal, or not appropriate. Data loss can occur for different reasons, including data corruption, data theft, or virus infections deleting files. It happens when one or more data elements can no longer be utilized by the data owner and is also known as data leakage.

A loss of data integrity or data availability results in substantial legal, operational, and reputational risks as well as investment risks. For companies whose business activity is fully or even partially based on data, unauthorized access and data loss may lead to the temporary or permanent cessation of business activity.

Experts in the six Central American countries expressed concerns about the risk of unauthorized access and data loss. In addition, experts mentioned the potential threat of cyber-attacks. Electricity grid operators in Nicaragua have already experienced cyber-attacks on the electricity system. In El Salvador and Honduras, there is a high risk of data change and manipulation. This is related to the fact that consumers may hack the smart meters and change the data on electricity consumption. In Costa Rica and Guatemala, there was a significant potential to improve with respect to risk awareness. The experts emphasized the need to establish system surveillance measures and regular software updates.

Mitigation Measures

- Analyze possible security threats (cyber-crime, wrong authentication etc.)
- Allocate necessary capital investments to security measures
- Leverage the industry experience to detect unsafe services and applications
- Clearly define access levels
- Provide disaster recovery plan
- Educate employees about data security
- Regularly back up the data
- Track the motion of data within the companies.

6.2.4 Technological Employment Transition

Digitalization leads to the automation of tasks and processes that were once handled manually by people (job displacement). Therefore, in the short-term, digitalization may lead to employment losses and create distortions of the labor market.

Automation of manual work and job alterations are relevant in all the countries around the globe that are upgrading the energy sector equipment with robotic solutions, AI, and the like. At the same time, among Central American countries, only in Costa Rica have the experts mentioned that the digitalization process leads to the risk of technology unemployment.

Mitigation Measures

- Create regulation that boosts/does not inhibit new job creation
- Help workers adjust to new occupations, establish lifelong education policy
- Focus school and university education on more productive jobs.

6.2.5 Environmental Harm

One of the enabling conditions of digitalization is installation of physical, tangible parts and components, such as smart meters, smart grid infrastructure, and electric vehicle charging stations. Digital technology installations are highly dependent on rare metals, such as cobalt (li-ion batteries), tantalum (powder and wire for capacitors) and indium (transistors), etc. The extraction and refinement of those rare metals might cause vast environmental damage. In addition, outdated pieces of hardware, often called digital waste, contain potentially hazardous chemical substances and materials which eventually pose risks to health and environment.

Without proper waste management, dangerous chemical materials within the electronic components can harm the environment and human health. In fact, the recycling and disposal of electronic waste itself may pose significant threat to the health of workers and neighboring communities.

Environmental risk is relevant for all countries that implement digital electronic solutions. Among the Central American countries in our study, experts in El Salvador have emphasized the need to evaluate the environmental impact of digitalization.

Mitigation Measures

- Establish regulation over equipment quality standards, use "green" energy solutions
- Establish waste management and recycling policy and law
- Educate the population on how to manage the electronic waste in the households and industry.
- Maintaining electronic equipment in a good condition to ensure the long life.

7. Conclusions and Recommendations

In this chapter, we first discuss general, regional conclusions, and then present our specific recommendations.

7.1 Regional Conclusions

7.1.1 General Observations

As outlined in Chapter 4, the structure of the electricity market varies in Central America. In some countries the electricity market is liberalized (e.g. El Salvador), while in other countries the market is only partially liberalized, with dominant state-controlled electricity companies (e.g. Costa Rica). In all countries, generation capacity is partly owned by the private sector. Some countries allow several distribution companies (e.g. El Salvador) while others only have one company (e.g. Honduras). Several countries have established a wholesale market for electricity with PPAs possible between generators and large customers (e.g. Panama).

In all countries, there is a tariff that is set by a government agency, but the price-setting mechanism follows varying procedures and comprises varying components. There is strong socio-political pressure to reduce tariffs, limiting the opportunity for action and investment in local utilities (e.g. in digital technologies). There is a general trend in the region to phase out oil and coal and to switch to natural gas and renewable energies as energy sources. All countries are heavily involved in renewable energies, which hold an overall average of 70 percent share in electricity generation capacity. Yet, as we have described in detail, no one electricity market structure prevails across Central American countries.

Despite regional variation, with respect to **digital technologies** and use cases, stakeholders across different countries share a common sense of urgency in implementing digital technologies. They see digitalization as helping them overcome challenges posed by energy transition and global energy trends. Nevertheless, gaps in the framework conditions that enable digitalization still impede their deployment of digital technologies and use cases. These gaps are mostly due to policies at public institutions and in government, and partially due to limitations in human capabilities (e.g. knowhow) and organizational structure (Figure 119). Despite having a common goal to digitalize, the region is hampered by setbacks.

In addition, based on the results presented above, we can derive stakeholder-specific conclusions. One crucial conclusion is the need for a consistent long-term strategy for the energy market, such as the one Costa Rica pioneered in its National Sustainable Development Strategy from 1988 (ECODES) and the more recent Seventh National Energy Plan (VII Plan Nacional de Energía 2015-2030). Without **policy makers** establishing long-term commitments, and considering global energy trends, regulators cannot set regulatory frameworks. Uncertainties impede market actors from investing in digital technologies and use cases.

A second conclusion is that there is a need for training. We observed a technological "know-how" gap throughout the region between the **regulator** and the market, partially based on limited knowledge of digital technologies and use cases. This uncertainty in turn may lead to a rejection of tariff adjustments that results in a lack of resources on the market side to implement digital technologies. We also observed that **market participants,** including private and public utilities, did not fully understand the socio-economic benefits of the technologies at hand. This, as with the situation with the regulator, is partially based on missing knowledge, which, in turn, leads to incomplete and vague cost-benefit estimations, making it difficult for them to obtain internal and/or external funds and approvals (e.g. from regulators).

Even though we observed an effort to close gaps in human capabilities, there is still a missing link between academia and the market. This exists regardless of positive steps such as institutionalized collaborations between academia and the market. One example is the dependency of research institutions on datasets produced by the industry to develop innovative solutions (e.g. algorithms).

A third conclusion is that there is a need for consistent communication. System operators, acting as the connection link between multiple public and private participants throughout the energy value chain, depend on frictionless data flow to maintain reliable operations, including generation forecasts. Nevertheless, data flows are not yet smooth in the region. Stakeholders and system operators often share information on energy generation and transmission capacity demand in an unstructured manner through e-mail, word documents, phone calls, and the like. Disorganized communication results in erroneous, non-transparent, and delayed transmissions.

This challenge is likely to be exacerbated by the decentralization of generation and by exponentially increasing amount of data produced by emerging technologies such as smart meters. Nevertheless, there are potential solutions. For example, the system operator in Guatemala has set up a structured approach, although it still depends on manual data transmission. Standardizing communication practices will go a long way in improving data flow.

7.1.2 Impact of Global Energy Trends and Challenges

The regional assessment on the impact of global energy trends varies (Figure 127). We identified increased volatility and supply security as having the largest impact, followed by decentralization and competition, emissions reductions, and increased demand.

Increased volatility and supply security leads other global energy trends in affecting the region. Challenges revolve around the intermittent nature of renewable energies. Seasonality (hydropower) and changing weather (solar, wind) have a profound impact on the available generation capacity as well as the stability of the grid. All countries in the region face electricity losses. Technical losses come from bad infrastructure and grid congestion, while non-technical losses come from electricity theft or insufficient billing systems.

Decentralization and competition trends also affect the region, but to a lesser degree. Self-sufficiency is growing, especially to increased access to electricity in remote areas. However, a share of consumers is also driven towards self-sufficiency, putting pressure on energy companies to find other means to recoup their investments through electricity tariffs. With fewer customers, energy companies set higher prices, which, in turn, drive more customers towards cheaper self-generation. Increases in self-sufficiency can destabilize the electrical grid. In countries without a wholesale electricity market there is lack of competition. For some countries, the current structure of electricity tariffs and high electricity prices in the region are challenges for market participants.

Emissions reductions ranks as the third most impactful global trend in the region. Due to the geographical location all countries in the region are vulnerable to climate change. In particular, there are high emissions from the transport sector, although these may be mitigated by converting to electric transport vehicles. In terms of the addition of new renewable energy capacity, there is a lot of uncertainty about the implementation of projects in some countries.

Demand increase ranks fourth in impact on the region. There is uncertainty about whether demand will increase in the future. On the one hand, increases are driven by a shift to industrial production, urbanization, and growth of residential energy use. On the other, decreases result from higher energy efficiency and economic downturns. Some countries in the region also face the issue of overcapacity (Costa Rica, Guatemala, Panama), while other countries do not have sufficient capacity (Honduras, Nicaragua).

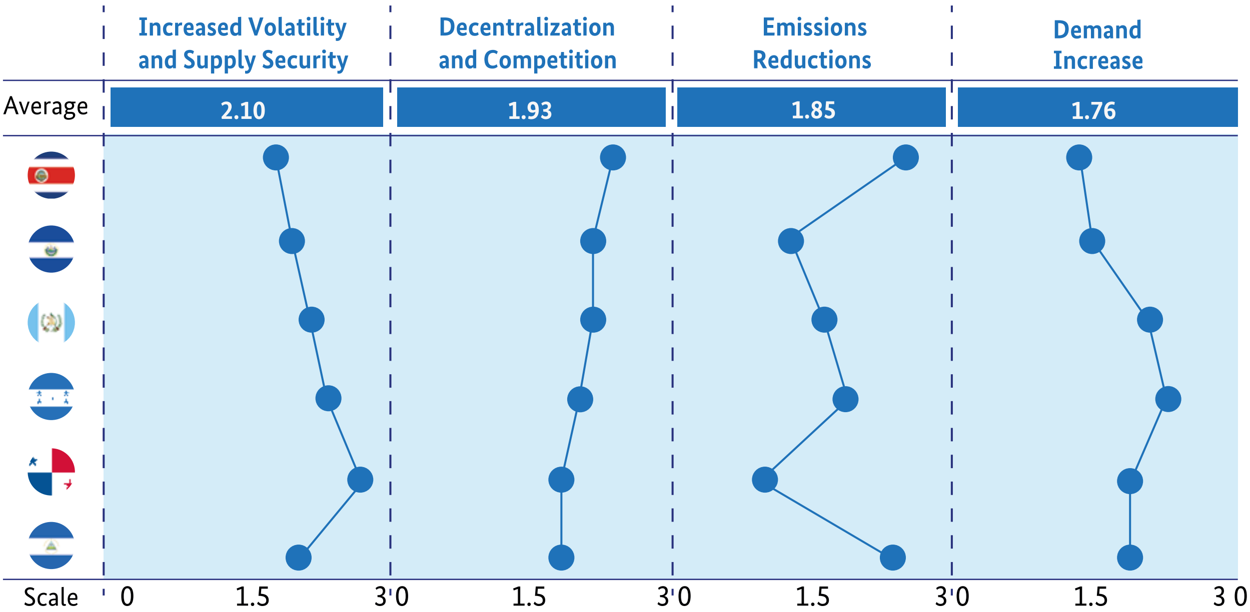


Figure 127. 2030 Global energy trends impact assessment Central America

An additional challenge aside from the ones emerging from the global trends is that any digital applications necessitate data. There are issues regarding the quality of data in the region. This especially concerns the data gathered on the electricity market for legislative, regulatory, and operational reasons. Often, the data is inconsistent due to decentralized data storage. This leads to inconsistency of the datasets (e.g. varying information about the installed electricity generation capacity).

Another issue is missing data. In some cases, market participants do not share data with other parties, leading to imprecise forecasts. For example, many prosumers do not report the installed capacity to the authorities, and the resulting lack of information leads to issues in planning the dispatch of electricity. Lastly, outdated systems and old data formats can lead to data loss, a challenge for consistent data storage. Moreover, different parties often save and transfer data in incompatible data formats. Market participants trying to aggregate and use the data thus face challenges in utilization.

For a successful digital transformation of the electricity sector, these issues must be addressed. There is not only a need to solve the issues for the digital transformation. The issues also cause problems to the agents: operators cannot plan their dispatch systems correctly, the lack of data leads to uncertainty for investors, and policy makers struggle in formulating goals that reflect digitalization. A condensed list of the challenges is in Appendix 10 .

7.1.3 Outlook and Improvement Areas

Figure 128 represents each parameter's potential to improve if additional (political) action takes place across the region. The colored bars reflect the countries experts' individual assessments. A detailed overview per parameter is in Appendix 11. First, the challenges from the global energy trend increased volatility and supply security may be improved through additional action. Experts indicated that there is high potential for improvement for the number of smart meters and a rather high potential for improvement for the system average interruption downtime. Stakeholders can improve both parameters by sharing knowledge among themselves. This could involve knowledge exchanges about effective policies for smart meter deployment or an exchange of best practices regarding attracting infrastructure investment for a better grid stability.

Additional action can also address challenges brought about through the trend towards decentralization and competition. There is rather high potential for improvement for the parameters wholesale electricity market and market liquidity. To improve the wholesale electricity market, Costa Rica and Honduras could build upon the experiences of the other countries that have already created a wholesale market while changing their systems. To improve market liquidity, the countries could exchange knowledge about efficient trading processes.

Regarding emissions reductions, there is high potential for improvement for the parameter energy loss. Countries can improve this parameter through collaborating to deploy use cases that address the issue of energy losses. The parameter energy mix has a rather high potential to improve from political action. Here, a joint regional approach could have an increasing impact on the parameter.

In terms of demand increase the parameter electric vehicles has high potential to improve from additional action. Considering that charging infrastructure is paramount when pursuing the promotion of electric vehicles and transport, a regional collaboration on an area-wide charging network strategy (e.g. based on the IDEM initiative) could set the base for future advancements.

