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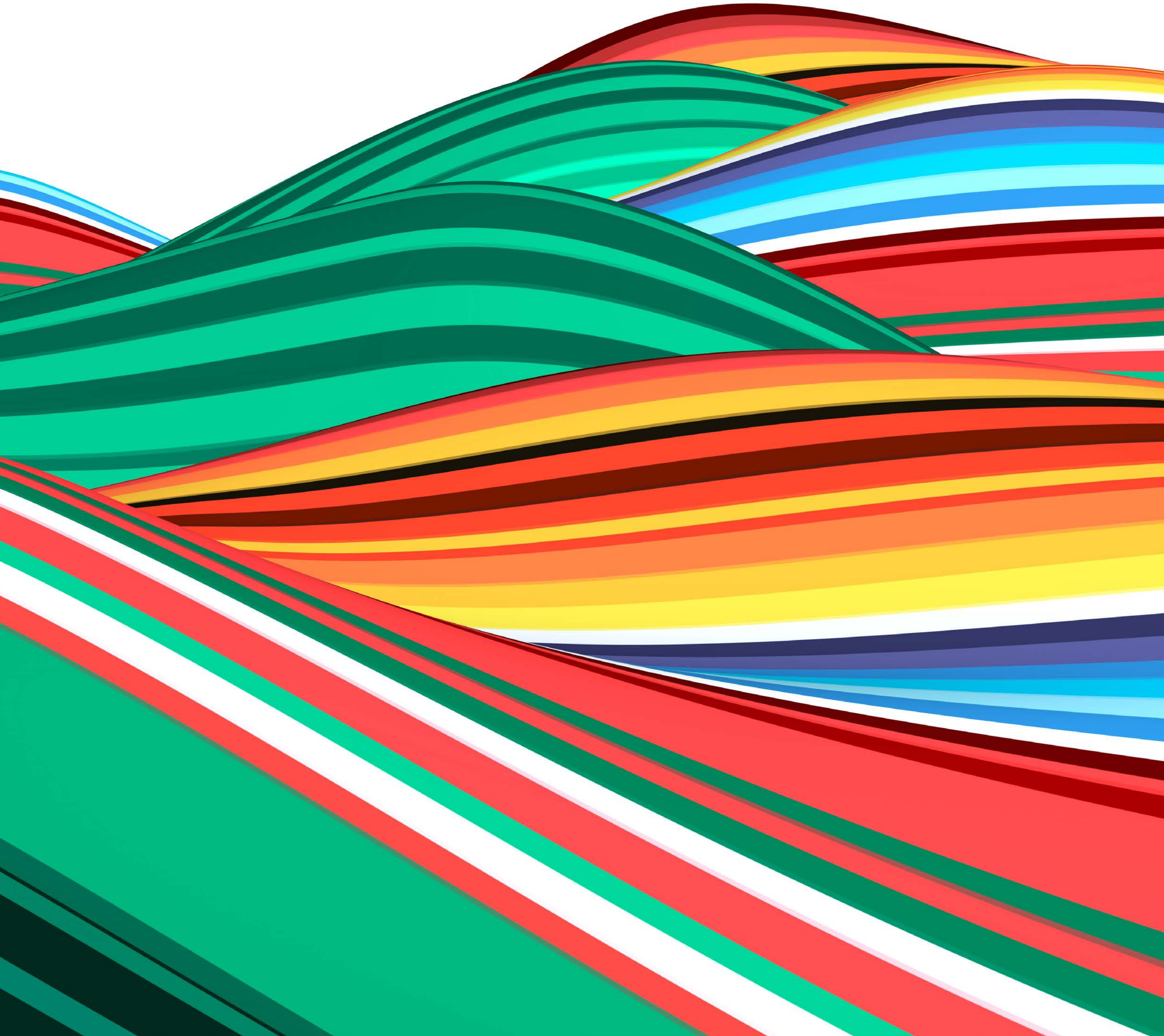
FIRM CAPACITY IN CENTRAL AMERICA

DEFINITIONS AND IMPLICATIONS FOR VARIABLE RENEWABLE ENERGY



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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

ABOUT THE CLEAN ENERGY CORRIDOR OF CENTRAL AMERICA (CECCA)

IRENA developed the Clean Energy Corridor of Central America (CECCA) initiative in 2015 to support the accelerated deployment of renewables at the regional level in Central America and, in the context of the Central American Electric Interconnection System (SIEPAC) line interconnecting Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, promote the cross-border trade of electricity coming from clean energy sources. CECCA was built around key pillars of implementation: power system operations and regulatory frameworks for increasing variable renewable energy shares; country and regional power system planning with renewables; zoning and renewable resource assessment; and capacity-building and information dissemination.

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International Renewable Energy Agency

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ABBREVIATIONS AND ACRONYMS

AMM	Wholesale Market Administrator of Guatemala (Administrador del Mercado Mayorista)
CENACE	National Energy Control Centre (Centro Nacional de Control de Energía), Mexico
CND	National Dispatch Centre (Centro Nacional de Despacho), Panama
CNDC	National Dispatch Centre (Centro Nacional de Despacho de Carga), Nicaragua
LTRS	long-term reserve service
MER	regional electricity market
ODS	System Operator (Operador del Sistema), Honduras
PPA	power purchase agreement
PV	photovoltaic
SDDP	stochastic dynamic dual programming
SIGET	Electricity and Telecommunications General Superintendency (Superintendencia General de Electricidad y Telecomunicaciones), El Salvador
VRE	variable renewable energy

GLOSSARY

bilateral agreement	Agreement between two parties in which both sides agree to fulfil their obligations.
capacity balance	Organised balance typically performed by a system operator in which the Firm Capacity surplus or deficit of an agent is estimated based on the Firm Capacity of its own assets, purchases and sales of Firm Capacity through contracts and its Firm Capacity commitments.
capacity market	Registered exchange in which parties buy or sell Firm Capacity requirements.
capacity	Ability or potential to deliver electricity.
contract market	Registered exchange where energy and capacity are traded.
debt-service coverage ratio	Measurement of available cash flow to pay current debt obligations.
deficit probability	Probability of not being able to supply the full demand at a given time.

effective capacity	Maximum amount of capacity that a generator is capable of injecting into the grid considering its technical and regulatory restrictions.
efficient Firm Capacity	Necessary Firm Capacity in the system to supply the expected demand.
energy	Product traded throughout wholesale electricity markets.
energy buyers	For the purpose of this document, all energy sector participants that demand (buy) electricity, such as distributors and qualified users.
electricity market	System or mechanism for exchanging electricity-related products and services between participants, entities or countries.
Firm Capacity	Tradeable product that a generator could offer through a market or mechanism.
Firm Capacity deviation	Differences between the Firm Capacity recognised for an agent and its Firm Capacity commitments.
Firm Capacity regional contracts	Contracts to sell Firm Capacity between agents of the regional market located in different countries.
firm demand	The Firm Capacity requirements of an agent.
instant production rate	Production capacity at any given time.
internal rate of return	Metric used in financial analysis to estimate the profitability of potential investments. It is a discount rate that makes the net present value of all cash flows equal to zero in a discounted cash flow analysis.
Long-Term Reserve Service	Annual tender in which long-term Firm Capacity is negotiated (Panama).
power	The amount of energy divided by the time it took to use the energy.
settlement	Process of completing the payment for an exchange of products or services.
sufficiency of the system	Probability that the system will supply the demanded electricity during critical hours.
weighted average cost of capital	Average cost of capital from all sources, after tax. It is the average rate that a company expects to pay to finance its assets.

EXECUTIVE SUMMARY

The concept of Firm Capacity of a power plant is an assessment of its contribution towards meeting demand during critical conditions of an electrical system. This guide aims to provide an overview of the current definition for Firm Capacity within the regulatory framework of the Central American power sector, with a focus on its application to variable renewable generation, and the effect it has on the power purchase agreement (PPA) market (contract market).

Worldwide, Firm Capacity is a commercial attribute that allows generators to use it as a trade asset in an electricity market or offer it as a guarantee to the system in exchange for a regulated payment; the signing of long-term contracts with distribution companies and large consumers is also an option for commercialisation.

Some of the key findings from the analysis include:

The definition of Firm Capacity must take into account the underlying conditions of the power sector for each country (generation mix, demand profile, flexibility, etc.) but also must consider its expected development. The expectation is for variable renewable energy (VRE) generation to increase its share in the generation mix across countries in Latin America, as initiatives like RELAC[1] begin an implementation phase that will transform the energy landscape in the region.

An important characteristic of VRE generation is that its variability depends on unpredictable natural resources; countries with high shares of hydropower generation and strong transmission grids have the ability to absorb high levels of variable generation and compensate the variability by optimising the use of the energy stored in the reservoirs.

Countries with low shares of hydropower generation or with weak transmission grids may face increasing operative problems with the additional variability. In this context, the contribution of each technology to the reliability of the system may be significantly different depending on these conditions.

The circumstances affecting an electrical system should also be considered when describing Firm Capacity. Challenges related to a dry year or short-term problems arising from restrictions to compensate both the variability of the load and of natural resources are examples of atypical situations. The definition of Firm Capacity should reflect the critical conditions that the power system might face.

1 *Renewables in Latin America and the Caribbean Initiative.*

The definition of Firm Capacity must consider the real contribution of VRE generation to the sufficiency of the system by using optimisation and simulation models used typically for dispatch scheduling.

The fact that a specific technology offers an energy supply that depends on the availability of a natural resource, potentially a challenge for the system operator to manage, should not be a barrier to the recognition of Firm Capacity for that technology.

The critical period in which Firm Capacity is evaluated should be aligned with the hours corresponding to lower reserve margins.

The methods used for Firm Capacity calculation should aim to allow all technologies to compete for Firm Capacity recognition (as it happens for energy) and not include external barriers (like restrictions to participate in tenders).

The methods used for Firm Capacity recognition should consider the future adoption of new technologies into the energy system (*e.g.* storage) and for the participation of all agents (energy buyer or off-taker, distribution companies, distributed generation activities and large consumers who manage the demand side).

Clear definitions and methodologies should continue to serve as a signal for the development of new energy generation and for the guarantee of continued supply in the long term.

The definition of Firm Capacity is set by the regulations of each country, and that has worked as a hindrance for the development of Firm Capacity contracts in the regional market. As observed, the definition is not consistent across the six participating countries, and the meeting point of Firm Capacity estimated by one country and recognised by its neighbours has yet to be identified.

ABOUT THIS GUIDE

Analysis for this document has focused on the methods used in Central American countries to recognise Firm Capacity, plus a benchmark analysis focusing on Brazil, Chile, Mexico and Peru. The rationale for selecting these countries, was based on the need to compare established wholesale electricity markets in the region that have implemented Firm Capacity recognition for renewable generation through different criteria.

Firm Capacity as a product aims to provide a stable price signal for the development of new generation capacity in the long term and ensure the security of electricity supply in the system. One of its main features is that it provides a stable source of income for power generators that allows them to cover fixed costs and develop new generation capacity that prevents the system from experiencing deficit conditions.

This report benefitted from the development of a case study based on the electricity sector of El Salvador (see section "Country Case: El Salvador"). The study analysed the impact of the Firm Capacity recognition methodology for power purchase agreements (PPAs), considering the different types of contracts and PPA strategies for the development of a solar photovoltaic and a wind power plant in the country.

For the purpose of this guide, the term "Firm Capacity" will refer to the concept of Firm Capacity as applied in different countries refer to the Firm Capacity concept used across countries.

This guide has been structured in four sections, aiming to provide an overview of the use of Firm Capacity throughout the region, analyse the different options available for applying this term, and highlight challenges and recommendations for the recognition of Firm Capacity in the development of variable renewable energy projects moving forward:

1.	**Central America overview:** a general overview of the region's seven countries, their relevant characteristics and their power sectors, including a description of market design and contractual mechanisms in the region.
2.	**Firm capacity for variable renewable energy in Central America and other countries:** a review of the specific regulatory framework for Firm Capacity recognition for variable renewable energy in Central American countries. The section also includes a review of the Firm Capacity concept throughout four countries in Latin America, providing a comparison of how related guidelines are applied outside Central America.
3.	**Conclusions:** main takeaways of the study.
4.	**Key guidelines for use of Firm Capacity:** guidelines relating to the main elements to consider for the definition of Firm Capacity and the methodology that should be contemplated for commercial use of the concept.

CENTRAL AMERICA OVERVIEW

The Central America region lies between Mexico and South America and comprises of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama.

Central America spreads across the isthmus located between the Pacific Ocean and the Caribbean Sea with an approximate distance of 1835 kilometres (km) from the northwest to the southeast point. All locations in this region are not more than 200 km from the sea, and the narrowest area of land is 50 km wide (Bushnell and Woodward, 2022). (See Figure 1)

Figure 1 Central America

Based on the United Nations map.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

The region has close to 51.5 million inhabitants (0.7% of the world's population) and a total estimated gross domestic product of USD 288 billion per year in 2021 (IMF, 2022; see Table 1).

Table 1 Central American countries, population and gross domestic product (GDP) 2021

COUNTRY	POPULATION (MILLIONS)	GDP (USD, MILLIONS)
Belize	0.4	2 426
Costa Rica	5.2	64 417
El Salvador	6.5	28 737
Guatemala	18.3	85 974
Honduras	10.1	28 490
Nicaragua	6.5	14 001
Panama	4.3	63 605
TOTAL	**51.5**	**287 650**

Source: (IMF, 2022).

In 2020, the total energy consumption of the region was 28 516 kilo tonnes of oil equivalent, with 45% from the consumption of oil and its derivatives (liquified petroleum gas, gasoline, kerosene, diesel, fuel oil, etc.), 36% from the consumption of wood and 14% from electricity consumption. In general, the region depends heavily on the use of crude oil and derivatives, which accounts for between 32% and 72% of the total consumption.