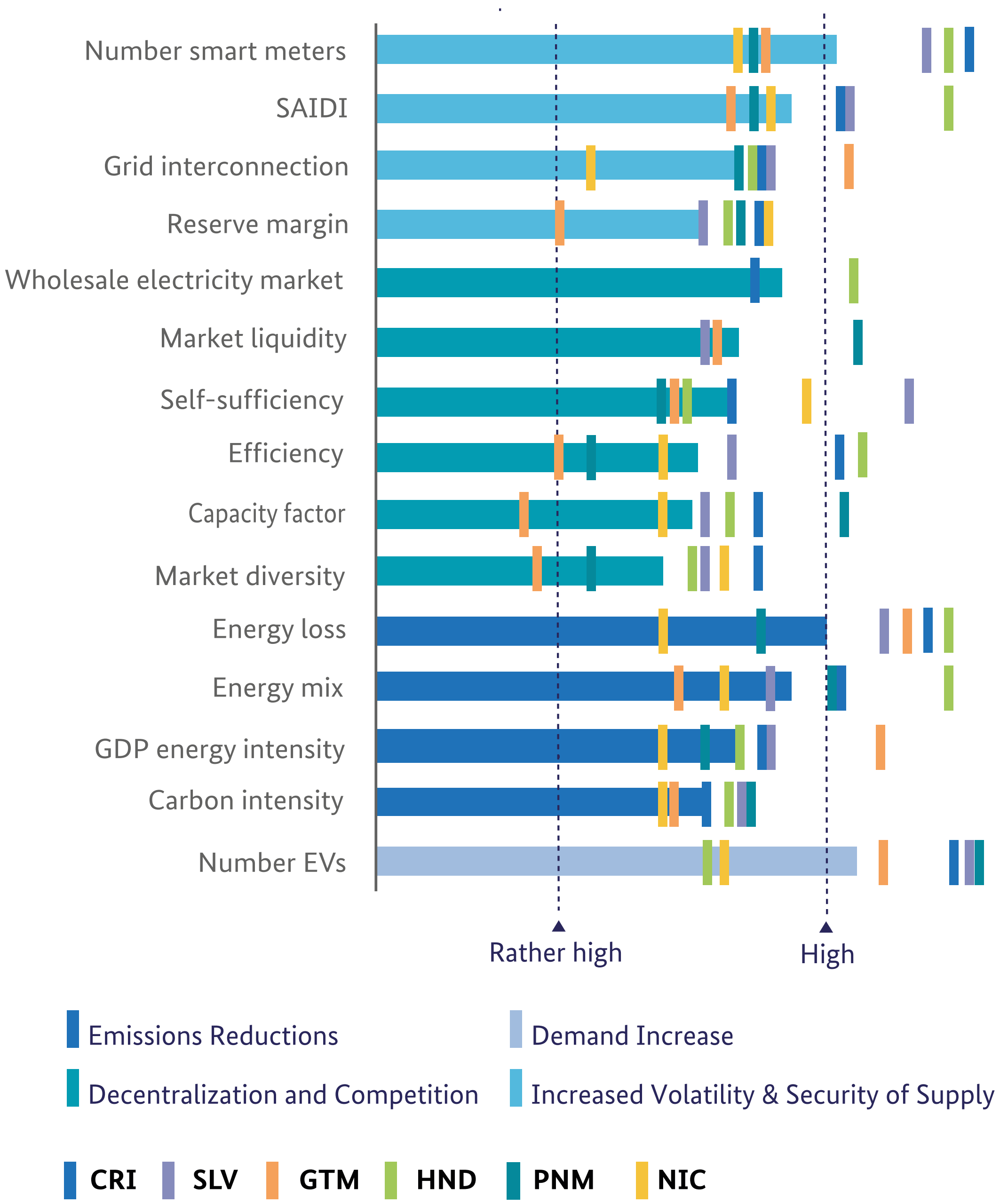


Figure 128. Potential for improvement of energy parameters until 2030 in Central America

7.1.4 Framework Conditions

As indicated by the digital readiness benchmark at the end of the country sections, there are varying degrees of readiness within the region. While some countries are readier in general, each one tends to have specific strengths (Figure 129). In Costa Rica, digital technologies knowledge hubs are forming. In El Salvador, different use case pilot projects are ongoing. Guatemala has a strongly organized electricity sector, and Panama's organizational culture is innovation driven, with institutionalized processes and subsidies focusing on business disruption. In addition, the degree of readiness within each respective country enabler also varies, depending on which reference points are used and what areas are considered.

This overall partial presence of the enabling framework conditions (as seen in the digital readiness benchmark analysis) limits the implementation of digital technologies and use cases. With each country benefiting from the digitalization of their individual energy sectors, it would be an advantage for each one, as well as for the region as a whole, to increase each country's readiness.

Figure 130 provides a clustered overview of recommendations to increase the enabling framework conditions and thus facilitate the implementation of digital technologies and use cases. In addition to recommending proactive regulation on digitalization and respective technologies, we also recommend addressing the strong need for education and knowledge exchange (no. 4,5,6,8,12,14). Also, as reflected in the enabling framework conditions, one of the most limiting factors mentioned was a lack of knowledge, which causes uncertainty on how to proceed with digitalization topics. Therefore, experts across all countries uniformly emphasized the importance of collaboration between corporations within and across the energy and other sectors, between private and public entities, and between the industry and academia.

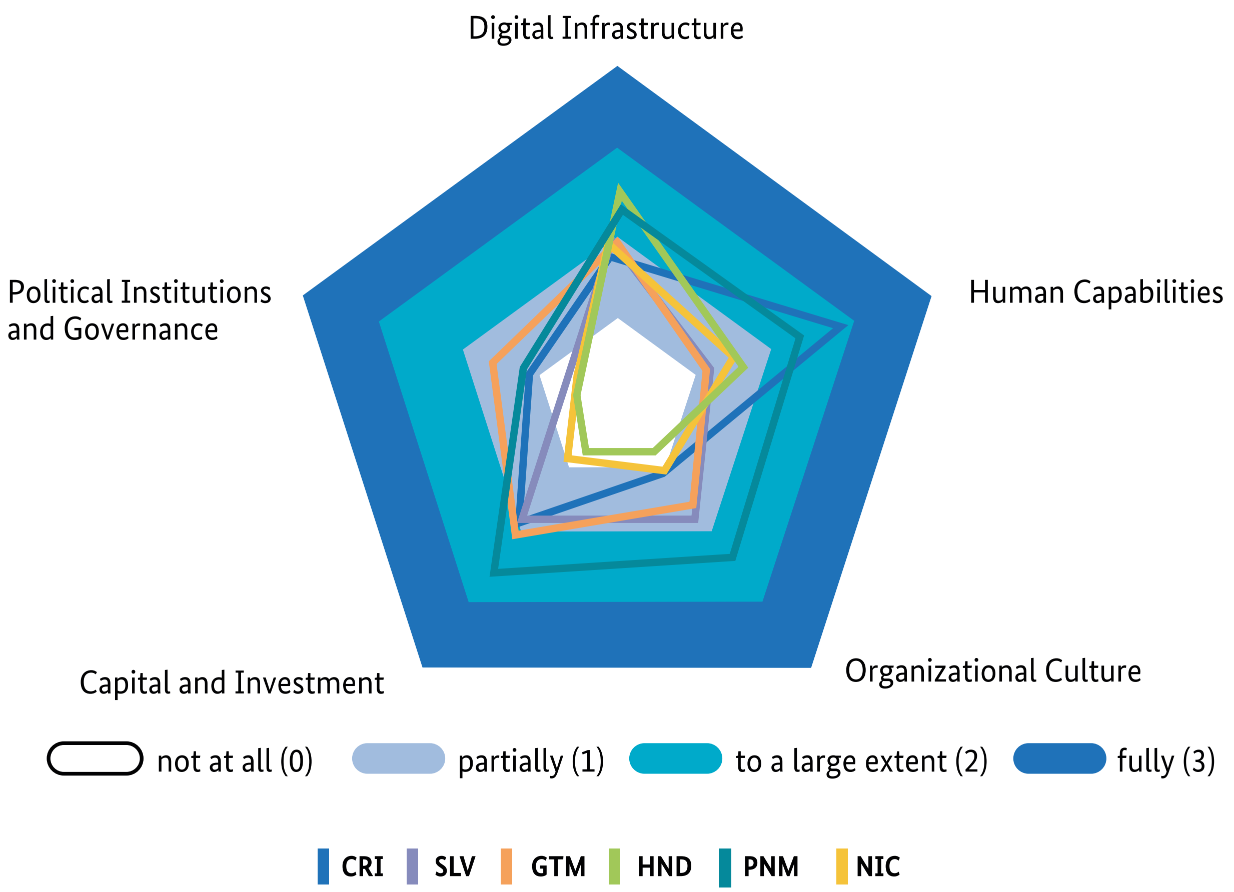


Figure 129. Framework conditions in Central America

#	Recommendation	Costa Rica	El Salvador	Guatemala	Honduras	Panama	Nicaragua
1	Implement enabling digital infrastructure	✓	✓	✓	✓		✓
2	Formulate strategy and implementation framework	✓	✓		✓	✓	✓
3	Create platform for knowledge exchange	✓	✓			✓	
4	Facilitate knowledge exchange between academia and industry	✓	✓	✓	✓	✓	✓
5	Facilitate knowledge exchange inside industry and across sectors	✓	✓	✓		✓	✓
6	Reform educational programs	✓	✓	✓	✓		✓
7	Facilitate knowledge exchange and cooperation within organization	✓	✓	✓	✓	✓	✓
8	Clarify technology applications (tangibility)	✓	✓	✓	✓	✓	
9	Provide transparent change management	✓	✓				
10	Create robust business cases	✓	✓	✓		✓	
11	Increase access to funds (FDI, tech. focuses funds, multilateral lenders)	✓		✓			✓
12	Increase knowledge of tech. applications within financial inst.	✓	✓				
13	Provide (proactive) regulation and standardization	✓	✓	✓	✓	✓	✓
14	Foster exchange between market participants and government	✓	✓	✓	✓		
15	Standardize data formats to facilitate exchange between agents	✓	✓		✓	✓	

Digital infrastructure · Human capabilites · Organizational culture · Capital and investment · Public institutions

Figure 130. Clustered expert recommendations.

7.1.5 Digital Technologies and Use Cases

Based on the results from the country-specific use case assessment, Figure 131 depicts the aggregated top five most relevant use cases indicated by experts. Even though there are certain use cases only relevant in individual countries, (e.g. virtual power plants with high relevance only in Costa Rica), there are multiple other use cases with pan-regional relevance, including Output forecasting for RE. This common relevance results from the joint regional challenges that have arisen from global energy trends.

The pan-regional relevant use cases span across all three digital technologies and therefore indicate areas of regional and cross-value chain collaboration.

#	Use case	Costa Rica	El Salvador	Guatemala	Honduras	Panama	Nicaragua	Regional relevance & frequency (sum)
1	Certification of energy products					✓		**1**
2	Virtual power plant	✓						**1**
3	Asset health monitoring and alerting system		✓		✓		✓	**3**
5	Output forecasting for RE		✓	✓	✓	✓	✓	**5**
8	P2P energy trading & micrograds	✓						**1**
10	Electricity wholesale		✓	✓	✓	✓		**4**
13	Remote monitoring and grid management	✓	✓	✓		✓	✓	**5**
14	Vehicle to grid	✓						**1**
15	Automated inspection and vegetation management			✓	✓		✓	**3**
17	Intelligent energy consumption	✓	✓	✓	✓	✓		**5**
22	Consumption optimization through machine learning						✓	**1**

Blockchain Internet of things Advanced Analytics

1) Use case is part of top 5 most frequent and relevant use cases in country

Figure 131. Top addressed use cases per country by frequency and relevance [1)]

7.2 Recommendations

Among the countries we analyzed, even though there are considerable differences, the impact of global energy trends (e.g., increased volatility and supply security) on the energy sectors and the associated challenges, such as integrating variable renewable energies into the grid, coincide on a regional level. This sets the ground for a necessary and potentially fruitful collaboration between the individual countries and their energy systems.

This collaboration should focus foremost on a selection of local and cross-regional easy-to-implement digital technology use cases (quick wins). The development and implementation of these should be facilitated by technology-specific Networks of Expertise (NoE)–a collaborative platform enabling interaction across the energy sector and throughout the region. Moreover, the implementation of digital use cases should be embedded in a regional data strategy that leads to the necessary data quality and integrity.

7.2.1 Networks of Expertise

Based on the experts' recommendations, our advice is that regional stakeholders create interdisciplinary, cross-value-chain, cross-institutional, and cross-country Networks of Expertise (NoE). NoEs will serve as institutional vehicles to implement digital technologies and use cases. They can potentially align and set in place the right framework conditions, mitigate resulting risks, implement the most relevant use cases cost-efficiently, and eventually overcome the mentioned challenges. They constitute a suitable approach to overcome challenges caused by global energy trends by applying digital tech and leveraging dispersed capabilities and experiences.

The idea is to streamline and channel available knowledge on selected areas and to facilitate frequent exchange within the region. Incorporating the individual strengths and know-how of the different countries' experts will help create clarity on digital applications and accelerate their implementation.

Those who oversee the NoEs should aggregate best practices and insights from pilot versions to provide an overarching orientation. They should take care to endow NoEs with a combined regional vision, formed as part of a combined strategy, and schedule them within a regional roadmap. We propose three NoEs in which experts can share knowledge, namely Blockchain, IoT and AA (Figure 132).

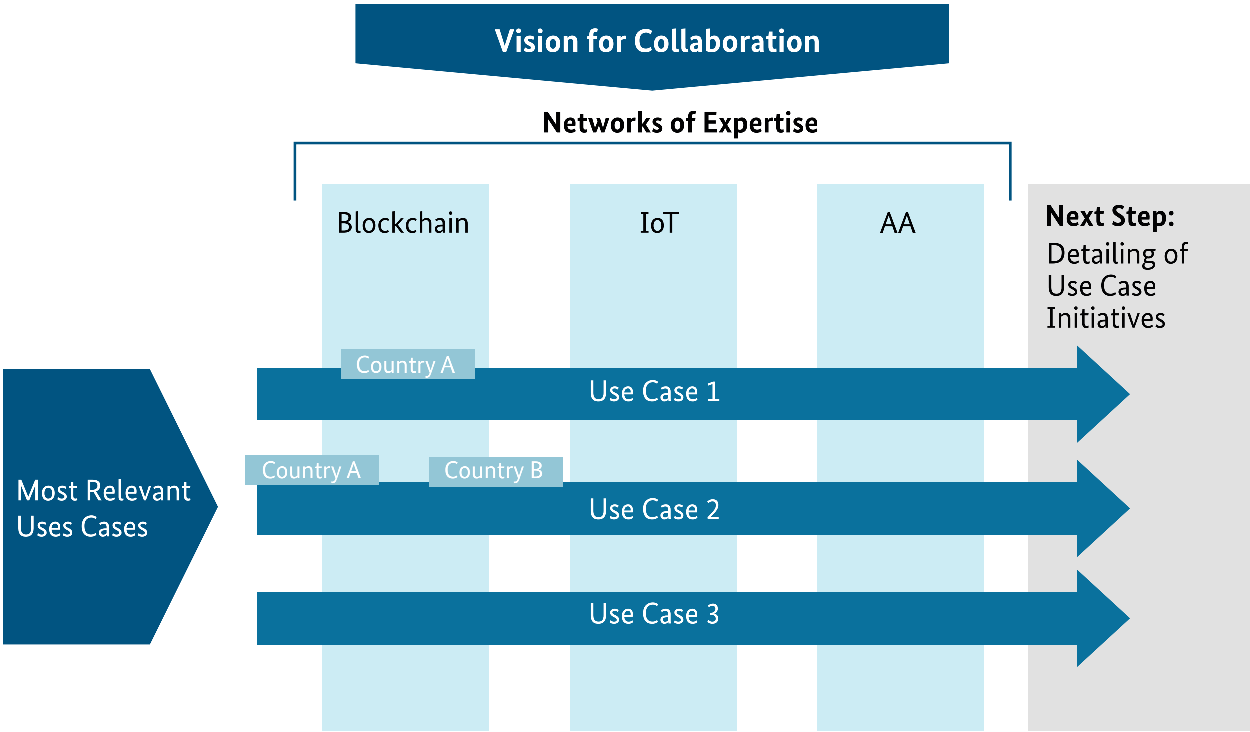


Figure 132. Schematic approach for Networks of Expertise

Each NoE brings together experts that will increase knowledge exchange and leverage country- specific capabilities to deploy mutually beneficial digital technology use cases. They connect relevant stakeholders in the energy sector while enabling full utilization of economies of scale across borders in Central America.

The NoE approach can serve as a catalyst to accelerate digitalization. When experts share knowledge, individual countries can realize the full potential of digital technologies and use cases while simultaneously benefiting from each country's unique strengths. While the approach will remain the same, the precise country-specific format of the NoEs can be adjusted according to varied circumstances. It is crucial that NoEs be supported by regional and country-level decision makers, as they should be actively involved in the collaboration process.

As a next step, NoE users need to determine a set of variables for the initial set up and the content for the network(s), such as:

- **The structure of the NoE** (e.g. governing bodies like an executive board)
- An **initial stakeholder composition** (e.g. a list specifying institutions and entities, with the individual stakeholder being defined subsequently according to each NoE's individual design)
- The **focus area** of the NoE (e.g. a certain use case or technology)
- A selection of **activities** for the NoE (e.g. workshops or publications)

We further explain and elaborate these variables below.