Wood is the main source of energy in Guatemala and a second option in Honduras and Nicaragua, encompassing more than 40% of the total energy consumption in those countries.

Electricity use accounts for between 7% (Guatemala) and 27% (Panama) of the total energy consumption in each country (OLADE, 2021). (See Figure 2.)

Figure 2 Final energy consumption per source in 2020

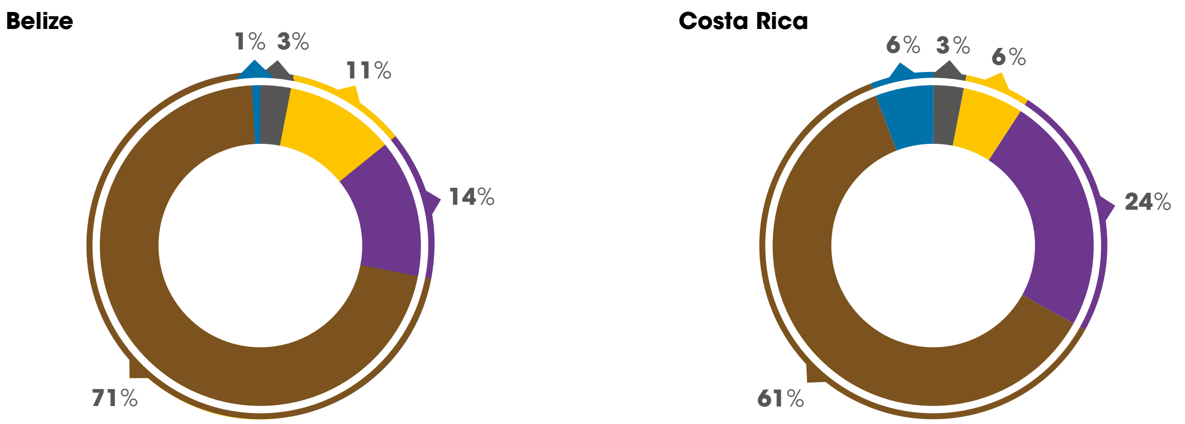
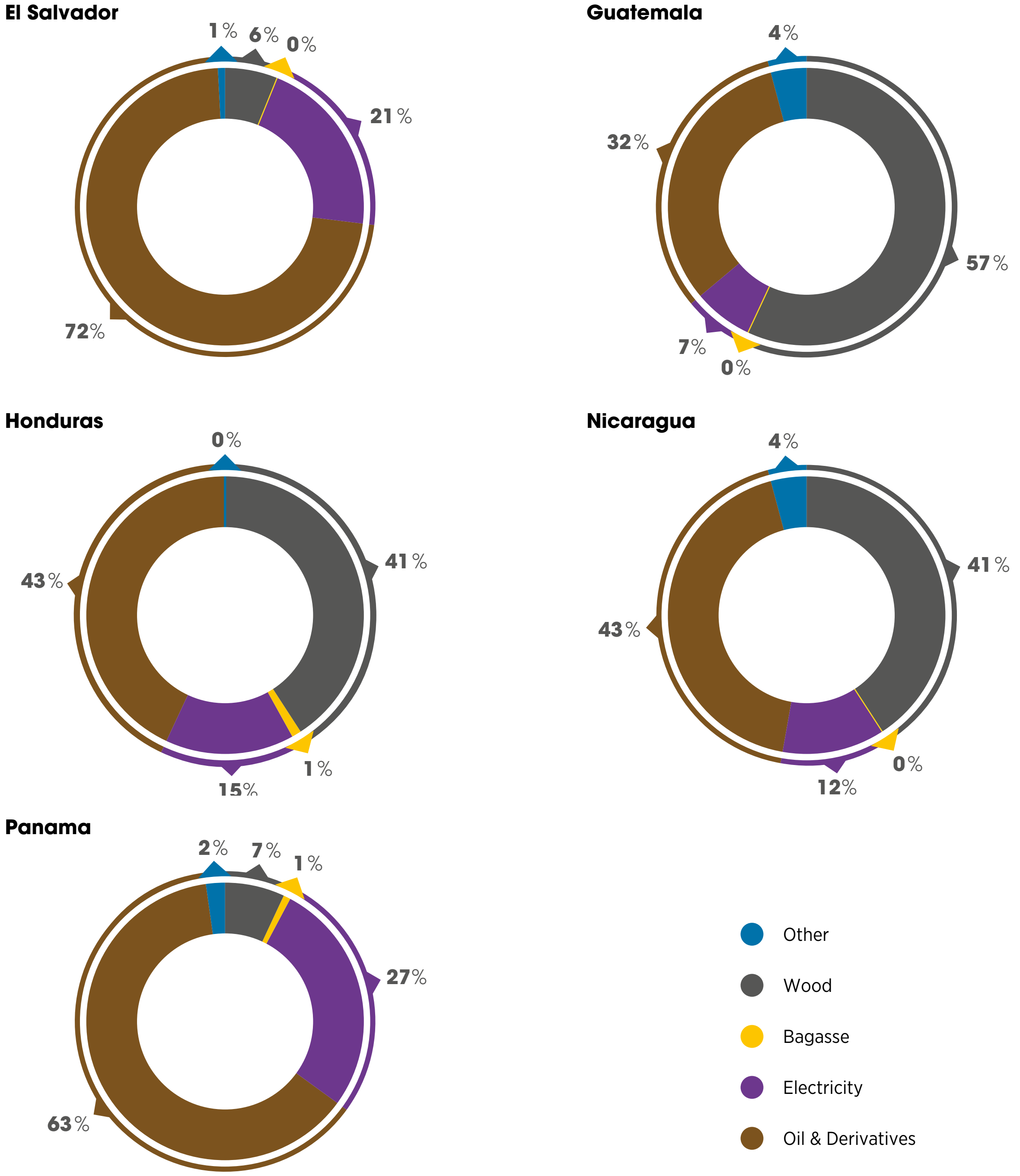


Figure 2 Final energy consumption per source in 2020 (continued)



Source: (OLADE, 2021).

In 2019, Central America's greenhouse gas emissions accounted for 160 million tonnes of carbon dioxide equivalent, including changes in land use and forestry, totalling approximately 0.3% of the global figure. The energy sector was responsible for 37% of the total emissions in the region, followed by the agriculture sector (22%) and land use change and forestry (18%). In terms of usage, transportation is the most significant driver of the total emissions for the energy sector (52%), followed by electricity and heat (21%) and manufacturing and construction (14%) (Climate Watch, 2023).

Deployment of renewable energy technologies and energy efficiency programmes, as well as the electrification of the end-use sector, can contribute to reduction of energy-related emissions in the region, specifically in emission-intensive sectors such as power and transport. IRENA's *Renewable Energy Roadmap for Central America: Towards a Regional Energy Transition* aims to provide strategies to accelerate the energy transition and, consequently, contribute to emissions reduction (IRENA, 2022a).

Box 1 Renewable Energy Roadmap for Central America: Towards a Regional Energy Transition

IRENA's Renewable energy roadmaps (REmap) programme assesses the renewable energy potential of countries, regions and the world, aiming to provide insights, strategies and pathways for the energy transition.

The outcomes of REmap for Central America are based on the context of each country, including its energy resources, regulatory environment and socio-economic status. The methodology of this energy assessment includes the analysis of four energy scenarios covering the period 2018-2050, based on data from end-use sectors, results from modelling individual and regional power systems, and a flexibility assessment of the electrical system. The study was accompanied by an analysis of the investment, costs and emissions of technologies associated with the end-use and power sectors.

The four energy scenarios considered in the REmap study were:

- Base energy scenario: This scenario is similar to a business-as-usual scenario. It shows possible outcomes under existing policies without changes in the short, medium or long term.
- Planned energy scenario (PES): The PES reflects the outcomes under the current plans and expected objectives of each country. This includes the nationally determined contributions submitted under the Paris Agreement.
- Transforming energy scenario: This scenario presents a determined pathway to meet the climate targets, it contemplates a wide deployment of renewable energy, the inclusion of new technologies and the rise of energy efficiency.
- Decarbonising energy scenario (DES): The DES is the most ambitious scenario under this analysis. It envisions further emission reduction alternatives for the energy system of each country.

Results drawn from the analysis show that the needed transformation of energy systems in Central American countries requires individual but also coordinated efforts through **integrated regional planning**, which is a central activity in emission reduction efforts and the energy transition. **A decarbonisation strategy** focused on the **electrification** of the **transport fleet** and the increasing penetration of **renewables can reduce fossil fuel consumption in the power sector by 90% and in the end-use sector by 65% by 2050** under the DES. These activities can be supported by using the total **renewable energy potential in the regional power system, estimated to be around 180 gigawatts**.

In 2019, the transport sector remained as the main contributor to regional emissions, followed by the power sector and industry (Climate Watch, 2023). The DES shows that **regional emissions can be reduced by around 70% by 2050** in comparison to the PES, as long as investment, technology costs and energy targets established under the DES are fulfilled.

Energy efficiency could further benefit from regional integration, through the definition and update of regional standards to increase efficiency. Such integrated standards could bring energy intensity down 43% by 2050.

Plans and strategies will require regional joint efforts and the execution of policies and regulations to achieve international and regional climate commitments.

The direct **use of modern renewables** such as bioenergy, geothermal, solar thermal and biofuels shows great potential to help reduce the use of fossil fuel in all end-use sectors. An example is the use of green hydrogen as a fuel for heavy cargo road transport and international shipping.

For more information visit: www.irena.org/Publications/2022/Mar/Renewable-Energy-Roadmap-for-Central-America

1 POWER SECTORS

Within each national power sector, several interconnected systems exist; these oversee the generation, transmission and distribution of electricity. The main objective of this collection of systems – referred to collectively as "the power system" – is to provide a reliable electricity supply to its consumers and, given its capabilities to incorporate renewable technologies and energy efficiencies across the system, its complex configuration and the policies that regulate it, play a major role in achieving an energy transition.

The way power systems are organised varies from country to country. Current electricity system structures range from fully regulated (generation and sale of electricity is not open to competition) to liberalised or deregulated (open to private competition), with hybrid models in between. Countries that share the same models can still have sizeable discrepancies in their power system structures due to the complexity of local conditions. The following is a classification of power systems (IRENA, 2022b). (See Figure 3 and Figure 4.)

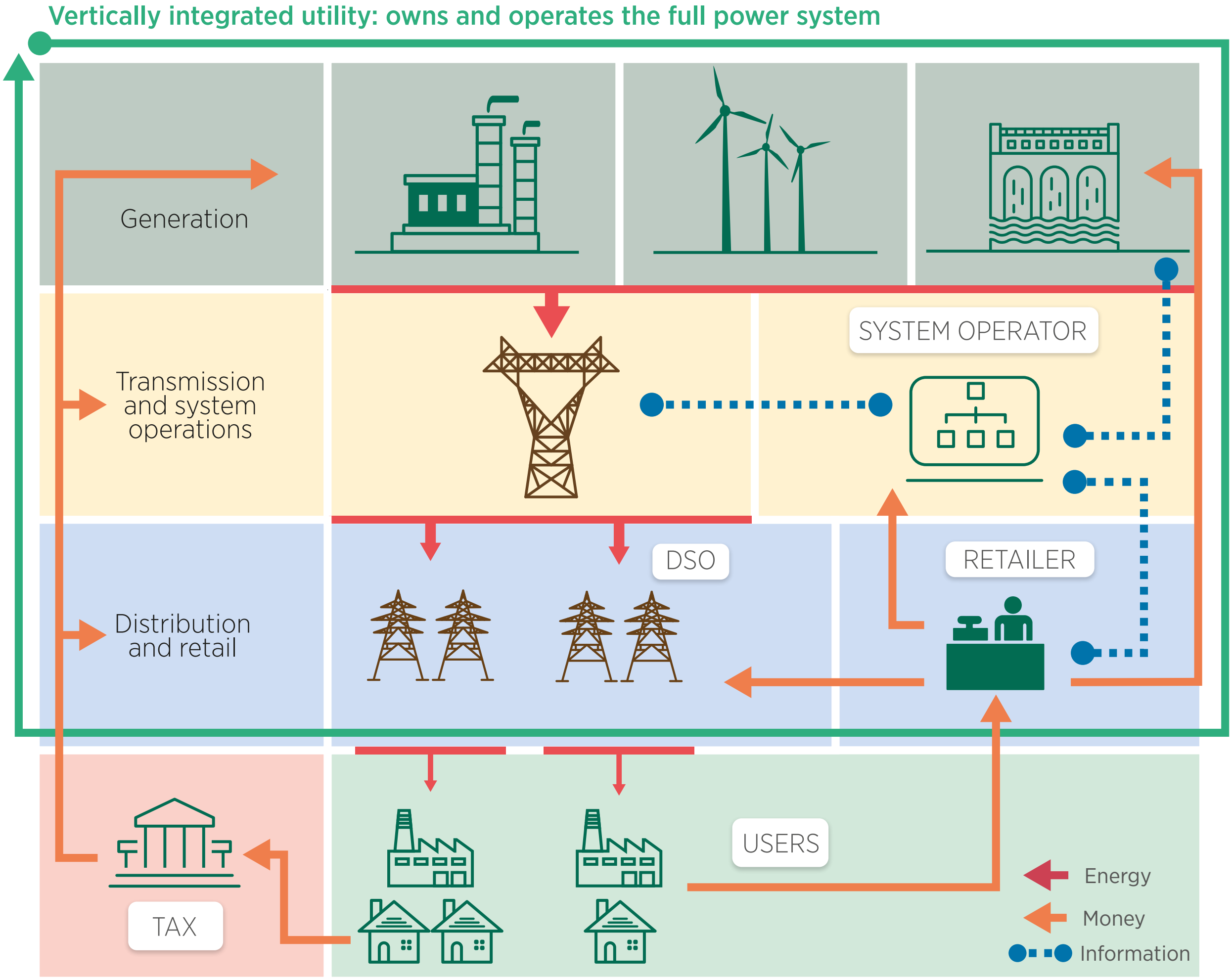
Regulated power system structures: A single utility owns and operates the generation, transmission and distribution of electricity. Utilities under this model can be publicly or privately owned.