Potential Structure of the NoEs

Considering the interdisciplinary, cross-value-chain, cross-institutional, and cross-national nature of the NoE, some of the governance components have to be addressed on a regional level, some on a country level, and some on both. An example is the executive board component: it is reasonable to not only have one committee per individual NoE, but also to have an overarching group of people that organize interaction among multiple NoEs and address common issues across all NoEs.

Potential Stakeholder Composition

In terms of stakeholder composition, it is important to involve representatives from all relevant energy market institutions and entities, given that a core strength of the NoE lies in common knowledge development and transfer.

- **Policy makers.** Policy and regulation must actively facilitate digitalization; hence, it is of utmost importance that policy makers understand common technology and use cases.
- **Regulators.** While price regulation focuses on consumers' interests, regulators need to understand and acknowledge relevant (digital) technology investments (e.g. to increase the operative efficiency) on a company side so that price regulation and technical aspects may be set accordingly.
- **Operators.** Responsible for the reliable transmission of energy, operators must be aware of digital applications relating to the grid infrastructure and its monitoring.
- **Distributors.** Due to the focal role of distribution grids within the energy transition, a regular exchange among distributors seems crucial for grasping the full potential of digital technologies.
- **Additional private and public market participants** (e.g. utilities, traders, generators). Collaboration within the NoE would increase knowledge sharing within private and with the public sector. Additionally, knowledge harmonization with the regulator and others would result in increased investment security.
- **Academia.** Local universities and other academic institutions will be able to increase collaboration with the industry on digital topics, potentially resulting in collaborative research projects and additional funds.

Focus Area of the NoE

The focus of each NoE should initially lie on the most feasible and relevant use cases. Possible design options are:

- Set up a NoE for an **individual use case**, with a focus on quick wins[15] from the shortlist. The advantage is a concentration of efforts and faster initial benefits of implementation, with the opportunity to later transfer knowledge gained to other use cases.
- **Cluster** similar **use cases** into one NoE based on similarities in requirements. The advantage is to benefit from similarities and synergies between them that allow simultaneous knowledge and infrastructure development.
- Focus an NoE on a **core technology area** as defined in section 3.2.2. The advantage of focusing on digital technology generally is allowing a broader perspective than that obtained from focusing on a specific set of use cases only. Participants might identify other uses in the process.

Potential Activities

The NoEs should agree on a common list of activities to target within their thematic focus. For example, workshops, publications, and similar projects could be within the scope of their arrangement. Each activity should be tailored towards the thematic focus and the underlying goal of fostering collaborative efforts within the network. Activities should be scheduled according to their feasibility, expected impact, and scalability.

Meeting Format

For a fruitful cooperation within the NoE, it will be important to find a suitable format for

[15] We explain quick wins in the next section.

meetings which can either take place in physical or digital space. As the different stakeholders are geographically dispersed within their network, it can be beneficial to leverage digital formats for regular alignment efforts. In a similar vein, participants should use in-person meetings as powerful tools of collaboration. It will be crucial to define feasible roadmaps that guide the projects in terms of meeting frequency and other relevant formalities.

7.2.2 Data Strategy

Local and regional institutions reported a strong need for the development of a collaborative data strategy as the current processes are partially unreliable, slow, and error prone (see section 5.1.1). This strategy is advisable as reliable data functions are the essential pillar of efficient and effective decision-making for all stakeholders involved. High-quality data that is reliable and consistent is of crucial importance for policy makers, regulators, and operators alike. Digital technology and the use cases proposed need and produce data in accelerating speed and dimensions and hence increase the urgency of a well-functioning data strategy.

Currently, the energy sector faces several challenges related to data availability and quality:

- **Inconsistency.** Due to decentralized data storage, information can be inconsistent and incoherent. Consequently, conflicting data sets can cloud the correct decision-making process.

- **Varying/Old Data Formats.** As data are often saved and transferred in different formats that are not necessarily compatible, market participants face severe challenges when they want to utilize and analyze data in an aggregated form.

- **Data Loss.** As the utilization of outdated systems is common for several stakeholders in the Central American energy market, data and valuable information can become irretrievably lost.

Data quality problems have detrimental implications for everyone. For example, operators cannot plan their dispatch system correctly, investors do not have the data to undertake reliable investment decisions, and policy makers struggle to formulate legislative strategies and goals that adequately reflect global energy trends and digitalization.

Hence, there is a strong need for setting up an overarching, regional framework on data gathering and flow management in the context of the proposed collaborative NoE. This data strategy benefits all stakeholders by combining and growing available data knowledge insights. Central data storage increases the data quality and brings it above the critical threshold value.

The objective is to create a holistic view on the energy sector(s) and the associated value chain, thus supporting policy development and decision-making. Once the plan is in place, stakeholders can implement digital technologies across the sector (e.g., for AI-based artificial neural networks, ANN). In this scenario, data refers to all information that represents and/ or relates to the energy sector, whether raw, unaltered, transformed, or enriched. The suggested scope of the strategy is to set clear principles and guidance on how to manage data in the energy market. To provide this guidance, we advise the following:

- A guiding maxim based on data management governing principles.

- A management framework that adheres to privacy, confidentiality, and security requirements while adapting to the changing and evolving needs for data collection.

- Stakeholder roles and responsibilities that ensure data governance.

- Requirements for data that incorporate applications that facilitate digitalization.

- Standards for data formats and exchange.

- Mechanisms for data collection and sharing that promote frequent exchange and access.

- A funding framework for collaborations such as data platforms.

- A review process of the overall strategy to maintain continuous relevance and impact.

We suggest three steps to start creating and developing a data strategy and its components.

First, relevant parties should perform a gap analysis and cataloging of existing energy market data. Second, they should conduct an effectiveness assessment of the current data exchange arrangements. Third, they should identify current and possible future barriers for the strategy, so that they can act proactively in tackling these. The objective is to build a high-functioning, sustainable data strategy to benefit the region as a whole and each individual country.

7.2.3 Quick Wins

Digital technologies and use cases allow stakeholders to overcome the challenges posed by global energy trends. We identified numerous use cases but pursuing implementation of all without a structured approach is neither feasible nor sensible. As stated above, the idea of the NoE approach is to focus on and facilitate the implementation of the most relevant use cases. In the establishing phase of an NoE it is especially important to concentrate on short-term feasibility, to create a prototype, and to lead digitalization through concrete, visible achievements. Thus, we suggest launching the project with quick wins–use cases that are both highly relevant and feasible.

With six countries and 22 use cases, there were initially 132 possible country-specific use case evaluations. We narrowed this list to the ten most-frequently addressed use cases per country, reasoning that what is prevalent within the experts' collective attention is generally of importance (Frequency Filter). To further distinguish among these, we considered which use cases the experts considered relevant to addressing challenges brought about by global energy trends. We determined the top five use cases per country (Relevance Filter). These 30 use cases then served as the basis for the shortlisting according to regional considerations (Regional Filter) and complexity (Complexity Filter).

Figure 133 depicts the process to derive the quick wins, which builds on the use case analyses in Chapter 4.

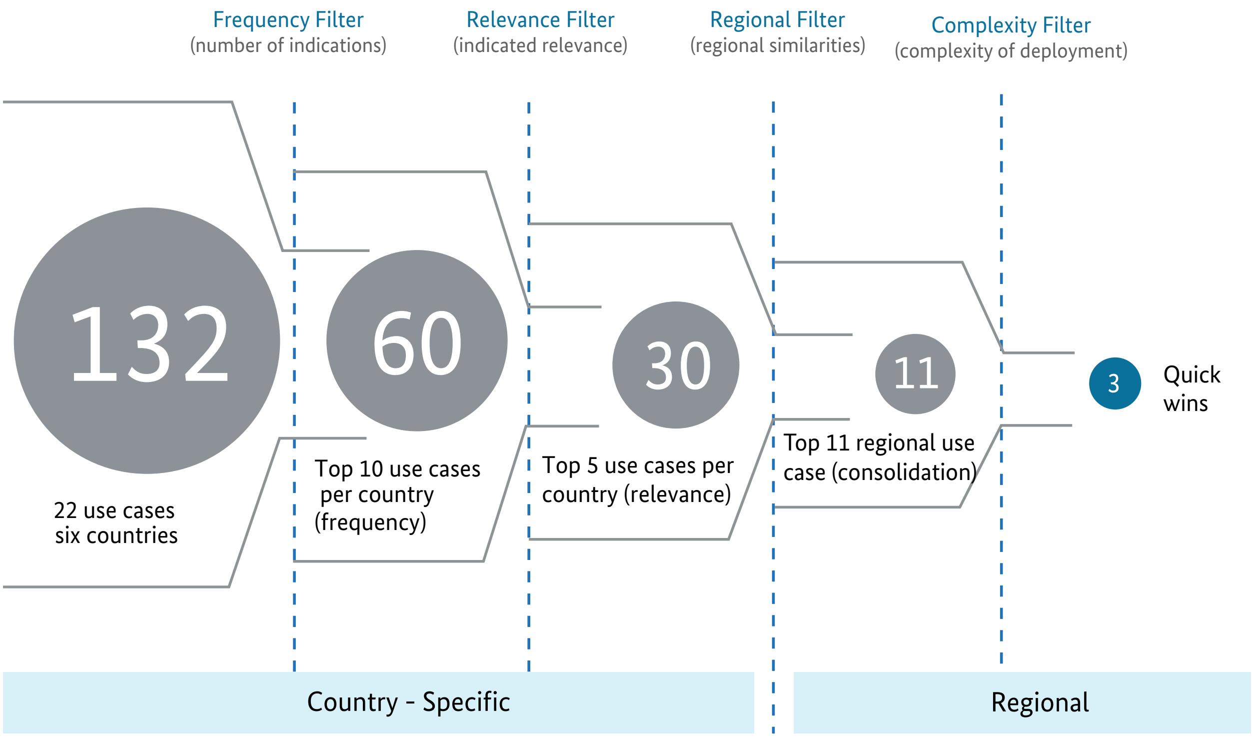


Figure 133. Quick win derivation

Use Case Shortlisting

To derive quick wins for the region, the results of the country-specific use case analyses were aggregated into a shortlist (Aggregation). The resulting list was then mapped according to perceived relevance and complexity of implementation (Prioritization). A two-component approach was used for each criterion:

- **Relevance.** We considered relevance according to what experts identified as most important for each country to address their specific energy sector challenges. First we considered the frequency with which experts identified a particular use case. Second, we considered experts' opinions on the relevance of these use cases. The frequency sum of the five use cases per country reflects the importance for the whole region.

- **Complexity.** We assessed complexity or feasibility of implementation according to the inherent magnitude of requirements and to each country's strengths for each use case. For the former, we considered requirements of either physical or digital natures such as sensors, data processing units, and IT systems, and for the latter, we considered whether there are pilots, initiatives, or enabling framework conditions in place.

The quick wins comprise the use cases that score high on relevance and low on complexity (Figure 134).

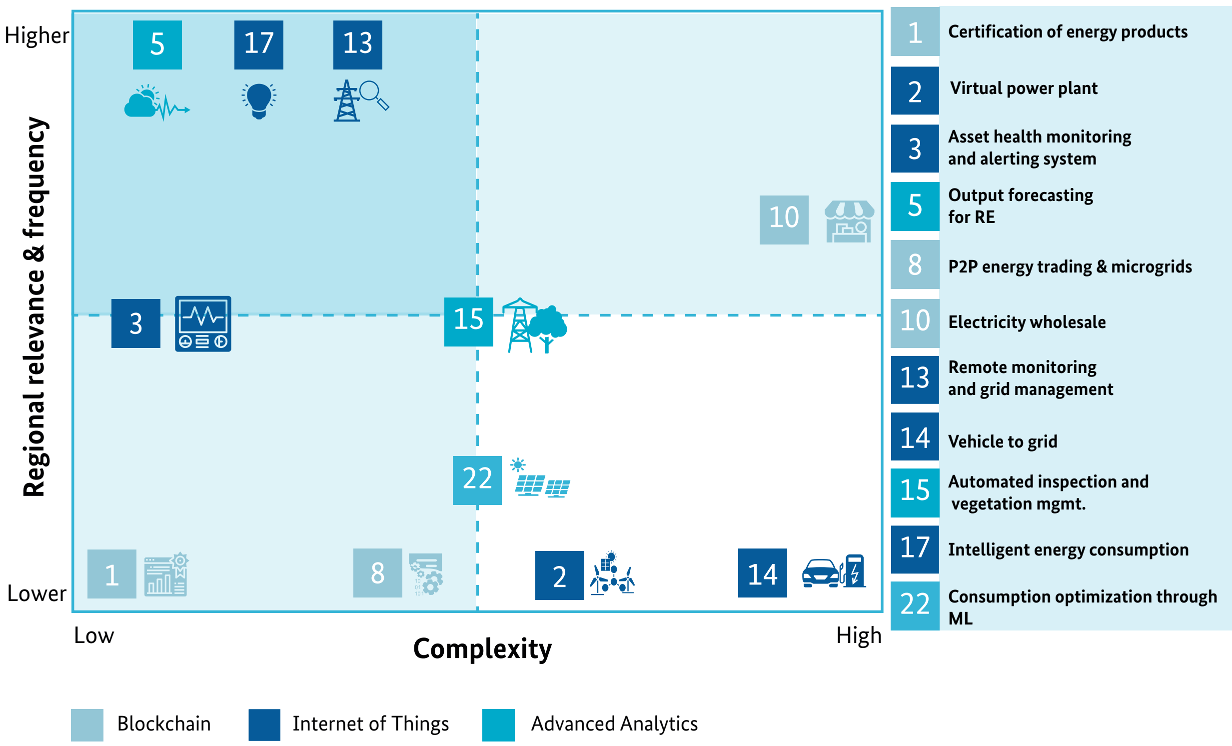


Figure 134. Use case quick wins for Central America

We consider three use cases to be quick wins, those with the highest estimated impact on the regional challenges.

- Intelligent energy consumption. Experts addressed intelligent energy consumption through the IoT in five countries. This is considered highly relevant for energy efficiency as well as relatively easy to implement. In Guatemala and Panama, relevant parties are testing pilot programs and services (e.g. in fast food chains).

- Remote monitoring and grid management. Experts addressed remote monitoring and grid management through interconnected devices (IoT) in five countries. These are considered highly relevant due to regionwide problems with high energy losses. Especially in Honduras, non- technical energy losses such as theft are prevalent. Pilot programs with SCADA systems are already in place in Costa Rica, El Salvador, Guatemala, and Panama.

- Output forecasting for renewable energies. Experts addressed output forecasting for renewable energies through advanced analytics in five countries, which is of high relevance due to high shares of RES generation across the region. While current forecasts lack in quality, pilot programs through cooperation with a German service supplier has begun in Nicaragua and El Salvador.

Selected Business Case Analyses

To increase the tangibility of the three quick wins, we conducted a qualitative cost-benefit analysis. We describe benefits from a regional macro-perspective, as they may vary from different perspectives along and outside of the value chain. We describe costs qualitatively, considering variability of the potential extent of the quick wins. We intend to highlight what the cost factors are with respect to the requirements for and nature of each quick win.

We briefly describe each quick win below, listing the benefits, costs, and an example.

Output Forecasting for Renewable Energy

Technology and Description

Machine Learning AI system that draws on pattern recognition and neural networks makes accurate predictions of power output based on a **wide range of sources:**

- **Sensor data** from wind farms, turbines, solar farms and panels
- **Weather forecasts** from different models and providers
- **Satellite images** and **sky imagers**
- **Pollution monitors**

Expert Systems aide decision-making by dispatchers (Decision Cockpit)

Core Factors and Example of Use Case

Sensory Turbines

- Real-time data sensors (nacelle wind speed, position, direction, yaw error, etc.)
- Static data (georeferencing, manufacturer data)

Artificial Neural Network Model

- Internal solution: development ANN and UI, hardware infrastructure
- External solution: SaaS costs

Highly accurate forecast of wind power

- Xcel Power uses AI-driven wind power forecasts of high accuracy (previously off by up to 20%) to integrate wind energy into the grid cheaply and reliably
- Quality of forecast allows shutting down many idling backup power plants – Remote control of blade angles allows exact matching of production with demand

Benefits and Impact

Improved grid balancing and reliability ✓

- Predictability of renewable output avoids unforeseen supply and demand imbalances

Improved bidding and dispatching ✓

- Forecasting accuracy allows for more exact planning of power dispatching and subsequently better markets bids
- Reduces curtailment payments

Reduction of backup needs ✓

- More accurate forecasts, utilities can cut the amount of power that needs to be held in reserve in the long-term

→ **Reduced CO_2 Emissions**

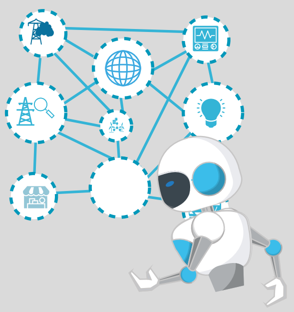
Figure 135: Quick win "output forecasting for renewable energy"

Remote Monitoring and Grid Management

Technology and Description

- **Smart meters** and **Sensors** generate a constant data feed on conditions and consumption in the grid
- **Existing powerlines** can be upgraded with smart infrastructure such as modems
- **Preventive maintenance** through early fault detection based on more accurate data

Core Factors and Example of Use Case



IoT infrastructure
- Real-time consumption data (sensors, smart meters, etc.)
- Remote controllable items (SCADA compatible, modems, etc.)

Monitoring and control software
- Internal solution: development of system & UI, hardware infrastructure (computers...)
- External solution: SaaS costs

Hypothetical area-wide implementation of remote monitoring systems in CA
- Smart meters deliver real-time consumption data, preventing tempering of counts
- Increased transparency on grid line efficiency through more available data
- Adjust grid management based on real-time data feed

OrbiSCADA, WebNMS, Comtrol, Chetu, devolo

Benefits and Impact

Improved grid balancing and reliability ✓
- Increased operation efficiency and grid integration through more available data and control mechanisms

Energy loss reduction ✓
- Reduce non-technical losses, especially theft, through increased transparency
- Reduce technical losses through better grid condition visibility

Increased energy efficiency ✓
- Reduced generation need through fewer distribution losses

→ **Reduced CO2 Emissions**

Figure 136. Quick win "remote monitoring and grid management"

Intelligent Energy Consumption

Technology and Description

- **Machine Learning AI** system that draws on pattern recognition and neural networks adapts to consumption pattern data from the IoT
- **Consumption patterns enable**
  - intelligent, automated **lighting**
  - intelligent, automated **heating**, and
  - intelligent, automated **cooling**
- **Smart connected devices** for remote control and programmable settings to better match needs

Core Factors and Example of Use Case

IoT infrastructure
- Real-time consumption data (sensors, smart meters, etc.)
- Remote controllable items (lighting, heating thermostats)

(Smart) analytics and control software.
- Internal solution: development of system and UI, hardware infrastructure (computers...)
- External solution: SaaS costs

Energy consumption optimization for cooling data centers
- In 2016 Google's DeepMind developed an AI-system to provide recommendations for cooling optimization of its data centers
- What started as a recommendation system for the data center operators has since been granted autonomous control, reducing the amount of energy for cooling by 40%

DeepMind, VERDIGRIS, C3.ai, lucid

Benefits and Impact

Improved grid balancing and reliability ✓
- Peak load reduction through cost-sensitive variable consumption optimization increases grid stability

Reduction of costs ✓
- Optimizing consumption reduces overall energy usage and waste
- Shifting of variable demand into lower load times where prices are less

Increased energy efficiency ✓
- Improved responsiveness of energy services with respect to user behavior

→ **Reduced CO2 Emissions**

Figure 137. Quick win "intelligent energy consumption"

7.3 Country-Specific Roadmaps

7.3.1 Costa Rica

Based on the impact of global energy trends we conclude that emissions reductions and decentralization and competition are the main factors influencing Costa Rica. The global trend demand increase has the lowest effect on Costa Rica.

Among the most important challenges Costa Rica faces are its current tariff structure, energy losses, generation overcapacity, and demand forecasting. Nevertheless, Costa Rica compares favorably to other countries on energy inefficiency, transmission lines, and remote generation.
To tackle the most important challenges on a local level, Costa Rica could implement digital technologies and use cases including vehicle to grid, virtual power plant, and P2P energy trading. Besides leveraging through the NoEs on a regional level, the following digital use cases could be further emphasized: remote monitoring, grid management, and intelligent energy consumption.

To implement these digital use cases in Costa Rica, a specific set of enabling framework conditions needs to be in place. Based on the results of this study, it is advisable to focus on the enabler capital and investment, reflected by the financial market situation, venture capital availability, ease of access to loans, and the availability and affordability of financial services. Still, Costa Rica performs relatively well with respect to human capabilities, which is reflected by its secondary education enrollment rate and the quality of its education system (WEF, 2018). However, we suggest a more specific analysis based on use case and project specific requirements with respect to its enabling framework conditions.

7.3.2 El Salvador

Considering the impact of global energy trends on the energy system, we observed that decentralization and competition and increased volatility and supply security have the highest impact on El Salvador. Trends with the lowest magnitude in El Salvador are increased demand and emissions reductions.

The development of these global and country-specific energy trends induces plenty of challenges. For El Salvador, the most urgent are related to transmission lines, electricity dependency, and data quality inefficiency, and energy losses, which are also regional challenges. Some challenges are less significant for El Salvador, such as energy inefficiency, tariff structure, grid instability, remote generation, and market frictions.

With respect to these challenges, El Salvador may consider the following digital technologies and use cases: asset health monitoring, alerting system implementation, and electricity wholesale. On the regional level, intelligent energy consumption, remote monitoring, grid management , and output forecasting for RE are relevant and can be developed in collaboration with the NoEs.

To facilitate the implementation of the above-mentioned digital use cases, El Salvador needs to focus on the following development areas and conditions: human capabilities, reflected by the quality of education system (although El Salvador is successful in secondary and tertiary education enrollment rates: WEF, 2018); spending on research and development; public institutions and governance, as reflected by organized crime; and transparency of government policymaking. For more details, specific use cases can be analyzed.

7.3.3 Guatemala

Guatemala is mostly influenced by the global energy trends decentralization and competition, demand increase, and increased volatility and supply security, though the magnitude of the latter is lower. Emissions reductions has the smallest impact on Guatemala's energy system.

These trends, along with the country-specific situation, create challenges for Guatemala. The most relevant for Guatemala are institutional challenges, electricity dependency, and transmission lines. There is less concern for challenges related to financial straits, market frictions, decentralization, grid instability, and remote generation.

We advise Guatemala to implement digital technologies and use cases, namely automated inspection, vegetation management, and electricity wholesale on a local level. Furthermore, we advise that they leverage opportunities offered by NoEs to implement intelligent energy consumption, output forecasting for RE, and remote monitoring and grid management on a regional level.

Nevertheless, for this purpose Guatemala needs to align its digital framework conditions. Having analyzed parameter-based digital readiness benchmarks, the main enabler is human capabilities, reflected through the quality of the education system; and public institutions and governance, as reflected in the burden of government regulation as well as perceived corruption. On the contrary, there are affiliated framework conditions in which Guatemala prevails, including capital and investment, as reflected in financial markets, availability and affordability of financial services, firm-level technology absorption, and business sophistication (WEF, 2018). Additional analysis of the framework conditions based on selected use cases is required.

7.3.4 Honduras

Global energy trends are having a considerable impact on the energy system in Honduras. The most considerable impacts come from increasing demand and increased volatility and supply security. Emissions reductions has the lowest magnitude effect.

From the perspective of Honduras, the most significant challenges induced by global energy trends include transmission lines, energy losses, decentralization, institutional challenges, and data quality inefficiency. We consider electricity dependency and tariff structure to be less relevant for Honduras.

With respect to these challenges, we suggest Honduras, on the local level, implement the following digital technologies and use cases: asset health monitoring and alerting system and automated inspection and vegetation management. Use cases from local and regional relevance include output forecasting for RE and intelligent energy consumption–these could be pushed forward through collaboration within the NoEs.

To implement these digital technologies, Honduras potentially needs to update its digital infrastructure, as indicated by its broadband fixed subscriptions and internet penetration. There are currently limitations: human capabilities, reflected by its education system; organized crime; and public institutions, reflected government regulation. At the same time, financial conditions appear to facilitate the process of digitalization, reflected by market development and access to loans (WEF, 2018) Nevertheless, a more thorough analysis of the framework conditions, based on the selected use cases, is required.

7.3.5 Panama

Based on the global energy trends impact assessment, the most relevant trends for Panama are increased volatility and supply security and demand increase. Emissions reductions in turn has the least impact on Panamas energy system.

The combinations of effects from these global trends and local conditions result in a set of individual challenges. While the most relevant challenges center on decentralization, demand forecasting, and transmission lines, less relevant challenges relate to generation overcapacity, financial straits, market frictions, grid instability, and energy inefficiency.

We suggest Panama, on the local level, use digital technologies and use cases to counter these challenges, such as certification of energy products and electricity wholesale. Additional regionally relevant use cases, suitable for collaboration (e.g. through the NoEs initiative) are intelligent energy consumption, output forecasting for RE, and remote monitoring and grid management.

To realize these digital technologies, Panama needs to enhance its digital readiness framework conditions. In general, parameter-based digital readiness benchmark analysis showed that the most important conditions for potential development are related to its digital infrastructure, as reflected by internet penetration and mobile cellular capacity. A closer look is needed for the framework condition human capital, reflected by its education system. Nevertheless, there are digital readiness conditions in which Panama succeeds, including its organizational culture, reflected by high levels of firm-level technology absorption; research and development spending; and business sophistication (WEF, 2018). Lastly, it is important to note that capital and investment are major facilitators for local digitalization. More details on precise points of engagement (e.g. for policy makers) can be identified through a use case analysis.

7.3.6 Nicaragua

Nicaragua's energy system is mostly impacted by the global energy trends emissions reductions and increased volatility and supply security. The lowest magnitude of impact was the trend decentralization and competition.

These global trends combine with country-specific situations to result in unique challenges for the Nicaraguan energy system. The most significant challenges we identified were grid instability, decentralization, data quality inefficiency, and financial straits. We consider electricity dependency, energy inefficiency, and tariff structure less relevant in the context of Nicaragua.

In this regard, we advise that Nicaragua implement a specific set of digital technologies and use cases. Most use cases should be locally developed, including machine learning-based consumption optimization, automated inspection and vegetation management, and health monitoring and alerting system. On a regional level, leveraging the possibilities offered by the NoEs, output forecasting for RE, and remote monitoring and grid management are highly relevant digital use cases.

To implement these use cases, and to enable the digitalization of the local energy market, we advise improving specific enabling framework conditions. One of the conditions with the most potential for improvement is human capabilities, as reflected by the quality of the education system and the availability of scientists and engineers. Enabler organizational culture, mainly reflected in business sophistication and university-industry collaboration are significant framework conditions with specific development and enhancement potential (WEF, 2018). Nevertheless, a more use case-based analysis is required to further specify the exact requirements.

7.4 Specific Recommendations for Stakeholders

Digital technologies and use cases are tools that help to overcome challenges faced by energy systems due to their current situation and the impact of global energy trends. Nevertheless, for stakeholders to engage and invest in digital technologies, use cases, and projects, policy makers need to provide long term planning security with respect to plans related to the global energy trends. They can set measurable and reliable energy-parameter values–clear short-, medium- and long-term goals for CO_2 reduction–and underpin these goals with a resilient strategy. Moreover, policy makers must communicate these goals. Policy makers need to ensure the required digital framework conditions, as outlined in Chapter 4, are in place.

Based on the goals and strategies set by the policy makers, regulators can develop specific and efficient regulatory systems, creating the right incentives for other stakeholders within the energy system, like distributors. Nevertheless, to grasp the opportunities presented by digital technologies, as indicated in Section 3.2, regulators need to enable and partially incentivize the roll out of digital technologies. Therefore, a thorough understanding of opportunities, costs and risks of these technologies is vital. This understanding in turn can be generated through a continuous exchange with the affected stakeholders (e.g. distributors). An increased and harmonized knowledge facilitates the evaluation and eventually the approval of beneficiary technologies and use cases.

Global energy trends, especially the energy transition towards a distributed, volatile generation pose a distinctive challenge for operators. Nevertheless, new technologies and use cases, facilitated by new (digital) devices and sensors (IoT) that collect unprecedented amounts of data, enable operators to optimize their dispatching, such as allowing them to reduce planning uncertainties.

If there is sufficient planning certainty and the respective regulatory framework is set, distributors need to engage in the identification, development, and deployment of digital technologies and use cases. To improve the approval of tariff-adjustments and, therefore, ensure investments, reliable use case-specific cost-benefit analyses need to be conducted and discussed together with tariff-approving entities (regulators). This process is facilitated by setting the right internal structures and entities, such as by setting up digital innovation hubs and fostering the continuing knowledge development of employees.

Other relevant stakeholders include academia and research institutions, which need to be involved regularly to profit from the knowledge exchange and ensure the deployment of cutting-edge technologies.

All in all, digitalization of the energy sector is neither a means by itself nor is it a stakeholder-specific initiative. After identifying the challenges of the energy system and setting clear objectives, a shared, collaborative approach is required to identify the most relevant digital technologies and use cases, align the enabling framework conditions, and ensure the deployment of projects.

8. Vision and Strategy

During a two-day vision and strategy workshop carried out June 19-20, 2019 in San Salvador, a group of 30 cross-country energy sector stakeholders gathered to discuss the results and recommendations described from Chapter 3 to 7. Based on the discussion, the stakeholders elaborated a regional vision for collaboration and developed a joint strategy, including a preliminary selection of focus use cases.

8.1 Vision

As illustrated in Figure 138, participants of the workshop, including national and regional policy makers, regulators, operators, distributors and traders, agreed on a vision for collaboration concerning the digitalization of the energy sector. Participants consensually aligned behind this vision and certified its aspirational, motivational, ambitious, and inspirational character.

We as a region strive to grant every citizen in Central America access to affordable, high quality, and clean energy.

To achieve this goal we aim to make the energy systems and intitutions in our countries more resilient for today's and future challenges by enabling them to take advantage of the oportunities of digitalization.

By intensifying the collaboration between countries and across institutions we will mutually benefit from our individual strengths and realize the full potential of our region.

Nosotros como región, nos esforzamos por garantizar a todos los habitantes de Centroamérica el acceso a energía asequible, de alta calidad y limpia.

Para lograr este propósito, nuestro objetivo es hacer que el sistema eléctrico e institucional del sector energético de nuestros países sea más resiliente para los desafíos actuales y futuros, permitiéndoles aprovechar las oportunidades de la digitalización.

Al propiciar mayor colaboración entre países y entre las instituciones, nos beneficiaremos mutuamente de nuestras fortalezas individuales y maximizaremos todo el potencial de nuestra región.

- ✓ Aspirational
- ✓ Motivational
- ✓ Ambitious
- ✓ Inspirational

Figure 138. Aligned vision for collaboration in the digitalization of the energy sector in Central America

8.2 Strategy

8.2.1 Final Selection of Use Cases

In a first step, workshop participants selected and prioritized a set of relevant use cases, based on current and planned digitalization projects and initiatives in the region. Thus, these complemented the recommended use cases (output forecasting for RE, remote monitoring and grid management and intelligent energy consumption) with additional ones: virtual power plant, P2P energy trading and microgrids, and vehicle to grid use cases. In addition, participants agreed on the overarching relevance of a joint digital strategy and management as illustrated in Figure 139.