- Vertically integrated utility model: A monopoly utility owns and operates all activities in the generation, transmission and distribution of electricity. Also known as vertical integration.
- Single buyer model: Similar to the previous model, a vertically integrated utility manages the entire power system, yet it allows some competition by purchasing electricity as a single buyer from independent power producers through a bidding process of power purchase agreements (PPAs).

Liberalised power system structures: The generation and distribution of electricity are open to competition.

- Wholesale electricity market: Electricity and energy-related products are exchanged between participants in a competitive setting. Key participants include energy regulatory authorities, market and system operators, generators, energy retailers, consumers, and energy-related service providers.
- Retail market: In some competitive markets, the retail activity has been liberalised by allowing participation of energy supply companies. These companies, also known as retailers, purchase electricity through wholesale markets, future markets and independent power producers or from their own power plants to then sell it to final consumers. Retailers compete by offering different tariff structures, prices and value-added services; in some cases, the source of the electricity they provide is disclosed.

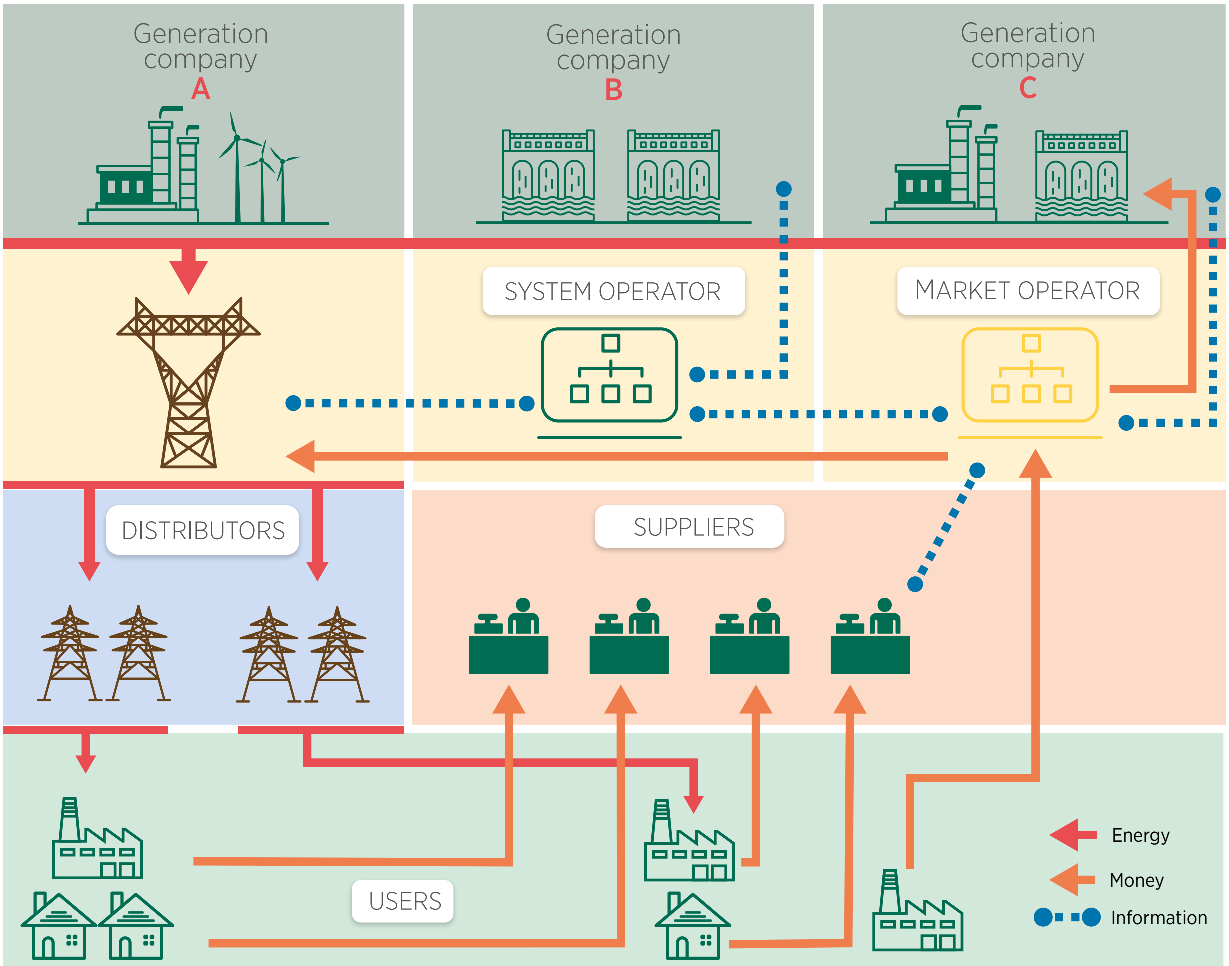
Figure 3 The single buyer model[2]



Source: (IRENA, 2022b).
Note: DSO = distribution system operator.

2 "A monopsony is a market condition in which there is only one buyer, the monopsonist. Like a monopoly, a monopsony also has imperfect market conditions. The difference between a monopoly and monopsony is primarily in the difference between the controlling entities. A single buyer dominates a monopsony market while an individual seller controls a monopolised market" (Young, 2022).

Figure 4 The wholesale electricity market model



Source: (IRENA, 2022b).

1.1 POWER SYSTEMS IN CENTRAL AMERICA

During the early 1990s, most of the electricity generation, transmission and distribution in Central American countries was based on vertically integrated state-owned utilities. Each country (with the exception of Costa Rica) faced similar issues across their power sectors, including power outages, deteriorated power plants due to poor maintenance, and lack of financial resources to update the existing infrastructure.

Additionally, recurrent dry years in the region, 1991 and 1994 (IRI, n.d.), seriously affected the highly hydro-dependent power systems, especially in Guatemala and Honduras, exacerbating supply shortages (CIDBIMENA, 2022).

In response to this situation, several countries implemented a power sector reorganisation with the intent to foster investments for the development of power generation and meet the expected future growth of energy demand. This transformation triggered the evolution of national power sectors at varying speeds across the seven countries, resulting in an array of different market and model structures consistent with each socio-economic, technological and political context.

Broadly speaking, the power market rearrangements in the region fall within the two categories previously described:

- Regulated power system structures: Belize and Costa Rica maintained a combination of a vertically integrated utility company and a single buyer model through state-owned utility companies.
- Liberalised power system structures: An overhaul of generation, transmission and distribution sectors resulted in liberalised electricity markets for El Salvador, Guatemala, Nicaragua and Panama; Honduras is still in the process of implementing laws towards establishing a wholesale electricity market.

A list of the existing regulatory frameworks for variable renewable energy (VRE) in each country and of the main energy sector institutions can be consulted in **Annex I**.

1.2 CHANGES IN THE POWER SECTOR

The reforms performed throughout the power markets and sectors of the region have had diverse implications and mixed results across countries; in Panama, the liberalisation of electricity generation led to increased private investment[3] and efficiency, improved the availability of energy supply and offered diversification from existing generation sources, among other benefits.

El Salvador implemented a price bid-based wholesale market structure, which has faced some difficulties in the context of a small sector and has migrated from a price-based wholesale market towards a cost-based wholesale market.

In Nicaragua, the power sector has also encountered some obstacles, as private operators have been unable to reduce the high level of electrical, non-technical losses, which reached 22.7% in 2019 (ECLAC, 2022).

Honduras approved its General Law of the Electricity Industry in 2014 (Act 404-2014), providing a legal framework for a new wholesale market-based electricity sector, but is still facing regulatory obstacles, delaying the proposed market in moving forward.

Belize and Costa Rica continue to operate a centrally planned system, with the private sector participating in relatively small-sized renewable-based generation, mainly through public auctions and PPAs, resulting in private investment flowing into the sector. The main characteristics of the power sector structure for each country can be further consulted in **Annex I**.

El Salvador, Guatemala, Nicaragua and Panama boast active participation of the private sector in activities related to generation and distribution of electricity. The success of these countries in attracting and retaining private capital in the sector reflects their ability to create an enabling environment that brings certainty to investors.

1.3 POWER SECTOR OUTLOOK

Compared with the situation prior to the implementation of market reforms, most countries have improved their power energy sectors, successfully attracting new private investment (INEC, 2021a), increasing efficiency, and improving the system's reliability and quality of service (ECLAC, 2003).

To achieve accelerated expansion of generation capacity, it is crucial that open access to the transmission system is provided and that government institutions play an active role so as to expand the grid and foster the development of a robust power system.

3 In 1998, USD 643.4 million of private foreign investment in the electricity sector (INEC, 2021a).

With the generation segment partly open to competition across the region, small markets have faced more challenges in increasing liquidity to guarantee strong competition. The trend of using public auctions to reach agreements for a significant part of the load helps minimise excessive market power and lowers price volatility while providing incentives for timely investments. This proves that in the case of small markets, government policy can be helpful in solving issues arising from a lack of competition.

Table 2 presents key electricity statistics for each country and the main operative interconnection nodes and transmission lines among them.

Table 2 Generation, installed capacity and peak demand in Central American countries for 2021

COUNTRY	ENERGY PRODUCTION (GWh)	INSTALLED CAPACITY (MW)	PEAK DEMAND (MW)
Belize[a]	703.5	76.8 (+55 imported from Mexico)	102.7
Costa Rica	12 540	3 584	1 763
El Salvador	5 243	2 344	1 038
Guatemala	11 943	3 985	1 830
Honduras	10 914	2 910	1 738
Nicaragua	3 699	1 599	727
Panama	11 304	3 917	2 020

Source: (AMM, 2021; Energy Unit, 2021; CENCE, 2021; CND, 2021; CNDC, 2021; INE, 2021; ODS, 2021; UT, 2021).
Note: [a] For Belize, the latest data available are from 2020; GWh = gigawatt hours; MW = megawatt.

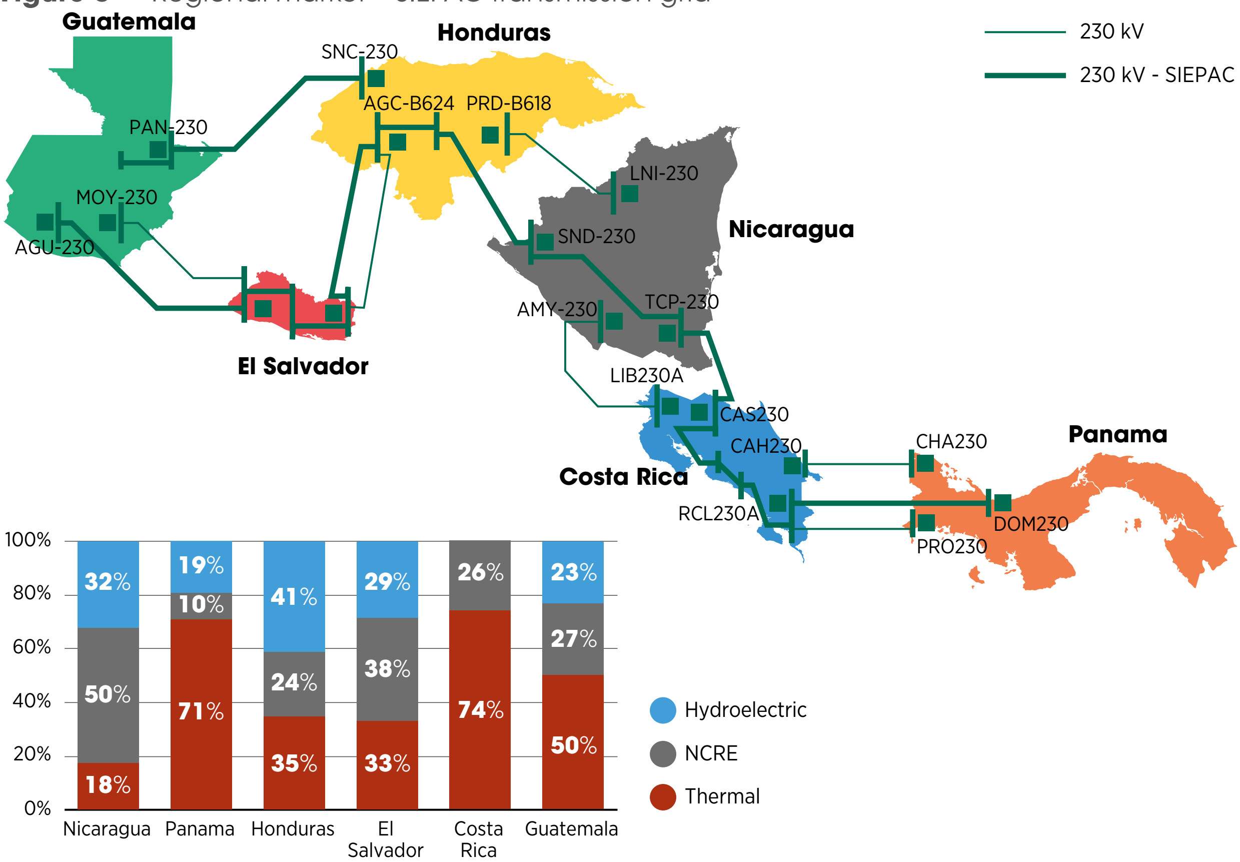
2 REGIONAL MARKET

The original design of the Central America Regional Electricity Market (MER in Spanish) aimed to create a seventh market to co-exist with the six existing ones of Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama. MER has been in operation since 2013, has independent rules and connects each country at specific points (substations) throughout the regional transmission grid, which outline the borders between the domestic and the regional market grids. Belize is not part of MER, and Guatemala has announced its decision to withdraw from the regional market starting in 2031 (MEM, 2021a). MER institutions are shown in Table 3.