23 **Data Strategy Management**[5]

	Generation	Trading	Transmission and Distribution	Consumption[2]
Blockchain	1 Certification of energy products	8 **P2P energy trading & microgrids**[4] 9 Enterprise asset mgmt. 10 Electricity wholesale	12 Load balancing through smart contracts	16 Smart contracts for variable billing
Internet of Things (IoT)	2 **Virtual power plant** 3 Asset health monitoring and alerting system		13 **Remote monitoring and grid management** 14 **Vehicle to grid**[3]	17 **Intelligent energy consumption** 18 Services for general metering point operators 19 E2E service platform (e.g. digital twins)
Advanced Analytics (AA)[1]	4 Self-optimizing generation system 5 **Output forecasting for RE** 6 Digital visualization and mapping of fossil ER 7 Identification of local waste streams	11 Algorithmic trading and price setting	15 Automated inspection and vegetation mgmt.	20 Automated lead mgmt. 21 Customer service bots 22 Consumption optimazation throught ML

1) Including Artificial Intelligence
2) Including services
3) Enabling vehicle to grid as digital use case requires previous deployment of EV
4) Enabling P2P energy trading required respective market structures
5) Additional regional use case

Figure 139. Final selection of use cases

8.2.2 Benefits, Questions, and Governance of NoE

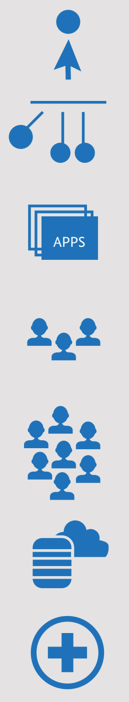
In a second step, participants stated the benefits they expect from using NoEs, such as exchanging knowledge, leveraging project synergies, accessing external sources and experts, staying aware of new projects, and having simplified access to project-related information (Figure 140).

Figure 140. Expected benefits from NoE approach

Next, participants determined project and use case-specific questions. They decided to address topics in their NoEs related to the following categories: (1) regulation, legal issues, and incentivization; (2) cost and benefits; (3) technology; (4) data generation and processing; and (5) use cases and projects.

Figure 141. Specific questions NoEs will address

Lastly, after setting a framework regarding the expectations and questions they want to address within the NoEs, participants derived a governance structure for the NoEs along seven major dimensions. As illustrated in Figure 142, major governance dimensions include **activities** to be realized within the NoEs as well as the **stakeholder** structure, among other dimensions.



Lead- NoE specific leardership teams[1] will assume responsibility for the content selection and development while institutional partners (e.g. CECACIER, EOR) will support activity operations.

Activities- major activaties realized within the networks of expertise include presentations, topic-specific workshops, trainings and the c-development of white papers.

Use cases- based on the results of the study and the vision and strategy workshop a set of focus use cases was identified-these use cases act as guidelines fot content generation (e.g. selection of relevant project presentations).

Core stakeholders- regional and local policy makers, regulators, operators, distributors, generators as well as traders form the core group of stakeholders- with each group naming a designated member to the leadership team of NoEs.

Associated stakeholders- additional stakeholders supporting the activities realized in the context of the NoEs initiative, contributing with expertise and insights from outside the core group (e.g. academia).

Data platform- based on the initial data acquired within the study and the workshop, each network will gradually build up an up-to-date centralized data base on digitalization initiatives and projects- including project and contact details.

Non- monetary contributions-participants and partner institutions agree to rotate and on a voluntary basis, contribute with facilities, expertise, contacts and time commitments toward the initiative.

[1] A leadership team, consists of the NoE responsible ("godfather") and a designated member from each stakeholder group. Tasks of this leadership include the development of relevant activities.

Figure 142. NoE governance along core dimensions

As the next and final step of the study, we conducted a webinar. We discussed the overall results of the study and the vision and strategy workshop to a wider stakeholder group and launched the NoE initiative.

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Appendices

Appendix 1. Survey A

We administered Survey A to validate our approach and our desk research findings, create common ground with participants, and assess potential areas for improvement. We created Survey A using a three-step approach (Figure 143).

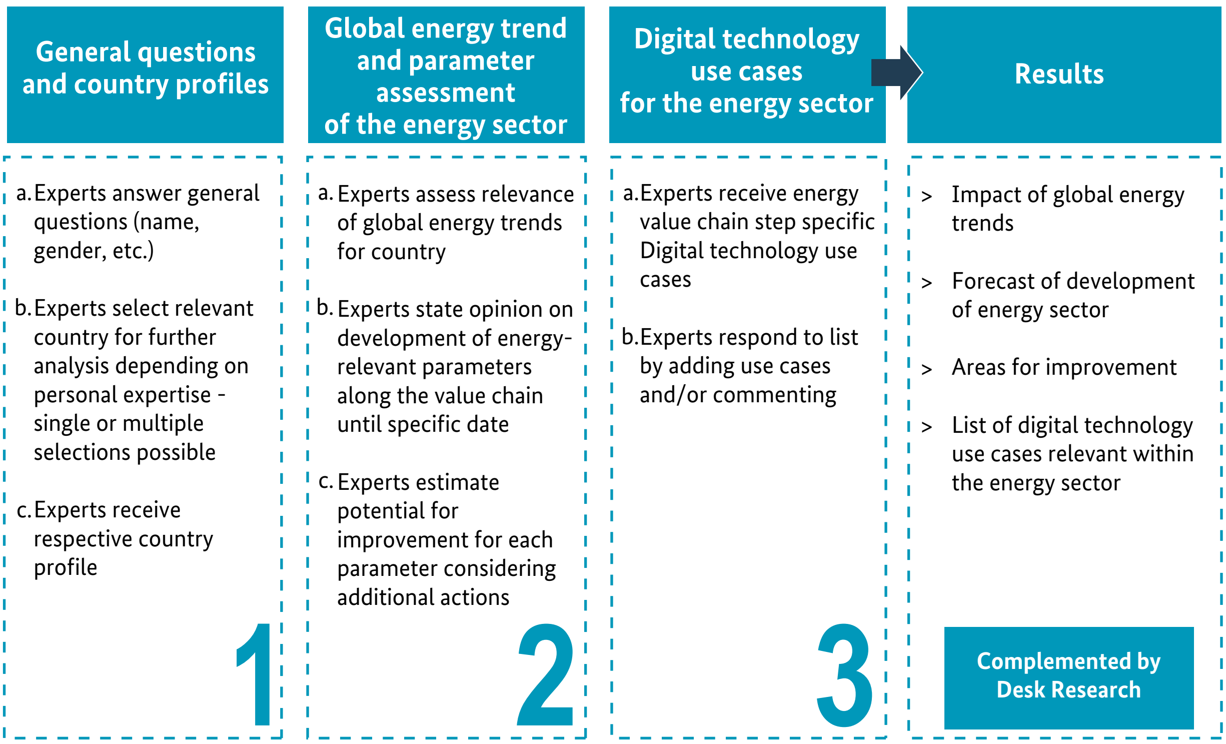


Figure 143. Survey A approach

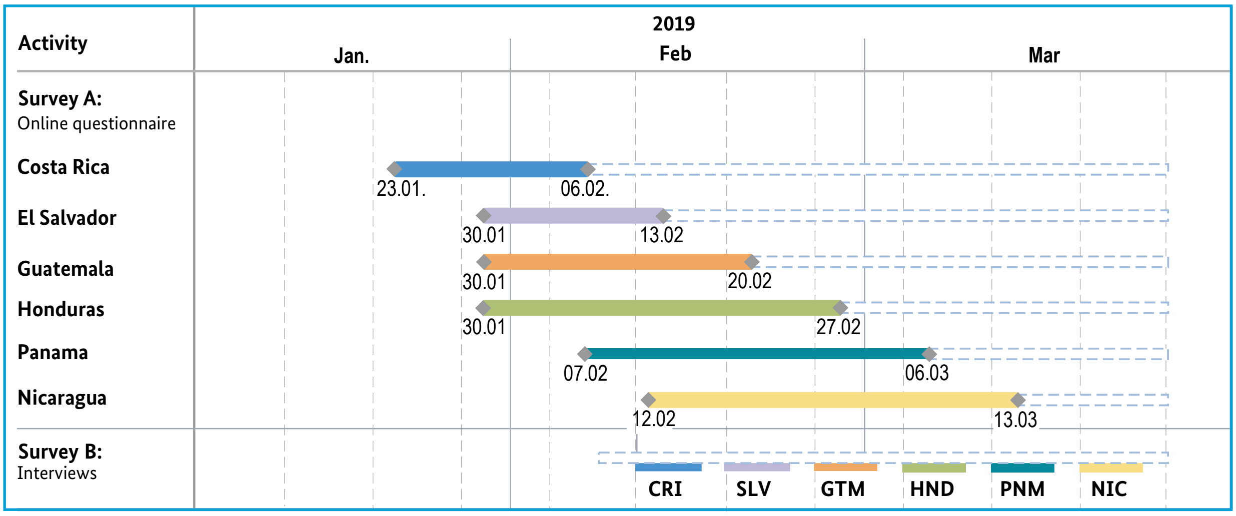
The survey consisted of one general section (nine questions) and three subject matter sections (114 questions [16]). Experts could complete the survey in multiple sessions through re-logins. Additionally, we made several questions optional so that participants could focus on their areas of expertise and skip areas where they had limited expertise. Most survey items used a Likert scale. We included a few open-ended response inputs, but we restricted these to comments to enhance comparability. We present the thematic structure and content in Figure 144.

[16] Every required input was counted as a question, except for use cases. These were only counted once per use case.

Survey A	
1.	Introduction
1.1	General Information
2.	Trend Assessment
2.1	Country Profile
2.2	Emissions Reductions
2.3	Decentralization and Competition
2.4	Demand Increase
2.5	Increased Volatility and Security of Supply
3.	Parameter Assessment
3.1	Generation
3.2	Trading
3.3	Transmission and Distribution
3.4	Consumption
4.	Technology Use Cases
Matrix	Generation (7), Trading (4), Transmission and Distribution (4), Consumption (7)

Figure 144. Survey A structure

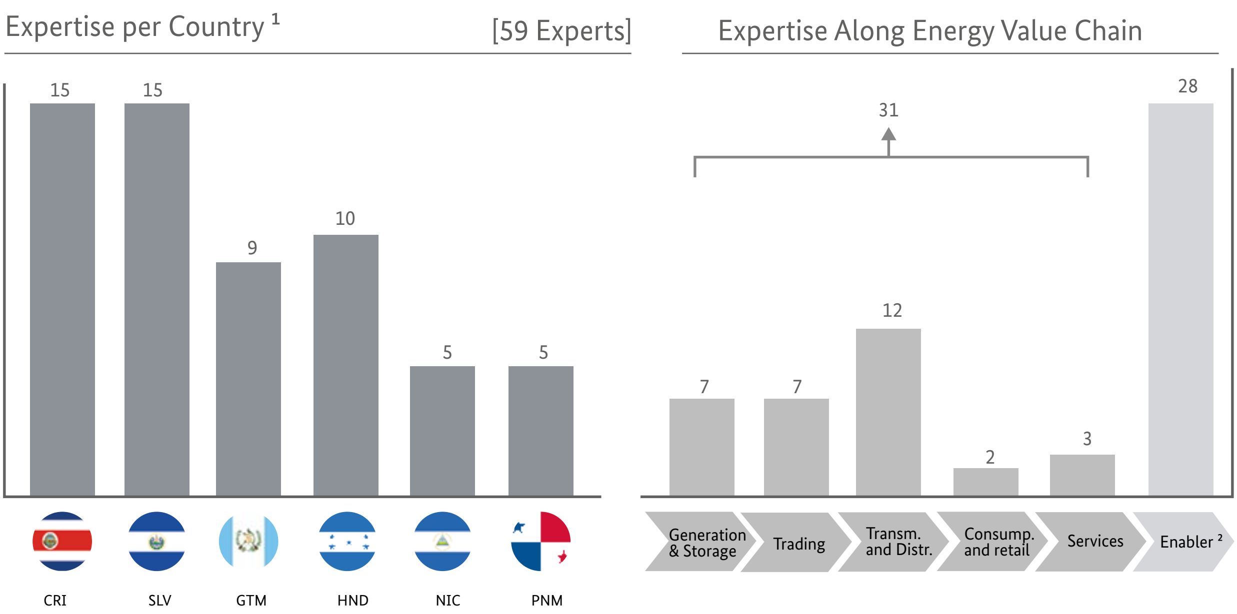
Experts could choose to complete the survey in either English or Spanish for one or more countries. Because some of the results of Survey A informed the results of Survey B, each country's survey A had a deadline. To increase response rates, we sent personalized survey links for country interviews. We monitored participation every day and called participants when necessary. For Survey A, we established a deadline after which the results would not be included in Survey B. Nevertheless, the Survey A link remained open to allow additional data gathering for the report. We outline the timeline of the surveys in Figure 145.



Survey online status: Survey A as well as the online version of Survey B will stay open to collect additional data.

Figure 145. Timeline of surveys

The final participation rate for Survey A was 73 percent, with 59 experts completing the survey (Figure 146). The majority of experts were from Costa Rica and El Salvador, with backgrounds in regulation and governance, as well as transmission and distribution.



[1] Experts migth have expertise in serveral countries, fields and along multiple steps of the value chain
[2] Enabler includes experts that are not attributable to a specific value chain step, e.g. governmental & regulatory, academia and financial services.

Figure 146. Final expert selection Survey A

Appendix 2. Survey B

Building on Survey A, we created Survey B to assess the digital readiness of the energy sector and to identify quick wins and risks. To create a picture of digital readiness, we opted for a two-sided approach, using a macro-perspective using country-wide benchmark criteria and a micro-perspective using data on the current state of digital technology and use case implementation. Although quick wins, risks, and mitigation measures were implicitly indicated through assessing digital readiness, we also explicitly addressed these. We present our conceptual approach in Figure 147.

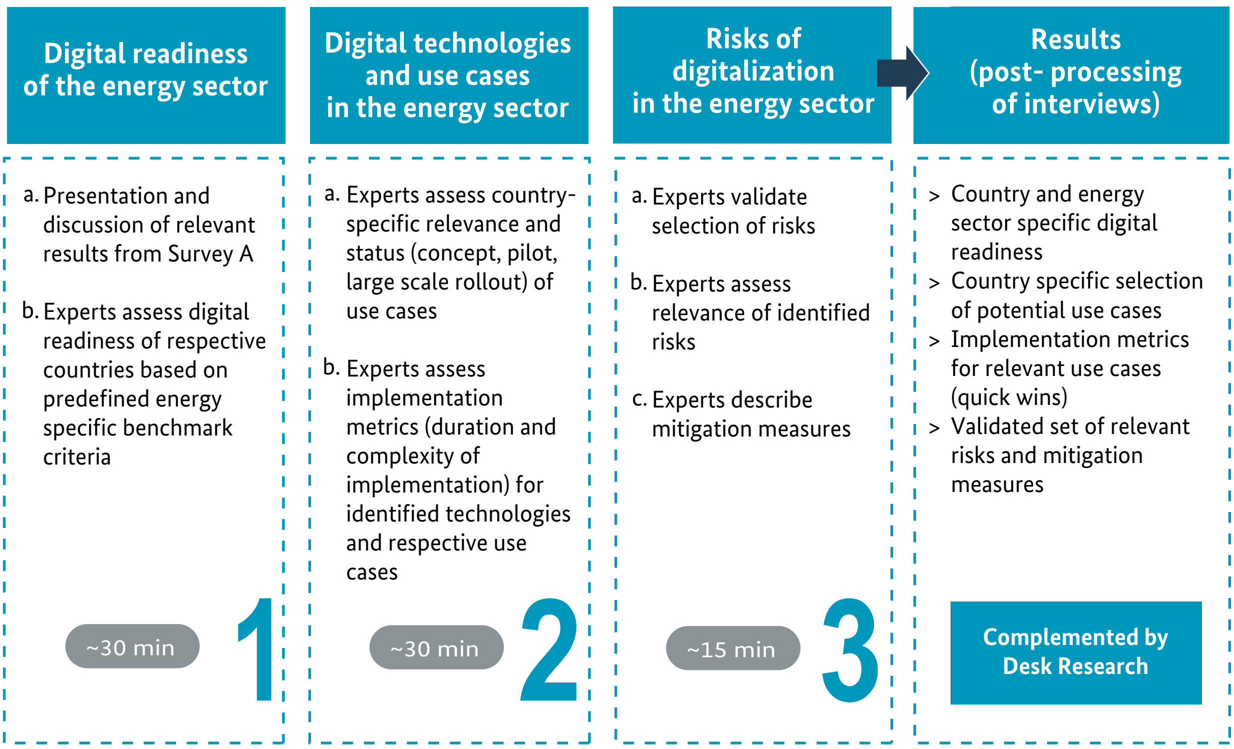


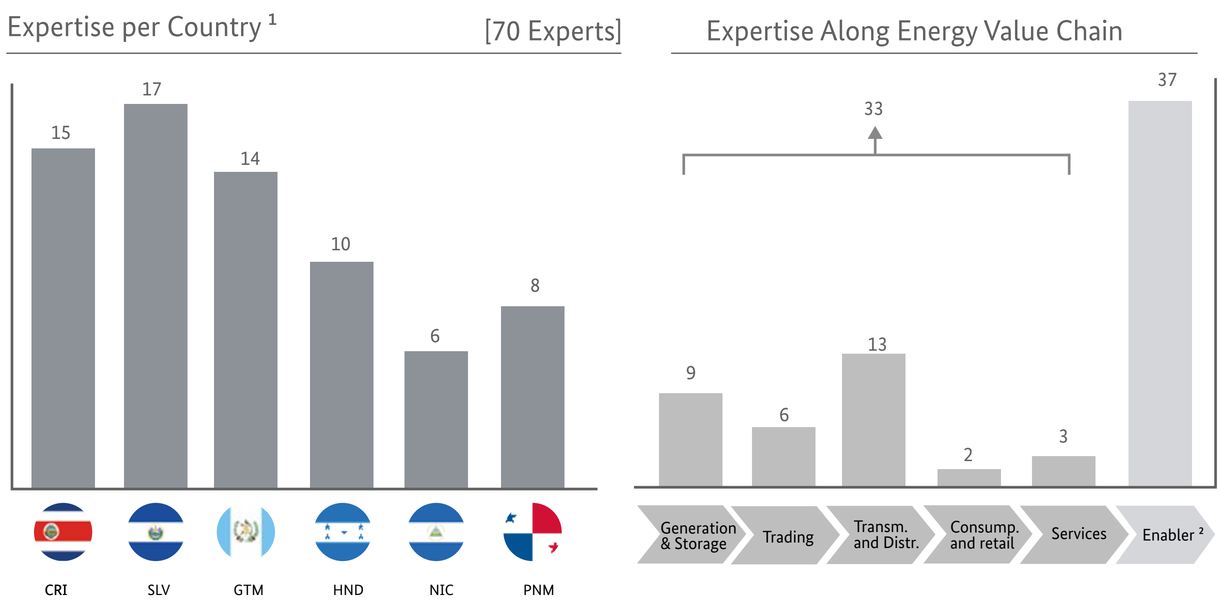
Figure 147. Survey B approach

Survey B	
1.	Introduction
1.1	General Information
2.	Survey A results
2.1	Trend Impact
2.2	Trend Potential
3.	Enabling framework conditions
3.1	Digital Infrastructure
3.2	Human Capabilities
3.3	Organizational Culture
3.4	Capital and Investment
3.5	Public Institutions and Governance
3.6	General Risks
4.	Technology use cases
4.1 - 4.7	Generation (7)
4.8 - 4.11	Trading (4)
4.12 - 4.15	Transmission and Distribution (4)
4.16 - 4.22	Consumption (7)
4.24 - 4.26	Quick Wins

Figure 148. Survey B structure

In Survey B, we first asked participants to confirm their general information, then administered three sections (138 items) of country-specific questions addressing the aforementioned topics. However, the use case section on the energy value chain was optional, because it required specialized knowledge. Although we conducted Survey B as in-person interviews, we entered data into a digital form using Likert scales, value fields, and text boxes. To capture participants' insights that fell outside this form, we asked open-ended questions, which we recorded in the text boxes. We held interviews during a six-week period, with one week per country and 75 minutes per interview. We present the thematic structure in Figure 148.

We summarize Survey B participant demographic data and areas of expertise in Figure 149. We interviewed 70 experts, reflecting an 86 percent participation rate. While the aim was that the same experts participate in both Surveys A and B, not all who participated in Survey A also completed Survey B and vice versa. The discrepancy is due to schedule changes on short notice and differential participation in face-to-face interviews and online surveys. The participation rate in Survey B matches that of Survey A, with the majority of experts being from Costa Rica and El Salvador, with backgrounds in regulation and governance, as well as transmission and distribution.



[1] Experts migth have expertise in serveral countries, fields and along multiple steps of the value chain.

[2] Enabler refers to experts in government and regulatory bodies, academia and financial service, who do not directly contribute to the value chain

Figure 149. Final expert selection for Survey B

Appendix 3. Megatrends Description

Demographic Dynamics

Growth. By 2030, world population will reach 8.6 billion people, a sixteen percent increase (0.98% p.a.) from 2015 (UN DESA, 2017). Ninety-seven percent of population growth will stem from developing countries, especially India, Nigeria, and Pakistan. Nevertheless, the speed of growth will slow compared to the the previous fifteen years (1.2% p.a. between 2000 and 2015).

Young versus old countries. By 2030, the global median age will increase by 3.4 years, meaning that half of the world's population will be older than 33 years (UN DESA, 2017). While the youngest countries are all located in Sub-Saharan Africa, most aging countries are European.

Migration. International migration flows remain but are slightly slowing as 2030 approaches (UN DESA, 2017). Most migrants come from Asia, while North America and Europe remain key destinations. The main reasons for migration are economic, demographic, political, social, and environmental nature.

Urbanization. Changing living conditions have increased the number of people living in urban areas worldwide. By 2030, 94 percent of total growth in urban population will take place in developing countries (UN DESA, 2014). More than half of the fifteen biggest urban agglomerations will be in Asia with megacities performing poorly in terms of sustainability, including waste management.

Globalization and Future Markets

Facets of globalization. Globalization is a multifaceted process not limited to economic effects – political and social aspects run in parallel. Developing countries, particularly in the Asian Pacific, will be able to bring their economies to the fore (Euromonitor). While household income is overall growing thorugh 2030 and inequalities between developed and developing countries are shrinking, income inequality within countries will increase slightly (Oxford Economics, 2017).

Economic integration. Global flows show strong trade relationships between regions – intraregional integration plays a major role (WTO, 2017). Therefore, free trade agreements are essential for an effective and smooth exchange of goods and services, yet future developments are not self-evident as free trade agreements currently face several serious challenges.

BRICS and beyond. Among both developing and developed countries, BRICS (Brazil, Russia, India, China, and South Africa) clearly lead the way in GDP growth through 2030 (Oxford Economics, 2017). Real GDP is expected to increase by 100 percent between 2015 and 2030. China and India are the main drivers of economic power and future development of the BRICS cluster. Following economic growth, rising annual disposable income will gradually help to establish a middle class in developing countries.

Scarcity of Resources

Energy. Until 2030, fossil fuels will continue to meet the majority of the world's primary energy demand, and their use is expected to increase 17 percent by 2030, mainly driven by emerging markets, especially China and India (ExxonMobil, 2016). Growing population, GDP growth, urbanization and the expanding middle class are main contributors to the increasing demand. The future development of oil prices is uncertain. Roland Berger predicts oil prices to stay low for much longer.

Water and food. Global water demand will increase 32 percent by 2050, driven by the growing use for manufacturing and electricity (OECD, 2012). At the same time low water resources are a reality. Even some European countries face occasional or local water stress. Population growth (75%) and a higher per capita consumption (25%) will drive the rising demand for food.

Other commodities. An EU study identified 20 critical raw materials of which China is the main supplier (European Commission, 2014). In 2030, the supply of barite, borate, and molybdenum will be at risk if countries continue to produce the same share of their reserves.

Climate Change and Ecosystem at Risk

Global warming. The rise in temperature since 1900 (+1.5°C) has been strongly correlated with increasing CO2 emissions (C-ROADS, 2017). Due to slow removal of atmospheric CO2, global warming cannot be halted in the short term, causing severe long-term consequences, such as financial risks and biodiversity loss. There are cooperation arrangements to fight climate change, but efforts must be increased.

Rising CO2-emissions. The main lever to reduce greenhouse gases is the reduction of CO2 from fuel combustion. Therefore, the use of fossil fuels must be reduced, as indicated in the IEA 2°C scenario (IEA, 2017). In this context, future emissions highly depend on actions being taken by China, India, and the USA.

Ecosystem at risk. Anthropogenic factors are drivers of the decline in the worldwide potential of biodiversity (OECD, 2012). From a geographic point of view, over 60 percent of the world's biocapacity is held by only ten countries, which in most cases suffer from heavy land and forest degradation. Although rain forest loss captures most of the attention, also the northern hemisphere is suffering from strong deforestation (WWF, 2016).

Dynamic Technology and Innovation

Power of innovation. We still face major challenges in the context of megatrends, yet many promising fields of innovation are expected to overcome these by 2030. Over the next decades, disruptive as well as sustaining innovations will change our lives. Moreover, creating wealth and increasing prosperity through innovation will be more sustainable than through resource exploitation (WIPO, 2016).

Life sciences. The powerful network of biology, pharmacology, and chemistry in life sciences provides answers to future challenges for humanity. Emerging countries in particular face major challenges which they can address with enhanced capabilities in life sciences (WEF, 2016).

Digital transformation. Following digitalization of the consumer sphere, digital transformation is permeating all areas of the economy, taking effect via digital data, automation, connectivity, and digital customer access. Roland Berger forecasts vast market dynamics, with digital transformation boosting the global economy throughout upcoming decades. In addition, AI will change our future through systems that have visual, cognitive, linguistic, and motor abilities.

Global Knowledge Society

Know-how base. The length of education–a prerequisite of a strong know-how base–pays off in terms of financial prosperity. There exists a positive correlation between years of education and GDP per capita (WEF, 2016). In 2030, almost all children (99.6%) will be going to school according to the University of Denver. However, regional imbalances exist regarding tertiary education, with only ten percent of Africa's relevant age group graduating in 2030.

War for talent. The importance of global knowledge and different demographic factors in developed and emerging countries causes a war for talent. The increasing number of higher-level qualified talent provides a chance to ease the intensity of the war for talent. In addition, developed countries can tap into the high outbound mobility of students originating from developing countries.

Gender gap. Three of the main factors impacting the gender gap are years of education, labor force participation, and disposable income. America and Europe are the regions enjoying gender parity in terms of years spent in education. Regarding labor force participation and disposable income equality, Scandinavian countries are the benchmark (Euromonitor, 2017). In contrast, developing countries show the biggest gender gaps in education and income.

Sustainability and Global Responsibility

State. Good governance is the basis of strong and sustainable policy actions. Regarding the UN sustainable development goals, governments can deploy different instruments across three actionable areas, namely healthy communities, economic vitality, and natural environment. Nevertheless, multiple policy options remain unsolved, and violent conflicts and weak international solidarity threaten sustainable actions. Thus, action by other stakeholders is required.

Society. NGO and charitable foundations' donations represent key contributions from society. Moreover, philanthropists account for almost one third of total development assistance. In the future, high expectations for sustainable development rest with the engagement of the global middle class, as well as an increasing demand for sustainable products and behavior of companies that aligns with corporate social responsibility.

Businesses. For sustainable development, companies face a challenging decoupling of their economic objectives. Customer demands and pressure from other stakeholders drive companies to act as good corporate citizens. Companies acting as corporate citizens are not altruists but add economic value and bring sustainability to their business models.

Appendix 4. Value Chain Description

Generation

Electricity needs to be produced from primary energy sources. These include fossil sources such as coal (anthracite and lignite), gas, and oil. These primary sources are characterized by their high CO2 intensity. Furthermore, nuclear power generation is available and relies on the fission of uranium atoms. Finally, renewable energy refers to hydro (e.g. run-of-the-river, pump-storage), wind (on- and offshore), and solar (PV and thermal) sources. Other sustainable energy sources are waste-to-energy and geothermal energy. Main actors in power generation are utilities. However, independent operators (e.g. wind farm operators) and prosumers are spreading.

Trading

Wholesale electricity markets (exchanges) allow matching supply and demand. Auctions take place until the day ahead of delivery (spot market) and intraday continuous trading compensates short-term imbalances. There are a variety of contracts available in the market, ranging from quarter-hourly products to block contracts for specific demand regimes (e.g., peak vs. base load or working days vs. weekends). Participants in trading are market operators, utilities, local power distributors, and energy-intensive industries among others.

Transmission and Distribution

The electricity grid physically connects consumers with geographically distant generation units. High voltage lines carry power from generation sites to sub-stations and medium/low voltage lines carry power to consumers. Transmission system operators (TSOs) and distribution system operators (DSOs, mainly utilities) manage the electricity grid. The transmission and distribution grids are normally split geographically among the different TSOs and DSOs.

Consumption

Electricity is mainly employed for heating and cooling, lighting production, and transportation. Temporal factors drive consumption during the year (winter versus summer), week (working days versus weekend days), and day (day versus night). Households, businesses, and industry are the main consumers of electricity. Transportation is expected to increase demand for electricity consumption.

Service

Service enhances the value of energy and ensures efficiency from generation to consumption. It includes installation as well as operation and maintenance (O&M) of equipment throughout the value chain. Service operations can be run either by utilities, transmission and distribution system operators themselves, or by third party O&M providers. Smart grids, including smart metering, are some of the most important digital use cases in the service industry.