Power generators and users located in any of the member countries can freely decide to carry out their energy transactions through MER or within their own domestic markets, allowing a generator from one country to sell its production to a client located in different country.

The Central American Electric Interconnection System (SIEPAC) project was built to facilitate energy trade among MER-participating countries. It consists of a 230 kilovolt (kV) circuit with a transmission capacity of 300 megawatts (MW) running through the six member countries. (See Figure 5.)

Figure 5 Regional market – SIEPAC transmission grid



Based on: (AMM, 2021; CENCE, 2021; CND, 2021; CNDC, 2021; INE, 2021; ODS, 2021; UT, 2021).

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In practice, the operation rules for MER have migrated to a single-market set-up, with a three-step mandatory daily dispatch for system operators in each country:

1. Isolated pre-dispatch: domestic systems.

2. Regional pre-dispatch: Generators not participating in the domestic dispatch supply the regional spot market of MER. The potential demand in regional spot market is composed of those generators that were dispatched in Step 1 and whose variable costs are higher than the generation supply of the regional spot market.

3. Final domestic pre-dispatch: The operator of each domestic system adjusts the dispatch carried out in Step 1 according to the results of the regional dispatch in Step 2: it substitutes local generation (imports) or increases local generation (exports) to comply with the exchanges calculated in Step 2 at each border node.

These operation rules are currently in force with specific restrictions. Issues related to operational security and allocation of responsibilities between country operators and the regional operating entity, coupled with additional technical details, have proved problematic for realising full implementation.

MER is organised into a regional contract market and a regional spot market, with the following transactions available to participants:

- Firm energy contracts: These contracts have an implied obligation[4] to execute, as the amounts of contracted energy must be injected into and withdrawn from the regional transmission network at the nodes indicated by the parties of the contract. The amounts under contract are not subject to the regional economic dispatch but are dispatched ex ante.
- Non-firm energy contracts: With no transmission rights, the physical amounts contracted may be limited in case of constraints in the regional transmission network.
- Opportunity transactions: These are bids to physically inject and withdraw energy into and from the regional transmission network, made by licensed agents for each market period of the following day (the adopted market period is one hour). The regulatory set-up of MER allows for opportunity transactions based on price bids as well as the possibility of long-term contracts between generators and consumers from different member countries (long-term contracts are restricted in practice due to a market design hurdle that overlooks long-term firm transmission rights).

Transactions between a MER market agent and non-member countries are also allowed in the market if such countries' networks are linked to the regional interconnected system, either directly or through the national network of a member country. Mexico is able to participate through its connection with Guatemala; Colombia could potentially participate by interconnecting with Panama.[5]

Regulated market institutions:

- Transmission company: Grid owner company
- Policy maker: Directive council of the regional market
- Regulator: Regional electricity interconnection commission
- System and market operator: Regional system operator

4 Can be backed up by the physical injection of the unit or by purchases in the market.
5 In July 2021, an agreement was signed between both countries to establish general guidelines for the Regulatory Harmonization Scheme for the development of electrical interconnection (IADB, 2021).

3 POWER PURCHASE AGREEMENT MECHANISMS

Central American countries have structured their power markets either by implementing vertical integration, with one off-taker of electricity, or by creating a wholesale market for stakeholders to participate along the value chain. Overlapping with these local markets is MER, implemented in the countries interconnected by the SIEPAC line: Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama. Nevertheless, each country has the authority to design its internal policies and regulate the power sector according to its needs.

PPAs are bilateral contracts between a generator of electricity (an electric utility or an independent power producer) and a buyer of electricity (energy distributors, public or private utilities, and large consumers).

The PPA addresses the commercial terms and agreements for the transaction of electricity, incorporating within its tariff structure associated energy products, such as payments for capacity and ancillary services. PPAs are used in both regulated and liberalised organisational structures, and they are regulated by the energy authority (IRENA, 2022b).

A typical PPA in the single buyer model includes a fixed payment related to the capacity made available to the utility and a variable payment for the energy delivered. In the case of variable renewable generation, the fixed payment may be not included, and no spot exposure is associated with this type of contract (neither price nor volume risk).

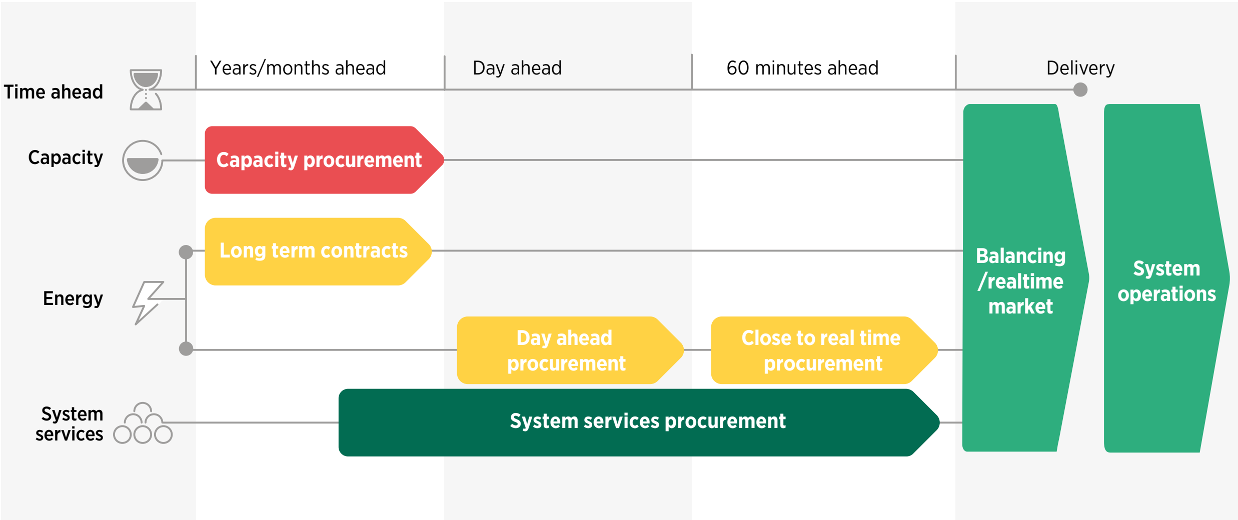
In Central America, the Firm Capacity concept and trading mechanism has been used differently in each country. Belize and Costa Rica operate a single buyer model and have no need to describe Firm Capacity, as its requirements are managed internally by the utility.

For the rest of the countries, Firm Capacity is clearly identified and used, with the regulator or system operator overseeing the setting of the amount recognised for each generator. Typically, Firm Capacity is traded through contracts or through a short-term balancing mechanism.[6]

In a wholesale electricity market, two different trading markets can be observed: (i) a spot market (short term, typically reduced to real time) and (b) a contract market (long term). The main difference lies in the time horizon considered for the transaction, with the former having energy and/or available capacity negotiated for minute, hour or day, and the latter featuring trades where the generator commits its power generation and/or its available capacity for a longer period of time. (See Figure 6.)

6 *In Panama, a bidding market was implemented.*

Figure 6 Main elements of power system procurement



Source: (IRENA, 2022b).

The objective of the spot market is to provide a mechanism in which generators can purchase or sell any exposed disparity between long-term commitments and the actual dispatch.

In Central America, a high share of users purchase electricity through PPAs, meaning that only a small portion of the traded energy is exchanged on the spot market, mostly imbalances. (For reference, in 2021, spot transactions in Guatemala represented 18% of the total (AMM, 2021).) In contrast, the contract market aims to ensure the load supply in the long term by anticipating the purchase of electricity and, therefore, providing stable sources of income to develop the necessary generation.

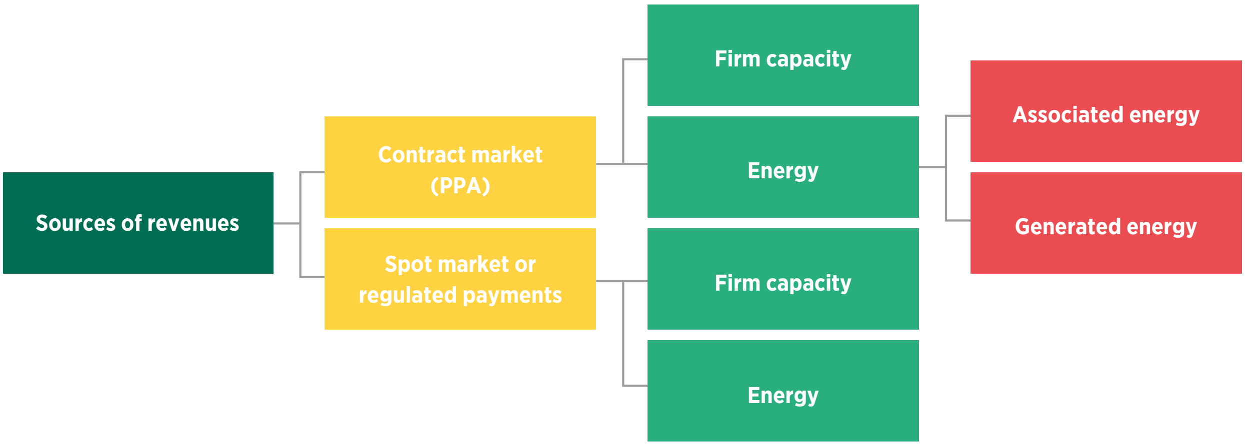
While in other regions energy transactions are formalised as physical contracts, in countries throughout Latin America and the Caribbean deals are structured as financial contracts. In a physical contract, the power or capacity committed must be settled with an actual supply of power generation or capacity availability, whereas in a financial contract these deliverables are part of a financial agreement and actual production responds to dispatch rules, not necessarily related to the amounts committed.

In summary, a contract market has the effect of reducing price volatility while a spot market has the effect of instantly matching power demand and generation.

Figure 7 portrays the potential sources of revenue for a generator considering the two products that are typically traded in the different markets: energy and Firm Capacity.

In terms of types of contracts, a large variety are available in each market based on local regulations, with particular characteristics mainly depending on the commitments related to energy and Firm Capacity as well as the contract-associated prices. Contracts can be classified by two types – "as generated" contracts (low risk for the generator) and "load following" contracts (high risk for the generator) – with several combinations in between, depending on the risk tolerance of each generator.

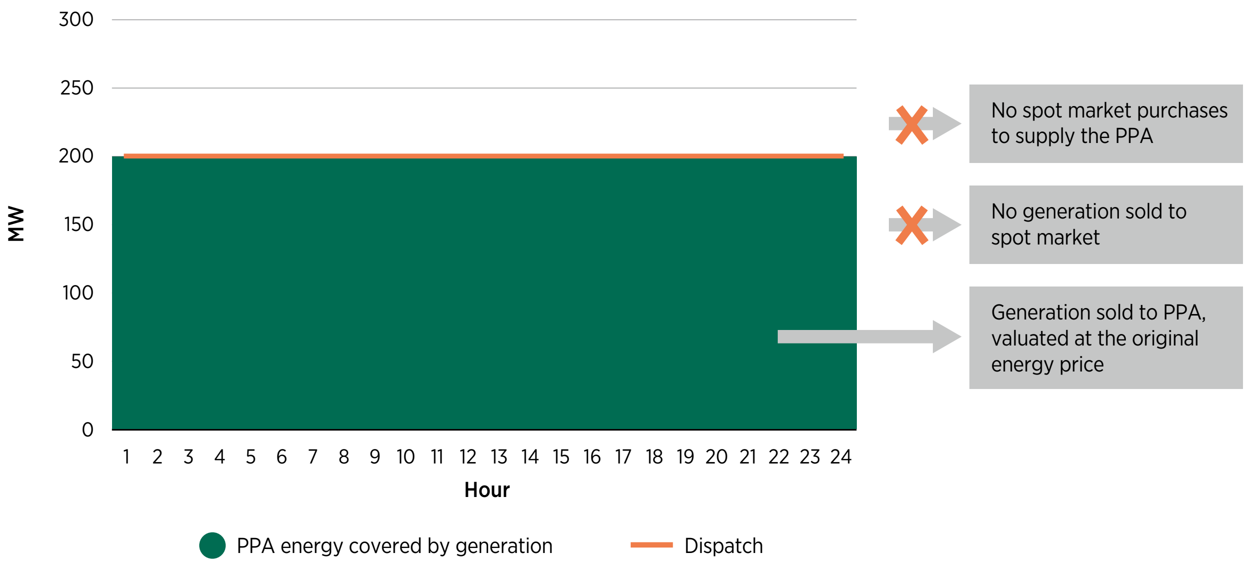
Figure 7 Sources of revenues for a generator: Energy and Firm Capacity



At the low-risk end, "as generated" contracts do not have a Firm Capacity commitment from the generator, and the associated energy equals the generator's dispatch for each hour. Since the variation in the electrical load over a period of time (load profile) is not likely to match the precise dispatch of the unit, in this type of contract the risk between the load profile and the injection profile is managed by the purchaser.

Figure 8 exemplifies an energy transaction by a normal generator with a flat 250 MW net generation. Since the energy commitment is 100% aligned with the dispatch of the unit, no spot exposure is assumed by the generator: the price is fixed and determined by the contract (PPA). The profile of the load does not affect the commitments of the contract.