Appendix 5. Energy Parameter Descriptions

Generation

	Parameter	Description	Formula
1	**Energy mix**	Indicates the split of energy production in a country by the share of generation from renewable energy. High shares of renewable energy are associated with lower emissions.	$\frac{GWh_{renewable}}{GWh_{generated}}$
2	**Carbon intensity**	Indicates the carbon emissions per unit of energy produced. A lower value stands for lower emissions.	$\frac{CO_{2\,generated}{}^{1}}{GWh_{generated}}$
3	**Efficiency**	Indicates the efficiency level of generation capacity and competition in the market. Lower prices reflect more efficiency in generation.	$\frac{\$}{MWh_{traded}}$
4	**Capacity factor**	Indicates the profitability of installed capacity. A higher capacity factor reflects a potentially higher profitability of installed capacity and more competitiveness.	$\frac{MWh_{generated}}{MW_{installed} * 365 * 24\,h}$
5	**Total generation**	Indicates actual demand and is obtained from total electricity production. Higher generation therefore reflects higher demand.	$GWh_{generated}$
6	**Total installed capacity**	Indicates the total installed generation capacity. A higher value stands for higher (expected) demand or a higher need of reserve capacity (intermittent generation).	$MW_{installed}$
7	**Reserve margin**	Indicates the agility of the system to handle mismatches of supply and demand. Higher values stand for higher security of supply.	$\frac{MW_{installed} - MWh_{peak\ demand}}{MWh_{peak\ demand}}$

1) CO_2 emissions from electricity production only

Trading

	Parameter	Description	Formula
8	**Market liquidity**	Indicates the competition in the market. A higher share of traded electricity reflects a free market with lower prevalence of monopolies or market power.	$\frac{GWh_{traded}}{GWh_{distribution}}$
9	**Net energy exports (MER)**	Indicates the net energy flow within the Regional Electricity Market (MER). A high positive (negative) absolute value indicates high exports (imports).	$GWh_{exported} - GWh_{imported}$

Transmission and Distribution

	Parameter	Description	Formula
10	**Energy loss**	Indicates the energy loss of transmission & distribution. Higher values stand for lower transmission efficiency, leading to higher emissions.	$\frac{GWh_{loss}}{GWh_{available}}$
11	**Grid interconnection (MER)**	Indicates the interconnection capacity (export) to the Regional Electricity Market (MER). Higher values stand for a better security of supply and resilience of the system.	$\frac{MW_{interconnection}}{MW_{installed}}$

Consumption and Service

	Parameter	Description	Formula
12	**GDP energy intensity**	Indicates the energy usage per million USD of GDP. A lower energy intensity stands for more efficient production and lower emissions	$MWh_{generated} / \frac{GDP}{10^6}$
13	**Self-sufficiency**	Indicates the degree of self-sufficient energy generation. A higher ratio implies higher decentralization.	$\frac{GWh_{prosumer}{}^2}{GWh_{consumed}{}^3}$
14	**Market diversity**	Indicates consumer choice by the number of options available (number of retailers) to each customer. A higher number indicates more competition and diversity.	$Providers_{total}$
15	**Number of electric vehicles**	Indicates total number of electric vehicles. A higher number indicates a growing demand for electricity.	EV_{total}
16	**Consumption split**	Indicates the sector specific ratio of electricity consumption to total electricity consumption. The values might indicate a sector specific shift of consumption and allows to trace drivers of demand growth.	$\frac{GWh_{industrial}}{GWh_{consumed}}$ $\frac{GWh_{residential}}{GWh_{consumed}}$ $\frac{GWh_{other}}{GWh_{consumed}}$ $\frac{GWh_{commercial}}{GWh_{consumed}}$
17	**System Average Interruption Duration Index**	Indicates the reliability of the energy grid. Shorter blackout periods per customer indicate a higher reliability and a higher security of supply.	$\frac{\sum customers_{interrupted} * \text{outages in } hours_{total}}{customers_{total}}$
18	**Smart meters**	Indicates the degree of digitalization. A higher number allows to derive demand patterns, increasing security of supply and making billing easier.	$Smart\ meters_{total}$

2) $MWh_{prosumer}$ includes electricity for self consumption only
3) $MWh_{consumed}$ includes electricity distributed and electricity for self-consumption not fed into the grid

Appendix 6. Use Case Technology Clustering

	Generation	Trading	Transmission and Distribution	Consumption[2]
Blockchain	1 Certification of energy products	8 P2P energy trading & microgrids 9 Enterprise asset mgmt. 10 Electricity wholesale	12 Load balancing through smart contracts	16 Smart contracts for variable billing
Internet of Things (IoT)	2 Virtual power plant 3 Asset health monitoring and alerting system		13 Remote monitoring and grid management 14 Vehicle to grid	17 Intelligent energy consumption 18 Services for general metering point operators 19 E2E service platform (e.g. digital twins)
Advanced Analytics (AA)[1]	4 Self-optimizing generation system 5 Output forecasting for RE 6 Digital visualization and mapping of fossil ER 7 Identification of local waste streams	11 Algorithmic trading and price setting	15 Automated inspection and vegetation mgmt.	20 Automated lead mgmt. 21 Customer service bots 22 Consumption optimazation throught ML

1) Including Artificial Intelligence
2) Including services

Appendix 7. General Parameter Sources

General Parameter	Year	Source[1]
Population	2017, 2009	World Bank
Life expectancy at birth	2016, 2009	CIA, World Bank
GIN index	2014, 2009/2006	CIA, World Bank
Human Development Index	2017, 2009	United Nations HDR
Inhabitants with internet access	2016, 2009	CIA, World Bank
Access to electricity	2016, 2009	World Bank
Cost of mobile data (1GB)	2018	Cable.co.uk
GDP	2017, 2009	World Bank
GDP p.c. (PPP)	2017, 2009	World Bank
Unemployment rate	2017, 2009	International Labour Organization
Inflation	2017, 2009	World Bank
CO_2 - emissions p.c.	2014, 2009	World Bank

[1] In sequence of year if different sources

Appendix 8. Energy Parameter Sources

Energy Parameter	Year	Source
Total generation	2017	ECLAC
Total Installed Capacity	2017	ECLAC
Reserve Margin*	2017	ECLAC
Capacity Factor*	2017	ECLAC
Efficiency	2017	MER
Energy Mix	2017	ECLAC
Carbon Intensity*	2017	ECLAC
Net Energy Exports to MER	2018	CRIE (MER)
Wholesale Electricity Market	2017	ECLAC
Market Liquidity	2017	ECLAC
Energy Loss	2017	ECLAC
Grid Interconnection*	2017	ECLAC, EOR
GDP Energy Intensity*	2017	ECLAC, CIA
Self-Sufficiency*	2017	ECLAC
Market Diversity	2017	ECLAC
Number of Electric Vehicles	-	no global database
System Average Interruption Duration	2018	World Bank
Number of Smart Meters	-	no global database

[*] calculated parameter with data from listed source, calculation in parameter appendix

Appendix 9. Use Case Descriptions

Use Case		Description	Status
1	Certification of energy products	Blockchain enables clear, tamperproof power attribution to the source. Allows differentiation of energy products (e.g. green, regional) and increases consumption transparency	Pilot
2	Virtual power plant	Network of decentralized power generating units controlled by an aggregator. Provides balancing services to the grid by adjusting power demand/ load shifting	Pilot
3	Asset health monitoring and alerting system	Sensors that enable a fully automated, real-time system to monitor conditions of assets. Allows for flexible, on-demand predictive maintenance to reduce operations and maintenance costs	Commercial
4	Self - optimizing generation systems	Machine Learning to increase efficiency by analyzing operations data across different generation systems / assets	Pilot
5	Output forecast for renewable energies	Correlate past weather and machine data to predict and optimize output. Integrate RE into the grid reliably and cheaply	Commercial
6	Digital visualization & mapping of fossil energy sources	Leverage data (seismic, geographic etc.) with AA to optimize development and exploitation of fossil reservoirs. Potential production from unconventional tight oil and shale gas wells	Concept
7	Identification of local waste streams	Increase energy efficiency by connecting industrial equipment to gain real-time data on the availability of local waste streams to convert to other forms of energy	Concept
8	Peer -to- Peer energy trading and microgrids	Microgrids that allow transparent and efficient energy trading among private participants without intermediaries. Transactions between participants executed and documented automatically by blockchain	Pilot
9	Enterprise asset management	Allows acquisition of asset fractions based on blockchain tokens (similar to ICOs), and enables consumers to co-fund a sustainable power system	Concept
10	Electricity wholesale	Electricity wholesale among utilities without intermediaries. Cost reduction, speed and transparency gains in trading	Pilot
11	Algorithmic trading and price setting	AI-based trading algorithms that autonomously trade and adapt over time. Reduces management costs for hedge funds	Pilot
12	Load balancing through smart contracts	Smart contracts for demand response in combination with remuneration concepts to balance power consumption and allow smart storage	Pilot
13	Remote monitoring and grid management	Better control mechanisms (remote monitoring, grid management, and transparency) reduces losses through increased operation efficiency and theft prevention, reducing energy generation needs	Pilot
14	Vehicle to grid	Electric vehicles as mobile batteries to allow intelligent storage. Increase utilization of renewable energy production	Concept
15	Automated inspection and vegetation management	Using drones, image processing, and remote-sensing methods to inspect and maintain power lines and enable predictive maintenance	Pilot
16	Smart contracts for variable Billing	Condition-based billing enabled by smart contracts	Pilot
17	Intelligent energy consumption	Responsive energy services, remote control, and behavioral prediction through sensors, e.g. automated lighting, heating & cooling services, and increased energy efficiency	Pilot
18	Services for general metering point operators	Utilities and service providers offer smart metering services to support metering point operators throughout the value chain	Pilot
19	E2E service platform (e.g. digital twins)	End-to-End (E2E), through digital twins more efficient planning and realization of energy solutions possible	Pilot
20	Automated load management	Based on load profiles, automatically manage leads according to customer type	Pilot
21	Customer service bots	Increase service level through chat bots (free of emotions, 24/7 available, no queue time), cost reduction (personnel)	Commercial
22	Consumption optimization through ML	Use machine learning and analytics to increase energy efficiency, e.g. optimize cooling of data centers	Pilot

Concept: theorized potential — Pilot: first pilots are implemented — Commercial: multiple successful implementations (i.e. large scale implementation)

1) Including services

Blockchain — IoT — AA

Appendix 10. List of Challenges

		Costa Rica	El Salvador	Guatemala	Honduras	Panama	Nicaragua
1	Data quality insufficiency	✓	✓	✓	✓	✓	✓
2	Financial straits	✓	✓		✓	✓	✓
3	Institutional inefficiency	✓		✓	✓	✓	✓
4	Market frictions	✓			✓	✓	✓
5	Decentralized systems	✓			✓	✓	✓
6	Electricity dependency		✓	✓		✓	
7	Generation overcapacity	✓			✓	✓	
8	Remote generation				✓	✓	✓
9	Energy losses	✓	✓	✓	✓	✓	✓
10	Transmission line congestions		✓	✓	✓	✓	
11	Grid instability (volatility of renewables)	✓			✓	✓	✓
12	Tariff structure inefficiencies	✓		✓		✓	
13	Demand forecasting inaccuracy	✓		✓	✓	✓	✓
14	Energy inefficiency			✓	✓	✓	

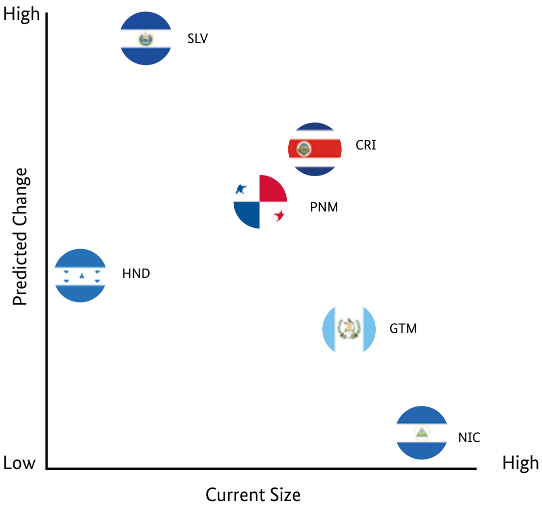
All | Generation | Transmission & Distribution | Consumption

1	**Data quality insufficiency**	Lack of high quality data leads to the inability to plan for market agents
2	**Financial straits**	Lack of investment into infrastructure and projects due to investor insecurity. This can lead to insufficient infrastructure
3	**Institutional inefficiency**	Public institutions (market operator, regulator) are not working efficiently or do not plan accordingly. This slows down development in the electricity sector
4	**Market frictions**	Non- liberalized electricity market structure leads to a lack of competition
5	**Decentralized systems**	Distributed electricity generation can cause stress on the grid and price competition to electricity companies
6	**Electricity dependency**	Dependence on energy imports from other MER countries or energy exports
7	**Generation overcapacity**	Challenge of having a too high installed energy generation capacity. This can lead to higher electricity prices
8	**Remote generation**	Electricity generation capacity is localed in different locations than the consumption requiring transfer lines
9	**Energy losses**	High (non-) technical electricity losses. This is expensive for the agents in the electricity sector
10	**Transmission line congestions**	Current transmission lines are not sufficient. This leads to power outages and grid instability
11	**Grid instability (volatility of renewables)**	High share of renewable energy sources can lead to an instability of the grid due to the volatile nature
12	**Tariff structure inefficiencies**	Tariff structure are outdated and lead to high and inflexible electricity prices
13	**Demand forecasting inaccuracy**	Uncertainties in the demand planning can lead to over -or under capacity of the energy infrastructure
14	**Energy inefficiency**	Not enough progress on energy efficiency. This increases the required energy generation

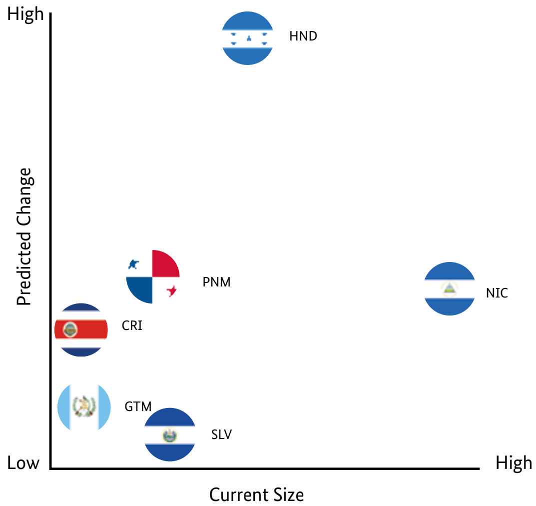
All — Generation — Transmission & Distribution — Consumption