Figure 8 "as generated" contract energy transaction

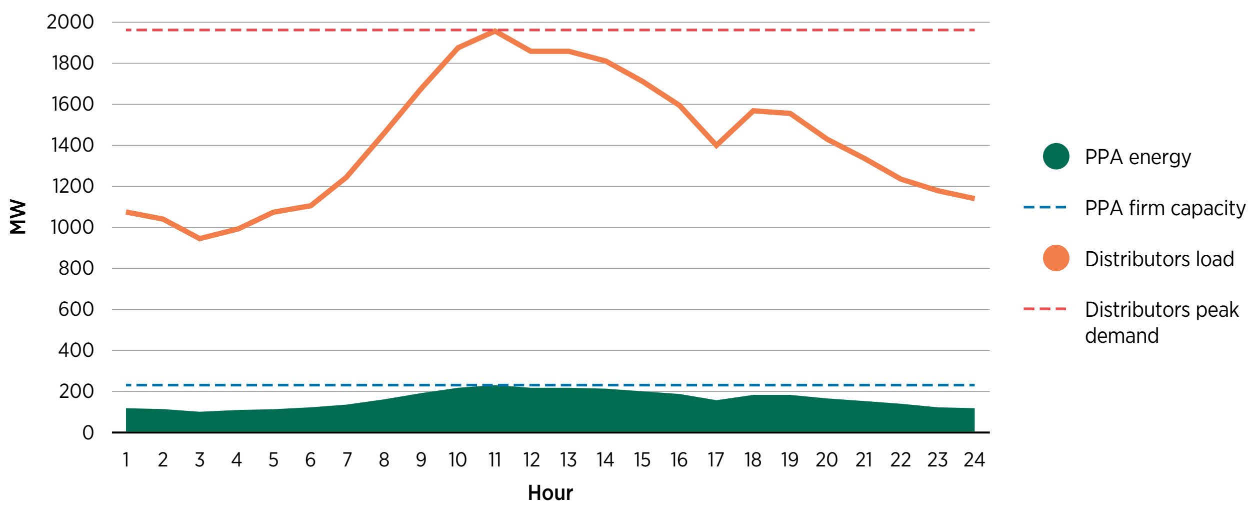


Note: PPA = power purchase agreement.

In "load following" contracts, a high-risk (for the generator) contract type, also known as Firm Capacity and associated energy contracts, the generator has a Firm Capacity commitment, with the energy commitment linked to the load of the purchaser. With a most likely outcome resulting in a difference between the dispatched energy and the existing load profile, the seller bears the transaction risk.

Figure 9 illustrates the energy transaction described above from the generator perspective. Both Firm Capacity and energy commitments are set in contracts. The energy commitment from the generator will cover a share of the load for each hour, with the final amount settled by the difference between the Firm Capacity commitment set in the contract and the total Firm Capacity that the buyer is legally required to acquire.

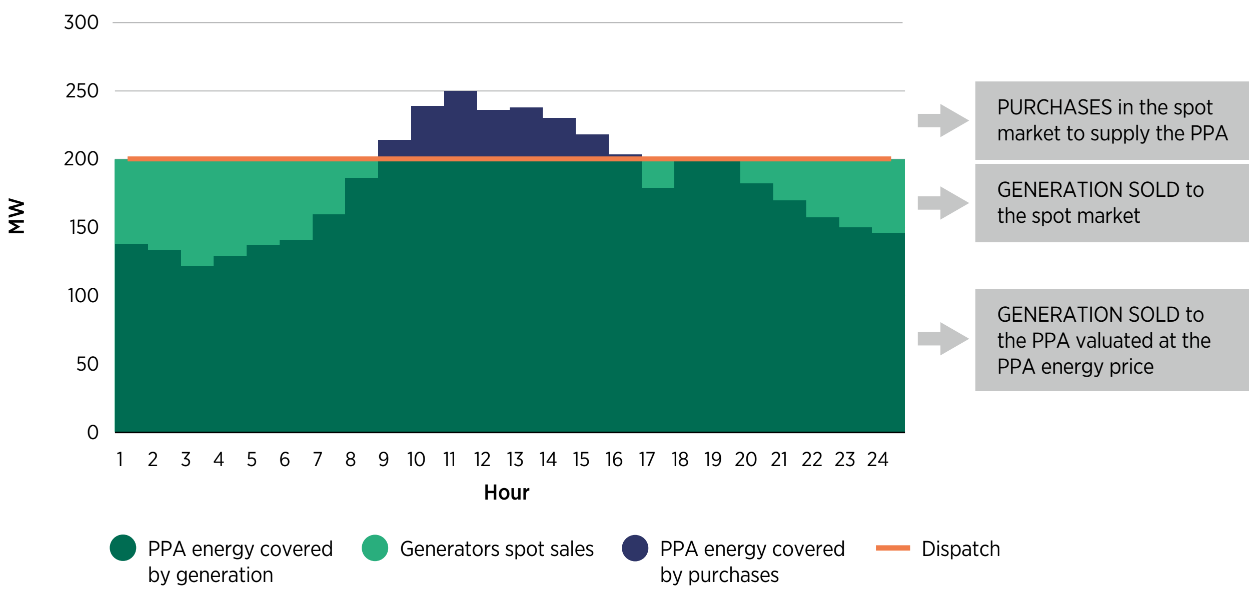
Figure 9 Firm capacity and associated energy contract: associated energy



Note: PPA = power purchase agreement.

The energy commitment in the contract is always a share of the load and is completely aligned with the load profile. The typical spot exposure of the generator can be observed in Figure 10. In the hours in which the dispatch of the generator is lower than the energy committed to the contract (associated energy, dark blue area), the generator will purchase the deficit in the spot market to cover the commitments of the contract. In the hours in which the dispatch of the generator is higher than the energy commitments of the contracts, the generator will sell the surplus energy to the spot market.

Figure 10 Firm capacity and associated energy contract: energy transaction



Note: PPA = power purchase agreement.

FIRM CAPACITY FOR VRE IN CENTRAL AMERICAN AND OTHER COUNTRIES

This section contains an extensive review of existing regulations regarding the definition of Firm Capacity and its commercial use for VRE generation (particularly for long-term contracts) in Central American countries.

In Belize and Costa Rica, the two countries with a vertically integrated utility model, there is no definition of Firm Capacity within their national regulatory framework. For other countries in the region where an electricity market exists, the concept of Firm Capacity is recognised with different designations and methodologies, varying from country to country; a summary of the main characteristics of the Firm Capacity concept in the countries under study can be found in **Annex I**.

To provide a more detailed and clear illustration of the use of Firm Capacity in the region, the following sections group countries by the type of energy market implemented nationally and then delve deeper in describing the understanding and use of the Firm Capacity concept, the methodologies employed for its estimation and the overall impact on the local market balances and settlements. In addition, key findings arising from this review are also included for each country.

1 REGULATED POWER MARKETS

1.1 BELIZE

Belize's electricity sector had an installed capacity of 194 MW and a peak demand just above 100 MW in 2020 (Energy Unit, 2021). The Electricity Act, Chapter 221 (revised edition of 2000) regulates Belize's electricity sector, its institutions and main stakeholders.

The development of private generation under PPAs is the result of a request for proposals (RFP) launched by the Public Utilities Commission. Once it has selected the best offer to the country, the Public Utilities Commission instructs the distribution company, Belize Electricity Limited, to sign PPAs with the awarded company.

In 2013, the RFP for electricity generation made a distinction between "Firm Capacity" projects (base load and/or intermediate load duty) and "solar and/or wind capacity" projects. In that context, it is understood that no Firm Capacity is currently recognised for solar or wind projects.

The specific definition of Firm Capacity as well as the corresponding remuneration of such capacity is set in the specific PPAs (not public information). There is no standard PPA that could have been included in one of the RFP processes. According to Belize Sustainable Energy Strategy, Volume 1, "there was no indication about most key terms of power purchase agreements (PPAs) to be signed" in the RFP for electricity generation 2013 (MESTPU, 2015).

1.1.1 Key findings

Belize's power sector relies on the single buyer model, with existing regulations not clearly providing a definition of Firm Capacity within the country and its commercial use for VRE generation.

The Firm Capacity concept is implemented within the definitions of each PPA signed with Belize Electricity Limited.

Modernising the existing regulatory framework and introducing more competition into the purchasing process for energy and Firm Capacity would allow technologies to better compete for the different products and services.

1.2 COSTA RICA

Costa Rica's energy sector has a vertically integrated structure, with the Costa Rican Institute of Electricity (ICE) as a state-owned autonomous institution that integrates the segments of generation, transmission and distribution in the country. Besides having the largest capacity in power plants, ICE manages the transmission network and distributes part of the electricity. It is also the sole buyer of electricity in the country.

New generators can sell their production to ICE through two mechanisms: through a regulated contract with ICE[7] or under the Build-Operate-Transfer scheme,[8] where prices are the result of a public tender.

National technical standards are described in the Technical Norms for Planning, Operations and Access to the Electricity System, published by the Public Services Regulatory Authority. The regulation mentions the concepts of nominal capacity, unavailability factor, forced outages, planned maintenance and other typical concepts necessary for the adequate operation of the electricity system (ARESEP, 2016).

1.2.1 Key findings

The Costa Rican power sector is organised under the single buyer model, with ICE as the sole buyer of electricity in the country. There is no open contract market or spot market (neither for capacity nor for energy) in Costa Rica, and the concept of Firm Capacity for market contracts does not exist.

The main challenges observed that would help accelerate VRE development are related to the modernisation of the regulatory framework with a focus on the introduction of more competition.

7 *Law No.7200 (1990) authorises private generation in Costa Rica, through plants up to 20 MW of installed capacity of hydroelectric power or unconventional sources; in addition, the law states that no projects should exceed 15% of the total output of the power plants of the national grid. All private installations must have at least 35% Costa Rican ownership. Under this scheme, private generators sign a PPA with ICE. The energy price at which ICE purchases electricity is calculated by the Public Services Regulatory Authority.*

8 *Law No. 7508, which corresponds to the second chapter of Law No. 7200, describes the Build-Operate-Transfer scheme, in which plants can have a maximum installed capacity of 50 MW and the contracting process is done by a public tender system. ICE is authorised to purchase up to an additional 15% of the national installed capacity (30% of the national installed capacity in total). Contracts and concessions can have a maximum term of 20 years, with the possibility of renewal.*

2 LIBERALISED POWER MARKETS

2.1 EL SALVADOR

Firm capacity is calculated annually, follows a specific approach depending on each technology (including VRE) and is determined on an annual basis in three stages: (i) initial (based on technology), (ii) provisional (using a demand adjustment factor) and (iii) definitive (considering observed maximum demand, dispatch, etc.)

Typically, long-term supply contracts include a Firm Capacity commitment and its associated energy, but in the particular case of VRE contracts, energy-only contracts have been awarded in the past. The Firm Capacity payment for generators is estimated at the base capacity price established by the Electricity and Telecommunications General Superintendency (SIGET) and is contingent on previous Firm Capacity transactions (in El Salvador's case, Firm Capacity balances).

2.1.1 Definition of Firm Capacity

The definition of Firm Capacity and its commercial use in El Salvador is described as the power that a generating unit or power plant can supply to the system, with a high probability, during critical supply conditions.[9] The critical period relates to the period in which the deficit probability is, in general, different from zero; this occurs during dry season when hydrological inflows are lower.

2.1.2 Calculation of Firm Capacity

Firm capacity is determined in different stages. The following subsections provide a more detailed description of the methodology used to reach the final number.

a Initial Firm Capacity

Initial Firm Capacity is calculated using different procedures depending on the technology of the power plant. Factors considered in the calculation are the availability of the primary resource (fuel, steam, water, biomass, wind, sun, etc.) as well as the forced outages rate and scheduled maintenance.

Non-conventional generating units

The initial Firm Capacity of existing non-conventional renewable generating units is determined as the annual generation divided by 8 760 hours for the year of operation with the lowest availability of the primary input (lowest estimated annual generation within a three-year history of natural resource measures or the minimum annual generation in real operation). For new non-conventional renewable power plants in the system, the owner must submit an estimated average annual capacity to SIGET for approval.

9 Regulation for the Operation of the Transmission System and the Wholesale Market based on Production Costs (ROBCP, "Reglamento de Operación del Sistema de Transmisión y del Mercado Mayorista Basado en Costos de Producción"), which became fully operational in July 2011 (SIGET, 2011).

Hydroelectric power plants

The initial Firm Capacity of a hydroelectric power plant is the power that the plant can provide in the critical period and under dry hydrological conditions.

For this calculation, the driest year is selected, according to the historical water inflows of the power plant. Using the inflows from the driest year, the generated weekly average of energy during the critical period is obtained and the initial Firm Capacity of a given hydroelectric power plant is then identified, considering the weekly energy optimisation and the initial distribution of Firm Capacity between each hydroelectric plant.

Thermal and geothermal power plants

The initial Firm Capacity is equal to the maximum net power, multiplied by an availability factor that considers maintenance, lack of fuel (or steam in the case of geothermal plants) and forced outages.

Self-producers or co-generators

For a self-producer or co-generator to have Firm Capacity recognised, it must be able to demonstrate to the power market administrator that it is able to inject power into the system from the surplus of its installed capacity in relation to its demand. To calculate Firm Capacity, the surpluses are represented as a thermal unit with a maximum capacity equal to the maximum power surplus. The initial Firm Capacity of a self-producer or co-generator is equal to its maximum capacity multiplied by its availability.

b Provisional Firm Capacity

Once the initial Firm Capacity of the power plants is calculated, the provisional Firm Capacity is determined by adjusting the sum of the initial firm capacities of all the units to the maximum demand of the system in the control period[10] as follows:

- The sum of the initial firm capacities is calculated.
- A demand adjustment factor is determined as the ratio between the maximum system demand in the control period and the sum of the initial firm capacities.
- The Firm Capacity of each generating unit is equal to the initial Firm Capacity multiplied by the demand adjustment factor.

The provisional firm capacities are calculated each year in June and remain in effect for 12 months.

c Definitive Firm Capacity

Once the annual period from June of the previous year to May of the current year has elapsed, the definitive Firm Capacity transactions are determined. To do this, the following procedure is followed:

- The real maximum demand of the system and the recognised demand are calculated based on the actual withdrawals that have occurred. This maximum demand will be used to calculate the final Firm Capacity of the power plants, using a demand adjustment factor, as was done to determine the provisional Firm Capacity.

10 The control period is defined as the peak hours (from 6:00 p.m. to 10:59 p.m.) and the rest (from 5:00 a.m. to 5:59 p.m.) of the critical period.

- Firm capacity balances will be calculated for subperiods in which addition or decommissioning of power plants or modifications in contracts have occurred.
- For each month, the corresponding capacity charge set by SIGET will be applied.

2.1.3 Firm capacity contracts, balances and settlements

Every month, the power market administrator examines the Firm Capacity balance and reviews the differences between Firm Capacity injections (Firm Capacity recognised to each agent), Firm Capacity withdrawals and Firm Capacity commitments, resulting in the following outcomes:

- Generators whose capacity committed in contracts is less than the sum of the firm capacities of their generation units (plus purchase through contracts) will be considered sellers of Firm Capacity due to the difference between both values. Otherwise, they will be considered buyers.
- Distributors, end users or traders whose recognised demand is less than the capacity committed in contracts will be considered sellers of Firm Capacity due to the difference between both values. Otherwise, they will be considered buyers.

Traded Firm Capacity is valuated at the regulated Firm Capacity price and can also be traded bilaterally through Firm Capacity contracts. Distributors are obligated to contract their Firm Capacity needs in advance through public tenders.

In June of each year, the provisional Firm Capacity and the projected Firm Capacity balance are calculated for the coming 12 months. During each of these 12 months (from June to May), one-twelfth of the annual amounts determined in the Firm Capacity balances will be settled monthly.

Once this period ends, the resulting final Firm Capacity balance is compared with the amounts paid as provisional Firm Capacity throughout the annual period from June of the previous year to May of the current year, and the differences are settled.

2.1.4 Key findings

The Firm Capacity concept in El Salvador is well defined. The methodology for Firm Capacity calculation follows the same pattern observed in the region and uses different methodologies for each technology, including a methodology for VRE.

In El Salvador, 100% of the demand of Firm Capacity must be contracted in advance by public tenders. So Firm Capacity purchase obligations act as a way in which the energy buyers secure their future requirements. The capacity market is the market in which the generator trades the Firm Capacity surpluses or deficits.

The Firm Capacity calculation methodology could be further modernised in the following ways:

- developing a unified methodology for all the technologies that allows fair competition between them
- introducing a capacity balancing mechanism in which the price is set by the balance of supply and demand.

2.2 GUATEMALA

Firm capacity is calculated annually, together with the long-term dispatch plan. The applied methodology aims to secure the supply of firm demand with effectively available and economically efficient generation for the system. Solar PV power are not considered in the Firm Capacity calculation methodologies, resulting in efficient firm supply[11] assigned to each plant through a dispatch simulation of the wholesale electricity market. Having an allocated efficient firm supply is a requirement for signing supply contracts with distributors or for trading Firm Capacity at the capacity daily balance.

There are two concepts related to the definition of Firm Capacity: firm supply and efficient firm supply. For the purpose of this section, the concept of efficient firm supply will be used to refer to Firm Capacity.

2.2.1 Definition of Firm Capacity

In Guatemala, the concept of Firm Capacity is slightly different than in other countries of the region as it considers economic efficiency. The Wholesale Market Administrator of Guatemala (AMM) oversees the calculation of the efficient firm supply (*oferta firme eficiente*, or OFE, in Spanish) based on the plant's maximum capacity, its availability, and economic efficiency through a simulation that optimises the dispatch of generators: this mechanism ensures that firm demand is covered with generation that is effectively available and economically efficient for the system. The efficient firm supply indicates the maximum amount that a power plant can commit in contracts to cover the capacity required by the demand (firm demand).

2.2.2 Calculation of efficient firm supply (Firm Capacity)

In the efficient firm supply recognition process, AMM considers:

- Firm Capacity obligation for energy buyers
- maximum capacity of the power plant (tested by AMM at least once every three years)
- availability coefficient of the power plant
- Firm Capacity estimation for each power plant, depending on its technology
- economic efficiency of the power plant with respect to the generation fleet.[12]

Additionally, there are well-defined procedures to calculate the firm supply of a given power plant, depending on its technology. Once firm supply for each power plant is set, efficient firm supply[13] can be calculated.

a Calculation of firm demand

The Firm Capacity requirement for energy buyers (firm demand) is the component of the maximum projected demand assigned to each distributor, exporter and large user and is determined as the proportion between the individual distributor, exporter or large user's declared projected demand and the sum of the declared demands of all distributors, exporters and large users, corresponding with the hour foreseen for the maximum projected demand. The corresponding demand of each distributor, exporter and large user is determined for the period and schedule foreseen for the projected maximum demand based on the demand projection and the typical load profile for that distributor, exporter or large user.

11 *Efficient firm supply is the term used in Guatemala for Firm Capacity.*
12 *The economic efficiency of each unit is determined through a two-year dispatch simulation of the wholesale electricity market.*
13 *Efficient firm supply is calculated annually according to the procedure detailed in the Commercial Coordination Norm N° 2 (NCC n°2, Norma de Coordinación Comercial). The NCC n°2 details the procedure to follow for the maximum capacity and availability tests, studies and information required, conditions, criteria, etc. (AMM, 2022a).*

b Calculation of the Firm Capacity for each technology

The firm supply (Firm Capacity) of each generation unit is equal to the maximum net capacity (discounting its internal consumption) that the generator can produce, depending on its technical characteristics, its maximum capacity and its availability. The calculation considers the restrictions of the plant and those related to its associated transmission system.

Firm capacity of hydroelectric power plants

The firm supply of hydroelectric power plants is determined through a simulation of the behaviour of the wholesale market using the long-term programming model (dispatch model). The model simulates the seasonal year (from May to April of the following year), including different stages and different hydrological series. The simulation uses a projected demand represented by a monotonic curve of at least five blocks, where the first block must have a duration of one hour and represent the projection of the maximum demand.

Firm supply recognition for this technology is calculated as the average injection of the power plant during the critical hours (higher thermal requirement) limited by the maximum available capacity.

Firm capacity of wind power plants

To consider that a wind power plant has a firm supply, it must substantiate the power that it can guarantee throughout the entire seasonal year through a study based on the height of the wind blades and the wind speed records of at least five years, also considering forced unavailability due to unforeseen loss of wind in the daily programming.

This is calculated based on the predictable energy production of the power plant during the maximum thermal requirement, with a minimum probability of 95% Annex II, Equations Guatemala).[14]

Firm capacity of solar photovoltaic power plants

Solar photovoltaic (PV) power plants are not considered in the firm supply calculation methodology.

Firm capacity of thermal units

The firm supply of thermal units is calculated based on the unit's maximal power output times its availability.

Firm capacity of thermal units using renewable fuels (biomass)

The firm supply of such thermal units is calculated based on the unit's maximal power output guaranteed throughout the seasonal year based on the minimum availability of the renewable fuel declared by the agent.

Firm capacity of geothermal units

In the case of geothermal power plants, the calculation of firm supply follows the same logic as for wind power plants: it considers the foreseeable energy with 95% of exceedance probability during the hours of maximal thermal requirement.

14 AMM is currently not recognising any firm supply from wind power plants.

c Calculation of the availability coefficient

The availability coefficient of the power plants is calculated annually considering the historic availability data of the last two years (available hours, hours in scheduled maintenance, hours of forced outage and the hours equivalent to the unit's degradation).

d Efficient firm supply in long-term planning

Once firm demand and efficient firm supply for each technology have been calculated, scenarios for the next two years (seasonal year plus one) are prepared using the optimisation model used by AMM for long-term planning (the Stochastic Dynamic Dual Programming, or SDDP, model), based on the maximum capacity of each generator, major maintenance plans reported, Firm Capacity regional contracts, load information, fuel prices and declared variable costs. If the simulation's outcome is for the plant to dispatch, then the efficient firm supply for each unit dispatched that year is equal to its Firm Capacity.

2.2.3 Firm capacity contracts, balances and settlements

In the Guatemalan electricity market, distributors, retailers and large users are obligated to purchase their Firm Capacity through contracts. Each year, AMM calculates the demand that each of them must contract. If the efficient firm supply available to cover the Firm Capacity demand is less than the generator's Firm Capacity commitments, they must acquire the shortfall through contracts with generators that have surplus efficient firm supply or through the daily deviation balance. Generators that did not commit the totality of their efficient firm supply through signed contracts may sell the part not committed to other generators (by contracts or by capacity balance).

The capacity deviation balance is a mechanism for daily capacity deviation transactions.[15] Any differences between the committed Firm Capacity (demand) and the Firm Capacity of generators (supply) are settled in daily transactions. Any differences between the effective firm demand of each distributor, large user or exporter and their contracted firm demand are required to be settled as well (AMM Resolution, 2002).

Additionally, if a generator does not have Firm Capacity in the country, it cannot enter into firm contracts to cover demand. It can only commercialise its Firm Capacity at the daily capacity deviation balance. The price at which generators and consumers currently sell their surpluses in the Firm Capacity deviation balance is substantially lower than the regulated price (there is a Firm Capacity surplus).

2.2.4 Key findings

The Firm Capacity concept in Guatemala is well defined and is known as efficient firm supply. The distribution companies that supply energy must purchase their Firm Capacity requirements, so Firm Capacity purchase obligations act as a way in which the companies secure their future requirements.

The methodology for Firm Capacity calculation follows the same pattern observed in the region and considers different methodologies for each technology, including a methodology for wind but not for solar PV.

In Guatemala, even though there is a methodology to recognise Firm Capacity for wind turbines, in practice no Firm Capacity is recognised. Furthermore, solar PV is not considered in Commercial Coordination Norm N° 2 or in Firm Capacity recognition methodologies. So, VRE is only partially included in the recognition process.

15 Governed by Commercial Coordination Norm N° 3 (NCC n°3, Norma de Coordinación Comercial) (AMM, 2022b).

The main challenge going forward that would help accelerate the development of VRE is to re-evaluate the methodologies, aiming for the elimination of barriers for VRE generation by including all the technologies in the regulations. In addition, increasing the level of competition in the Firm Capacity payments mechanism would help the market develop.

2.3 HONDURAS

Firm capacity is calculated annually according to a specific methodology for each technology (including VRE). Once calculated, generators can sell their Firm Capacity through contracts with distribution companies, traders, qualified consumers, and so on, or through the opportunity market (Firm Capacity deviations mechanism).

2.3.1 Definition of Firm Capacity

The definition of Firm Capacity and its commercial use in Honduras are described in the technical norm for Firm Capacity (CREE, 2021), which contains the methodologies that the system operator (ODS)[16] will apply to:

- Firm Capacity for each power plant connected to the national interconnected system
- requirement of Firm Capacity from distributors, traders and qualified consumers
- Firm Capacity deviations from both producers and buyers of Firm Capacity.

Firm capacity is defined as the capacity that a power plant can supply to the electrical system with a high certainty factor during the hours of the critical period of the system.

The critical period is described as a set of hours during a month or five consecutive weeks for which the "thermal requirement"[17] is at a maximum, according to probabilistic simulations of the system. Once the period of maximum thermal requirement is determined, the ODS must identify a set of hours or blocks of hours within this period for typical days (working days, Saturdays, Sundays, holidays). The critical period corresponds to those blocks of hours during which the power requirement is equal to or greater than 92.6% of the maximum power requirement of the month or group of five weeks identified for the year under study and the two previous years.

2.3.2 Calculation of Firm Capacity

The ODS simulates the systems' economical dispatch for each year, running 100 hydrological series using the same model and the information applied for planning the long-term operation, but without considering network restrictions. Based on the results, it will calculate the maximum thermal requirement and determine the hours corresponding to the critical period.

To determine the Firm Capacity that a power plant can sell, the ODS must consider unavailability factors such as self-consumption and auxiliary services, planned and forced outages (including unavailability of radial lines owned by the producer that connect the power plant to the transmission or distribution network of the zone), temporary physical degradation of the power plant, and limitations from the primary energy source (fuel, hydroelectric power, solar radiation, wind, energy from a geothermal field, etc.). The ODS does not have to consider unavailability caused by the main transmission system or local distribution networks.

16 The ODS is the institution in charge of the yearly calculation of Firm Capacity for each power plant connected to the national interconnected system and responsible for publishing the results by the end of November of each year.
17 The thermal requirement is the sum of the generation from power plants using fossil fuels, imports and energy not supplied.

For the purposes of calculating Firm Capacity, power plants are classified as follows:

- power plants that use renewable resources other than geothermal heat (including hydroelectric power plants):
  - with storage capacity and daily, weekly and monthly regulation
  - with no storage capacity and regulation (includes VRE, such as solar and wind power plants)
- thermal power plants using fossil fuels, power plants using biomass or biomass plus fossil fuels that operate year-round, and geothermal power plants.

a Solar PV and wind power plants

Each plant's generation is calculated by simulating the period of maximum thermal requirement. The firm energy is the value that is exceeded in 95% of cases. Firm capacity for each power plant is then calculated based on the average value of the hourly power generated during the hours of the critical period.

b Hydroelectrical power plants

Based on the system's economical dispatch mentioned before, the quantity of energy generated by each power plant during the period of maximum thermal requirement for a total of 100 hydrological scenarios is determined. The firm energy for each power plant is established as the energy that the plant exceeds in 95% of the total cases.

Firm capacity for hydroelectric plants without storage capacity and regulation

The Firm Capacity is obtained by dividing the firm energy calculated in the simulation by the total number of hours during the month or during five weeks of maximum thermal requirement.