Appendix 11. Energy Parameters Improvement Potential Comparison

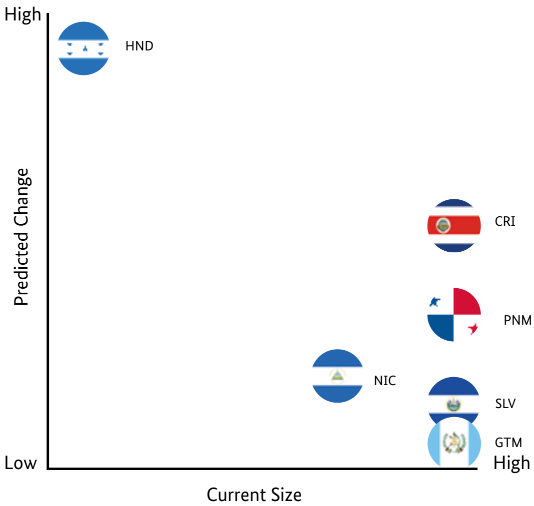
Reserve Margin



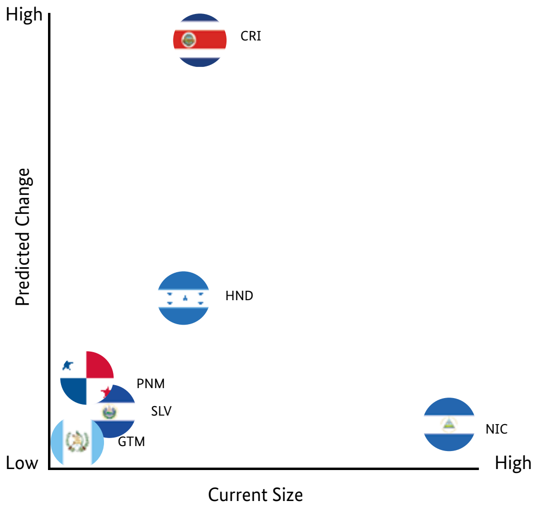
Grid Interconnection



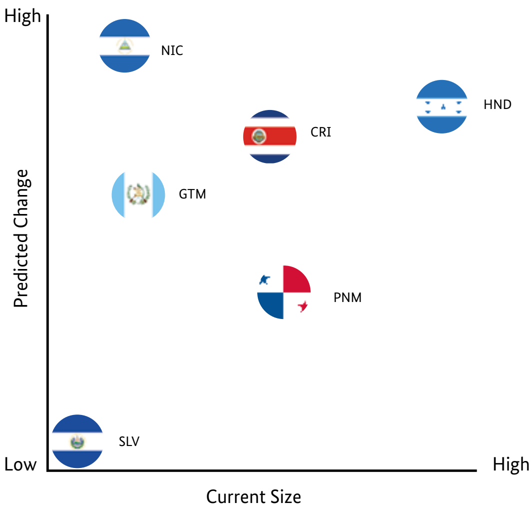
System Average Interruption Duration



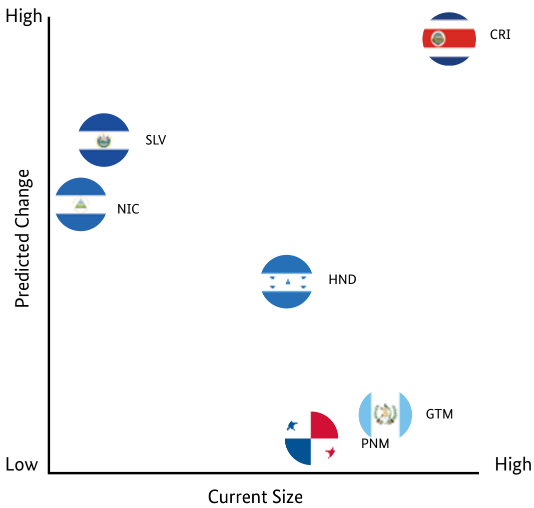
Number of Smart Meters



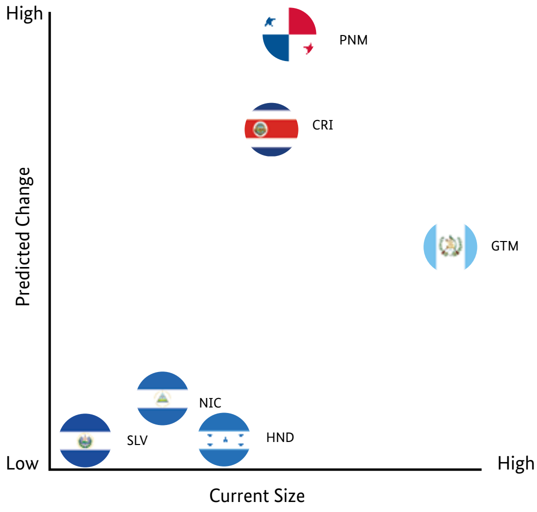
Capacity Factor



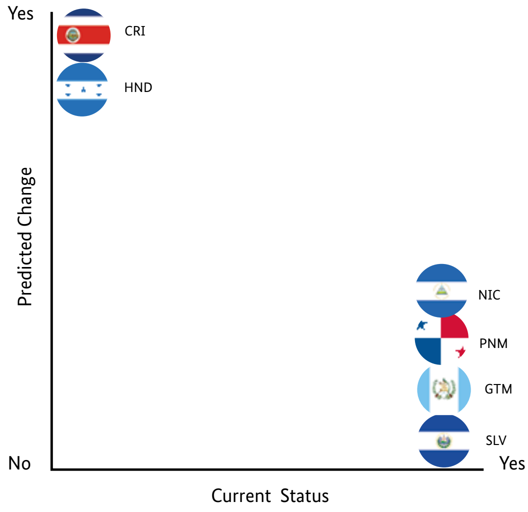
Efficiency



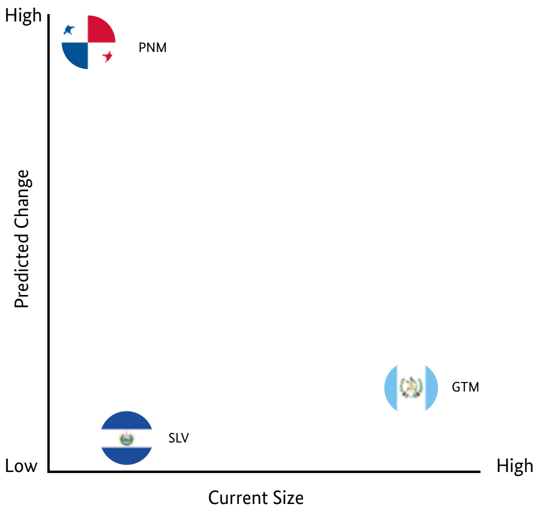
Net Energy Exports to MER



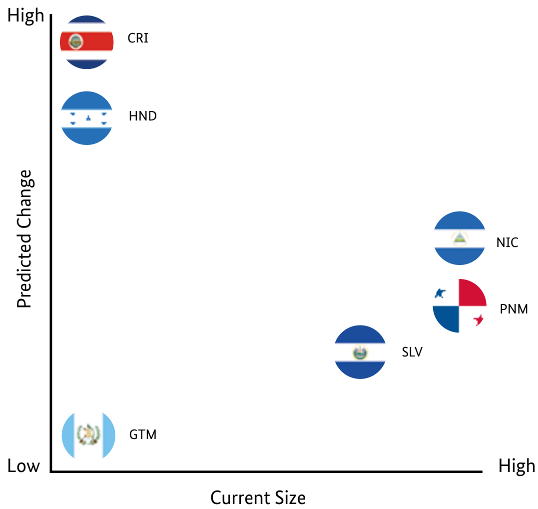
Wholesale Electricity Market



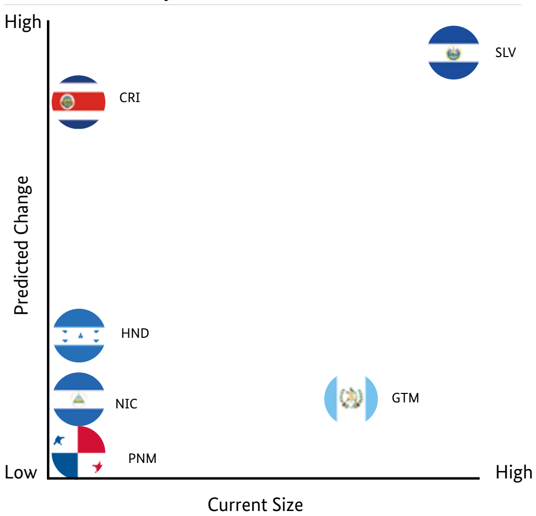
Market Liquidity



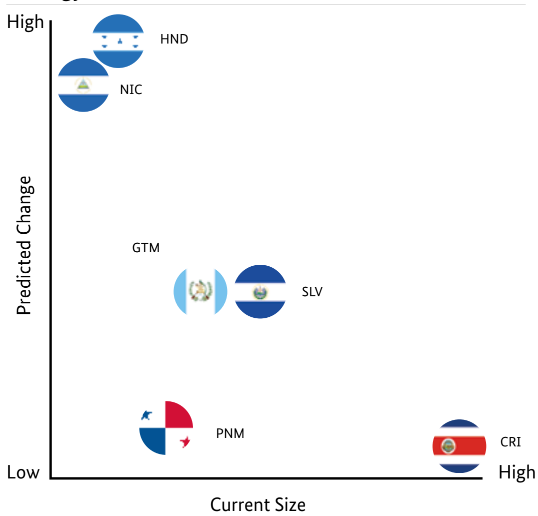
Self-Sufficiency



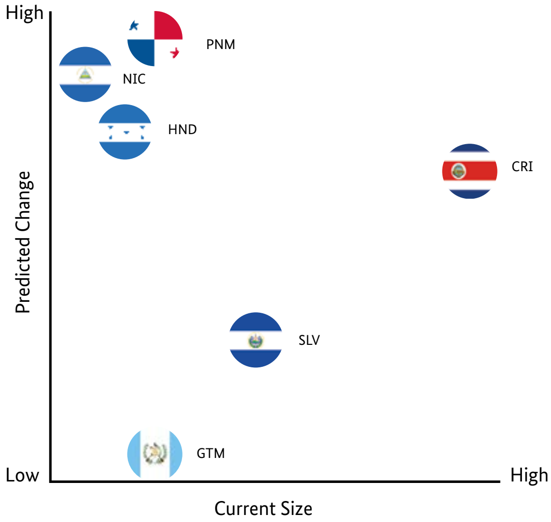
Market Diversity



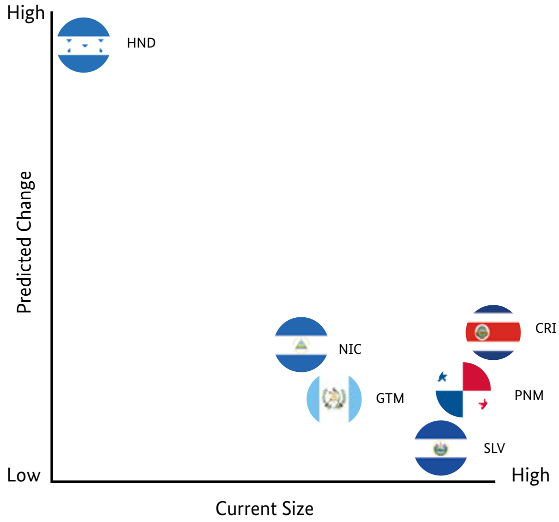
Energy Mix



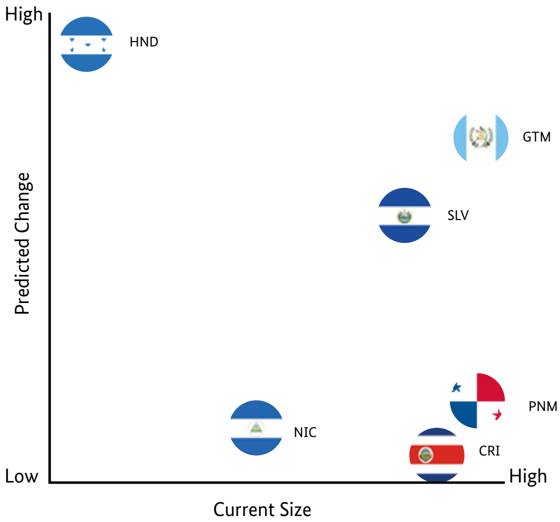
Carbon Intensity



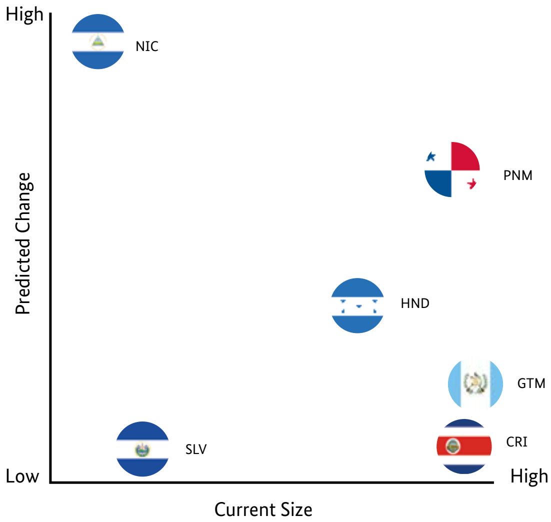
Energy Loss



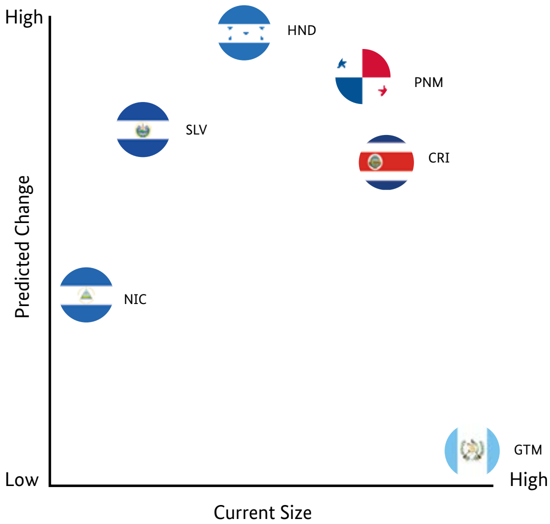
GDP Energy Intensity



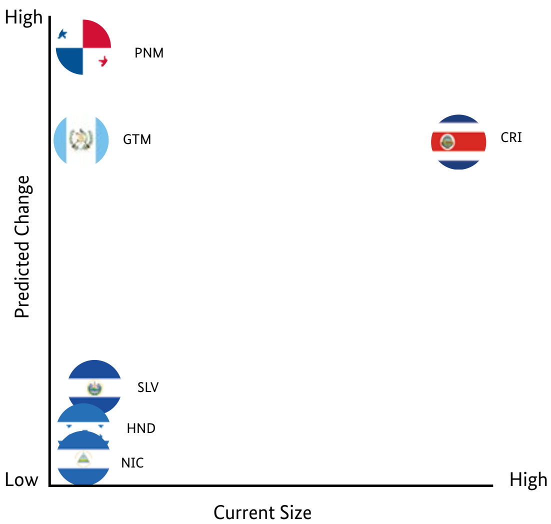
Total Generation



Total Installed Capacity



Number of Electric Vehicles



Appendix 12. Average Ranks in Digital Readiness Frameworks

Digital Infrastructure

	Broadband Fixed Subcriptions	Internet Users	Telephones Mobile Cellular	Average
Costa Rica	74	95	88	**86**
El Salvador	84	118	85	**96**
Guatemala	81	74	57	**71**
Honduras	104	103	98	**102**
Panama	83	113	114	**103**
Nicaragua	108	123	99	**110**
Germany	4	8	15	**9**
Chile	40	46	53	**46**
Source	CIA.gov	CIA.gov	CIA.gov	

Organizational Culture

	Business sophistication	Company spending on R&D	University-industry collaboration in R&D	Firm-level technology absorption	Average
Costa Rica	35	50	50	40	**44**
El Salvador	104	115	120	115	**114**
Guatemala	53	70	71	41	**59**
Honduras	88	102	101	65	**89**
Panama	68	59	79	35	**60**
Nicaragua	129	133	123	116	**125**
Germany	5	4	7	12	**7**
Chile	50	99	58	37	**61**
Source	WEF Index	WEF Index	WEF Index	WEF Index	

Public institutions & Governance

	Rule of law	Burden of government regulation	Transparency of government policymarking	Organized crime	Irregular payments and bribes	Corruption perception index	Average
Costa Rica	24	125	38	74	55	48	**61**
El Salvador	79	121	123	137	104	105	**112**
Guatemala	96	102	66	133	80	144	**104**
Honduras	103	126	95	136	93	132	**114**
Panama	61	50	60	68	74	93	**68**
Nicaragua	99	105	100	31	114	152	**100**
Germany	6	7	18	59	29	11	**22**
Chile	27	69	35	46	27	27	**39**
Source	World justice project	WEF Index	WEF Index	WEF Index	WEF Index	Transparency International	

Capital & Investment

	Financial market development	Availability of financial services	Affordability of financial services	Ease of access to loans	Venture capital availability	Average
Costa Rica	39	80	70	92	98	**76**
El Salvador	57	56	69	81	116	**76**
Guatemala	18	22	24	29	60	**31**
Honduras	38	50	55	47	79	**54**
Panama	14	11	9	14	26	**15**
Nicaragua	100	64	92	73	123	**90**
Germany	12	16	7	10	6	**10**
Chile	17	9	15	16	41	**20**
Source	WEF Index	WEF Index	WEF Index	WEF Index	WEF Index	

Human Capabilities

	Education Index	Higher education and training	Secondary education enrollment rate	Tertiary education enrollment rate	Quality of the education system	Availability of Scientists and engineers	Average
Costa Rica	68	31	11	52	27	27	**36**
El Salvador	115	104	90	82	132	134	**110**
Guatemala	125	99	102	95	123	70	**102**
Honduras	129	102	98	93	98	96	**103**
Panama	65	88	95	72	96	64	**80**
Nicaragua	132	110	96	n/a	134	130	**120**
Germany	6	15	36	32	9	11	**18**
Chile	41	26	45	7	86	22	**38**
Source	HDI ranking	WEF Index	WEF Index	WEF Index	WEF Index	WEF Index	

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