Firm capacity for hydroelectric plants with storage capacity and daily, weekly and monthly regulation

The Firm Capacity is obtained by dividing the firm energy calculated in the simulation by the number of hours of the critical period.

Firm capacity for hydroelectric plants with annual or multi-annual reservoir

The firm energy is determined with a simulation that considers the generation of the power plant during the critical period that has a 95% probability of being exceeded.

The ODS divides the firm energy by the number of hours in the critical period to obtain a capacity. The Firm Capacity of the power plant will be the minimum between this value, the product of its effective capacity and its availability factor, and the maximum capacity that the power plant can supply to the grid with the reservoir level at the end of the critical period.

c Thermal power plants

The Firm Capacity for each power plant is calculated based on its annual availability and its effective capacity, understood as the maximum power that the plant can supply given the local temperature and pressure conditions, its self-consumption and any other generation restrictions.

For the annual availability, the ODS must consider these four situations:

- programmed maintenance
- forced unavailability
- power capacity reduction due to degradation
- power capacity reduction due to delays, interruptions or reduction of primary energy supply.

2.3.3 Firm capacity contracts, balances and settlement

Through bilateral contracts, buyers agree to purchase Firm Capacity, energy and/or ancillary services from generators and traders located in countries that are part of MER. The price of these contracts is freely agreed between the parties, except for the distributors, which are obligated to contract via a public bidding mechanism.

For a given year, each power plant has the right to sell the Firm Capacity that the ODS previously recognised. In addition, each consumer has the obligation to cover its firm demand through Firm Capacity contracts, including related losses and reserve margin (Firm Capacity requirement, as defined by the ODS each year).

Additionally, each month the ODS verifies compliance of yearly values for Firm Capacity and Firm Capacity requirements (demand) compared with the real experience.

The ODS will settle capacity deviations on a monthly basis for both sellers and buyers of Firm Capacity. Payment of capacity deviations will be settled at the capacity reference price,[18] which is adjusted depending on the firm offer and demand balance.

2.3.4 Key findings

The Firm Capacity concept in Honduras is well defined. The wholesale electricity market was implemented in 2019, and the discussion regarding Firm Capacity benefitted from the experiences of neighbouring countries. Because of that, the methodology for Firm Capacity calculation increases the competition between the different technologies, creating similar methodologies for all technologies, including storage.

As is customary for the region, the demand of Firm Capacity must be contracted in advance by public tenders or bilateral contracts. The surplus or deficit of Firm Capacity is traded through a Firm Capacity balancing mechanism (within the spot market), causing Firm Capacity purchase obligations act as a way in which the energy buyers secure their future requirements.

The methodology applied (that allows competition between technologies) and the inclusion of VRE technologies shows that the regulatory framework includes some of the best practices from neighbouring countries. Nevertheless, the regulatory framework could be improved, for example by creating a capacity market that allow bids and promotes competition among agents.

In May 2022, the national congress passed the new Electricity Law, dissolving the ODS and transferring the system and market operation to the stated-owned National Electricity Energy Company. As such, the Firm Capacity trade mechanisms previously explained may undergo future changes. For the purpose of this review, we have analysed the regulatory framework in place in May 2022.

18 The regulated price established by the Electric Energy Regulatory Commission based on the investment cost and fixed operation and maintenance costs of a unit with adequate technology to supply the demand in peak hours, similar to the scheme in other countries of the region.

2.4 NICARAGUA

Firm capacity is calculated on an annual basis according to a methodology that applies only to dispatchable generation (generador a despachar, or GD, in Spanish) and thus does not include VRE technologies. Once calculated, generators can sell their Firm Capacity through contracts with distribution companies, traders, qualified consumers, and so on, or through the opportunity capacity market (spot capacity market). Loads (distributors or qualified consumers) have the obligation to cover 80% of their demand one year in advance and 60% of their demand two years in advance.

2.4.1 Definition of Firm Capacity

The concept of Firm Capacity in Nicaragua is described in the Operation Regulations (Normativa de Operación in Spanish), which define the maximum guaranteed power (*potencia máxima garantizable* in Spanish) as the plant's effective capacity (CNDC, 2022).

2.4.2 Calculation of Firm Capacity

By 15 October of each year, the National Dispatch Centre (CNDC) must determine for each generator (producing agent) the Firm Capacity of each of its "generating groups to dispatch" (*grupo generador a despachar*, or GGD, in Spanish) for the following year. This value is calculated as its effective capacity, unless the CNDC identifies a repeated deficit from the generator to the committed Firm Capacity that guarantees contracts throughout the year. In that case, Firm Capacity is calculated by multiplying the effective capacity by the registered average availability in the period.

During the year, the CNDC oversees the monitoring of the Firm Capacity deficit for each generator and includes any detected non-compliance (deficit) in its monthly or annual report. The CNDC considers the following situations that can affect performance:

- unavailability (except for planned maintenance)
- technical limitations of the generator units or the transmission lines if they belong to the production agent
- lack of fuels for thermal plants or water for hydroelectric plants, which limit their maximum generation.

Power plants that are non-dispatchable (such as run-of-river hydroelectric, wind or solar power plants) are not considered in this analysis, and they have no Firm Capacity recognised.

The Firm Capacity recognised for each power plant is included in the Demand Projections Report (Informe Proyecciones de Demanda in Spanish), published by the CNDC each year.

2.4.3 Firm capacity contracts, balances and settlements

Qualified consumers and distributors must purchase Firm Capacity to guarantee the supply of their requirements set forth in the Demand Projections Report, published by CNDC each year, for the next two years.

According to the Electricity Industry Law Regulations, distribution companies must enter into PPAs covering 80% of their expected demand one year in advance and 60% of the demand expected two years in advance (MEM, 2021a). Large users (consumptions greater than 1 MW) must purchase Firm Capacity in advance to cover 80% of their Firm Capacity requirements (and associated energy) at the contract market, buying the remainder in the spot capacity market (MEM, 2021b).

Energy and capacity can be purchased through PPAs in the contract market. Contracts can be signed for Firm Capacity and energy, to purchase only capacity or only energy. The quantities of Firm Capacity or energy contracted per day, per hour or per season may vary. The type of contract depends on the parties involved (supply contracts or generation contracts) and the location (local contracts and export or import contracts) but are always registered with the CNDC.

A generator may sell Firm Capacity (and energy) through contracts, limited to its own Firm Capacity (either with generating units that it owns or capacity contracts with another generator). The differences that arise for each agent between the contractual commitments and the actual operation will be managed by the CNDC in the spot capacity market. The remaining capacity can be sold in the spot market.

2.4.4 Key findings

A user (distributor or qualified consumer) must purchase in advance a share of its Firm Capacity requirements but not the totality of its requirements. Firm capacity purchase obligations serve as a tool for energy buyers to secure their future requirements.

The Firm Capacity concept in Nicaragua is defined and is limited to the characteristics of the generators, not to the critical period of the system. The methodologies used are limited to conventional technologies and do not include VRE generation.

The main challenge going forward to further the uptake of renewable technologies is the modernisation of the regulatory framework to increase system efficiency and competition in the wholesale electricity markets. The lack of participation of VRE in the generation mix and the modest competitiveness achieved by the related technologies call for a re-evaluation of the Firm Capacity concept and of the methodologies used to calculate it in order to eliminate barriers that hinder the development of these technologies.

2.5 PANAMA

Firm capacity is calculated annually according to a specific methodology for each technology. However, there is currently no recognition in practice of Firm Capacity for solar and wind. Distributors[19] are obligated to contract their Firm Capacity requirement in advance (100% of the Firm Capacity requirement must be purchased one year in advance). To do so, the main tool is the contract market: long-term supply contracts are usually for Firm Capacity and its associated energy (depending on the technology). Additionally, distributors can purchase Firm Capacity for the next year through the Long-Term Reserve Service (LTRS annual tender). In addition to the LTRS, generators can sell Firm Capacity in the spot capacity market (daily deviations market).

2.5.1 Definition of Firm Capacity

In Panama, the definition of Firm Capacity is stated in the Commercial Rules, and the term used is "long-term Firm Capacity" (ASEP, 2018). The methodologies to determine the Firm Capacity of the generating units is defined in the Rules of Operation (Reglamento de Operación in Spanish, 2018 version) and the Detailed Methodologies (Metodologías de Detalle in Spanish, 2017 version) (CND, 2022a and 2022b). This procedure has been in force, with some changes, since the beginning of the market's operation, the main change being the incorporation of the methodology to determine Firm Capacity for wind and solar power plants.[20] However, the methodology in place for VRE usually leads to Firm Capacity not being recognised for these technologies.

19 In Panama, distributors are private companies.

20 A consultancy study for the revision of the calculation of Firm Capacity for generation plants connected to the national interconnected system was developed in 2019, but its main recommendations have not been incorporated in the regulation yet.

The long-term Firm Capacity of a hydroelectric, wind or solar PV plant is defined as the power that can be delivered and guaranteed by the plant during the period of maximum system requirement, corresponding to the hours of maximum daily demand, for a 95% probability of exceedance, given the hydrological, wind or solar radiation regime of the plant.

The long-term Firm Capacity of a thermal power plant is the power that can be guaranteed under conditions of maximum system requirement, according to the plant's technical and operational characteristics.

2.5.2 Calculation of Firm Capacity

The procedure used by the National Dispatch Centre (CND) to determine the Firm Capacity of the different generating units[21] depends on the technology of the power plants and can be summarised as follows:

a Wind and solar power plants

Firm capacity is determined using a simulation model that reproduces the plant's operation in a meteorological period of at least 20 years, with the Firm Capacity determined for a 95% probability of surplus. Once in operation, Firm Capacity recognition can be adjusted to reflect the real operative conditions of the power plants.

Wind generators must present the CND with a database including specific information related to the project's site, such as wind speed distribution, direction, pressure, temperature and density, considering a historical horizon of at least 20 years and with real data from at least the most recent two years.

Solar generators must present information to the Electricity Transmission Company, including a hydrometeorology area and a database including specific information such as the latitude and longitude of the plant's location, light hours or solar brightness, cloud density, air temperature, percentage of humidity, orientation and inclination, considering a historical horizon of at least 20 years and with real data from at least the most recent five years.

As observed in the last Long-Term Firm Capacity Report for 2022, published by the CND, using this methodology in the recognition of Firm Capacity for solar and wind projects resulted in no Firm Capacity being recognised (CND, 2022c).

The results of the methodology show room for improvement since no Firm Capacity is recognised for solar PV generation, yet the maximum daily demand in Panama is during daytime hours.

b Thermal power plants

The Firm Capacity of a thermal power plant is equal to its effective capacity, affected by the unavailability rate that the generator undertakes, which cannot be higher than the actual unavailability rate of the plant in the last three years (the historical years considered are from August to July). Committed availability can vary throughout the year.

21 Before the 1 November each year, the CND must inform the market participants of their recognised Firm Capacity for the following year.

c Hydroelectric power plants

The Firm Capacity of a hydroelectric power plant is a function of the characteristics of its reservoir, which are determined by the PLANH model[22] following these distinctions:

Run-of-river hydroelectric plants

Historical flows determine the energy produced by the plant for each hydrological series. Firm capacity is the energy that has a 95% probability of exceedance divided by eight hours.

Reservoir hydroelectric plants

Firm capacity is determined by optimising the production of the power plants over a 30-year period considering the historical series of flows. The optimisation process calculates the energy that has a 95% probability of exceedance; Firm Capacity is obtained by dividing this energy by eight hours.

The PLANH model

PLANH simulates the operation of the reservoirs in the Panamanian system through a model whose objective is to emulate their "real" operation and, consequently, the production of electricity in the hydroelectric plants in the system, considering a long-term horizon (maximum of 38 years with monthly steps). This problem is formulated as a dynamic programming problem, in which the water balance equation between the "cascade" hydroelectric power plants and the turbine capacities in both reservoir and run-of-river plants (without regulation capacity) is represented.

PLANH also exemplifies the hydrological diversity of the hydroelectric inflows, particularly in the driest hydrology observed in the past, and shows both the existing and under-construction hydroelectric power plants. However, the model does not address the complete operational problem as it only tackles the hydroelectric system. In this sense, PLANH differs significantly from the model used for the actual operation of the Panamanian electricity system (the SDDP model).

2.5.3 Firm capacity contracts, balances and settlements

In the Panamanian market, energy buyers (distributors and large users) are obligated to contract their Firm Capacity requirement in advance (maximum generation demand). Commercial rules establish three ways in which Firm Capacity is traded:

- **Contract market:** In this long-term market, distribution companies (and large users) seek to guarantee supply to their regulated clients (or to meet large user demand). The contract market stabilises prices and promotes investment in new capacity, which, in turn, guarantees long-term supply. Contracts usually have a constant capacity payment for committed Firm Capacity and a variable energy payment based on the actual energy delivered.
- **Long-Term Reserve Service (LTRS;** in Spanish, Servicio Auxiliar de Reserva de Largo Plazo): This is an annual tender designed for distributors or large users to contract their Firm Capacity requirements not yet covered under long-term contracts. Once a year, usually on January or February of each year, the system operator (CND) calculates the portion of the projected demand not yet committed under long-term contracts and conducts a tender among generators to bid in the LTRS. Any generator can participate by bidding a price for its uncommitted Firm Capacity, and the CND ranks the bids in ascending

22 Software used by the CND to determine the Firm Capacity of the hydroelectric power plants in the Panamanian system.

price order until they meet the system's long-term reserve capacity requirement. The highest-priced accepted bid defines the price of Firm Capacity in the LTRS, and all generators whose bid has been accepted are assigned this same price. The price bid has a cap defined by regulation (same cap as for the daily capacity deviation market).

- **Spot capacity market (daily deviations market):** This market compensates short-term (daily) deviations between committed Firm Capacity and recognised commercial Firm Capacity. In this market, energy buyers and generators trade capacity in the hour of maximum generation of the day. Pursuant to present commercial rules, each market agent with a capacity surplus can bid a price at which it is willing to sell said capacity surplus. The bidding price cannot exceed the maximum price set by the CND for each day, estimated as the maximum capacity price of long-term supply contracts that are passed through to end user tariffs.

In the first two markets (contract and LTRS), generators can offer capacity until they reach their long-term recognised or purchased Firm Capacity (as defined previously).

In the spot capacity market (daily deviations market), generators can offer capacity until they reach their maximum commercial capacity.[23] In the case of a hydroelectric power plant, depending on the hydroelectric conditions, the available capacity for the daily compensation market may be higher than the long-term firm reserve. Only in very dry conditions will the long-term Firm Capacity equal the commercial capacity.

On each day, the CND will also settle the capacity deviations for both sellers and buyers of Firm Capacity. Payment for capacity deviations will be made at the resulting price of the balance between Firm Capacity bids (offer) and Firm Capacity demand. Typically, prices are set at low values, significantly lower that the regulated cap price.

2.5.4 Key findings

The Firm Capacity concept in Panama is well defined, and methodologies to calculate it are clearly stated for VRE generation, but the result always amounts to zero recognition. Even though it considers 20 years of historical data, according to agents in the market the null recognition for solar PV and wind technologies is a result of its restrictive methodology. Since Panama's peak energy demand occurs during daytime hours, a certain quantity of Firm Capacity from VRE contribution seems appropiate.

Energy buyers must purchase their Firm Capacity requirements one year in advance through tenders or the long-term ancillary services (LTRS). So, Firm Capacity purchase obligations serve as a tool for energy buyers to secure their future requirements. For generators, the capacity market (daily deviations market) facilitates daily trades of Firm Capacity surpluses or deficits.

The association of the Firm Capacity concept with the probability the technology can supply the demand in the critical period is well established in the regulations; nevertheless, the methodology applied in practice shows that it is a barrier to VRE generators due to the zero Firm Capacity recognition for these technologies.

A modernisation of the regulatory, commercial and operative rules is necessary to improve the price signals in each market and the definition of the Firm Capacity product and methodologies.

23 The maximum capacity that a generator can provide for a maximum period of 15 minutes, considering the operational restrictions of the unit (e.g. own restrictions, fuel constraints in the case of thermal plants, and transmission restrictions).

3 INTERNATIONAL BENCHMARK

This section describes the main characteristics of the Firm Capacity concept in four countries within the region that operate national wholesale electricity markets and that have implemented methodologies for the recognition of Firm Capacity for VRE generation. The purpose of this analysis is to understand the typical use of Firm Capacity throughout the region and further identify the best course of action moving forward.

It is worth noting that, while the Regional Electricity Market, MER, (Mercado Eléctrico Regional in Spanish) is organised into a regional contract market and a regional spot market that allows its participants to trade energy, there is no regional capacity market in MER.

3.1 BRAZIL

The reliability of the Brazilian system is guaranteed through the concept of physical guarantee (*i.e.* firm energy instead of Firm Capacity as observed in other countries). The physical guarantee is calculated according to a specific methodology for each technology (including VRE) and is an important parameter for the supply-demand balance, as it is used for two fundamental purposes in Brazil: it defines the maximum amount of energy that a power plant can trade in energy contracts and, in the case of hydroelectric plants, it defines the plant's share of participation in the Mechanism of Reallocation of Energy.

3.1.1 Definition of Firm Capacity

The Brazilian market does not contain an organised capacity market where generators can trade Firm Capacity. The reliability of the Brazilian system is safeguarded through the concept of physical guarantee (or firm energy certificate), which determines the amount of energy that a power plant can supply in a dry year.[24]

3.1.2 Calculation of the physical guarantee

The calculation of the physical guarantee of generation projects, as well as its revision, is the responsibility of the Energy Research Company (Empresa de Pesquisa Energética) and follows specific methodologies and criteria depending on the technology of the power plant.

The total physical guarantee of the system is defined as the maximum demand that the system can supply with a certain probability of exceedance during critical conditions (dry year).

This amount of energy can be shared among all the generation projects that make up the system. Thus, the value attributed to each project constitutes its physical guarantee, which is the physical back-up of said projects from the viewpoint of commercialising energy via contracts.

The physical guarantee is calculated at the connection node of the power plant. However, the reference point to verify the plant's sufficiency to supply the contracts is in the centre of gravity of each subsystem (the

24 Value in average megawatts is the energy of a time period (megawatt-hours) divided by the hours of the period. It is an approximation of the energy supplied or demanded in a period of time.

system is organised and divided into four regional subsystems). The centre of gravity of a subsystem is a reference location (reference node) in which the transactions are settled.

Thus, for projects connected to the transmission grid, both transmission losses and the plant's internal consumption need to be discounted (including losses from the plant to the transmission substation to which it is connected). In some cases, the firm energy certificate is calculated at the substation node, and in those cases internal consumption does not need to be discounted.

a Physical guarantee of wind and solar power plants

In the case of wind and solar projects, the physical guarantee is calculated based on production data certified by independent entities and takes into consideration the agent's monthly energy availability declaration.[25] In the case of wind projects, the physical guarantee is associated with production that has an exceedance probability of 90%, the assessed unavailability (forced and programmed) and the estimated annual internal consumption and losses (MME, 2016).

The certified annual energy production must consider losses due to the layout of the wind turbines, local weather conditions, air density and blade degradation, as well as aerodynamic losses of the park itself, and the wake and turbulence effects of other parks, among other factors.

In the case of solar PV projects, the physical guarantee is similar to that of wind turbines but associated with production that has an exceedance probability of 50%.

The certified annual energy production for solar PV considers losses related to temperature, dirt, angular and spectral shading, module degradation, mismatch, tolerance on the nominal power of the modules, internal resistance in the wiring, inverter efficiency and maximum power control, initial module degradation, and irradiance level, among other factors.

b Physical guarantee of hydroelectric power plants

For the calculation of physical guarantee for hydroelectric power plants, energy simulations of the centralised system in Brazil are carried out, using the NEWAVE and SUISHI hydrothermal generation models. The main simulation criteria included in the calculation are as follows (EPE, 2022a):

- five years of simulation
- construction of operational policy with 200 forward reports and 20 backward reports
- hydraulic coupling between equivalent energy reservoirs
- hydrological trends disregarded
- dispatch of thermal plants
- grid topology at a four subsystems level
- conditional value at risk with parameters alpha = 50% and lambda = 40% for hydrology series (MME, 2017).

25 Regulation Portaria MME Nº 101 of March 23rd, 2016, defines the physical guarantee for Solar PV and Wind projects.

Physical guarantees of hydroelectric plants must be reviewed every five years, and an extraordinary review[26] is required in the case of modifications like repowering, modernisation, change in the design, or similar. Ordinary reviews have been regularly postponed, with a first general review of values undertaken in 2017; any adjustment is limited to 5% of the original value.

c Physical guarantee of thermal power plants

For the calculation of physical guarantee for thermal power plants, energy simulations of the centralised system in Brazil are carried out using the NEWAVE dispatch model.

For thermal units, physical guarantee is a function of their available capacity (discounting scheduled maintenance and forced outages) and is adjusted by a factor based on their dispatch probability, which in turn depends on the variable cost (the higher the cost, the lower the recognition of the physical guarantee) and the inflexibility level.

The value of the physical guarantee is reviewed annually in August (and becomes effective the following January) and is based on the moving average of the actual unavailability of the plant in the 60 months prior to the month of calculation. The physical guarantee of a thermal power plant can be modified during its commercial operation due to changes in its performance.

3.1.3 Firm capacity contracts, balances and settlements

Since a Firm Capacity market for trading is not available, generators can trade physical guarantee (Firm Capacity) through bilateral agreements.

Brazilian supply reliability is ensured through the two basic rules of Brazilian electricity sector regulation:[27]

1. Energy buyers (both free and regulated) must acquire 100% of their demand through contracts. The coverage of the demand is verified ex-post by comparing the accumulated energy consumed versus the amount contracted. If the contracted energy is less than the consumed energy, the user must pay a penalty associated with the cost of building new capacity.

2. Energy contracts must be covered by the physical guarantee calculated by the Energy Research Company and stated for each project by the Ministry of Mines and Energy and should reflect the annual energy that the project can supply with certainty under specific situations.[28] The physical guarantee is the maximum amount of energy that the projects can commercialise in contracts.

The combination of the 100% demand-side contract coverage requirement and the 100% guarantee of average contracted power creates a link such that the growth in demand and the installation of new capacity guarantee the certainty of the system's supply in the long term.

Physical guarantee purchase-sale transactions between agents are bilateral, and the certificates can be negotiated. During the term of a contract, these guarantees can also be replaced by others.

The physical guarantee is an important parameter for the supply-demand balance and is used for two fundamental purposes in Brazil: determining the maximum amount of energy that a power plant can trade in energy contracts and, in the case of hydroelectric plants, marking the plant's share of participation in the

26 Additionally, authorisation from the Electricity National Agency and sanctioning by the Ministry of Mines and Energy is required.
27 New model established by Laws No. 10 847 (2004) and Law No. 10 848 (2004).
28 Such as equipment failures, unexpected problems in the fuel supply and, mainly, the occurrence of dry hydrological conditions.

Mechanism of Reallocation of Energy. The firm energy certificate is also part of the hydro concession contract and the thermal power authorisation.

3.1.4 Key findings, best practices and challenges

The Firm Capacity concept is not defined in Brazil, but a similar tool has been defined: the physical guarantee, which can be assimilated to a firm energy concept. Since Brazil has historically shown high levels of optimisable hydroelectric generation, the instant balance of the system has not been a problem, so the regulation is focused on balancing the system for the long term in critical conditions (dry years). With a higher share of VRE generation in the energy mix observed during the last few years, the Brazilian government has started introducing Firm Capacity signals, but these are limited to the introduction of capacity auctions (first one in 2021).

Energy buyers must purchase 100% of their energy requirements in advance, and the generator must back up 100% of their contract commitments with physical guarantee. With this rule, the market design ensures that the required supply will be available when demanded under critical conditions.

The methodology for calculating the physical guarantee is also defined for VRE generation, and the use of dispatch models to estimate the contribution of power plants towards reaching certainty of the system advances analysis of the impact and contribution of each power plant during the critical period.

Relying on dispatch models that optimise the use of storable energy (water reservoir, for example), the methodology considers the effect of the power plant in different periods of the day (generation during daytime stores energy in reservoirs for use during night-time) capturing the contribution of the flexibility to the reliability of the system.

One of the challenges for regulators is the need to introduce a formal definition of Firm Capacity related to the instant demand-offer balance, which may indicate the correct signals to improve the instant reliability of the system. A formal definition would help the development of solutions (like storage) that can provide the service and contribute to an increased development of VRE generation.

Another challenge is the creation of an organised formal Firm Capacity market in which agents can trade their surpluses or requirements and in which the National Electricity Energy Agency of Brazil can secure the competitiveness of these transactions.

3.2 CHILE

Firm capacity compensation in Chile is determined by a concept known as sufficiency capacity, which represents the capacity of a generating unit to secure supply to meet long-term demand. Sufficiency capacity is calculated in steps and according to a specific methodology for each technology (including VRE). Generators may sell or buy sufficiency capacity either through PPAs or to the monthly capacity balance.[29]

The potential new regulatory framework is focused on:

- unifying the methodology for Firm Capacity recognition for different technologies
- including new technologies (storage)
- including a penalisation factor for inefficient technologies

29 This section describes the regulatory framework in effect in January 2022 (Ministry of Economy, 2006); a new regulatory framework for Firm Capacity recognition was under discussion at the time of writing.

- changing the associated critical moment in which Firm Capacity is evaluated from the hours with maximum demand to the critical hours of the system.

3.2.1 Definition of Firm Capacity

Firm capacity in Chile is known as sufficiency capacity (*potencia de suficiencia* in Spanish), which refers to the ability of a generator to supply the demand in a critical scenario affecting the whole power system (peak demand under dry hydrological conditions, and unavailability of power plants). The sufficiency of a system or subsystem relates to its capacity to supply peak demand, looking at the reliability of supply from each of its generating units given the uncertainty associated with the availability of fuel, forced outages and unavailability of the infrastructure connecting the unit to the transmission or distribution system.[30]

Each generating agent must be able to meet its peak demand commitments each year, either through its own capacity or by contracting with other generators. Firm capacity transfers between generators are determined by the final Firm Capacity and the system's peak demand.

3.2.2 Calculation of Firm Capacity (sufficiency capacity)

The methodology to calculate Firm Capacity can be summarised as follows:

- Determine the initial capacity of thermal, hydro and non-conventional renewable energy power plants, based on primary energy resource availability.
- Reduce the initial capacity according to the scheduled maintenance periods and self-consumption.
- Perform a probabilistic analysis to obtain the expected value of the capacity that contributes to the sufficiency of the supply of the system or subsystem's peak demand. This result is called preliminary Firm Capacity.
- Adjust the preliminary Firm Capacity of each plant so that the sum of these capacities equals peak demand. These adjusted firm capacities correspond to the final Firm Capacity of the units.

The technologies covered by the methodology are thermal, hydroelectric, solar PV, solar thermal, wind, geothermal and biomass. The effect of storage on solar PV and wind is part of the methodology, but the benefits of these technologies are not properly captured. Current discussions by authorities relate to improving the methodology to better represent the flexibility of storage technologies in the system and their benefits.

a Initial and maximum capacity

The maximum capacity of a power plant is the maximum gross active power that a generating unit can sustain in a minimum period of five hours.

The initial capacity takes into account the maximum capacity and the primary energy resource availability (for thermal units, the initial Firm Capacity considers the availability of fuel supply). It is thus lower than or equal to the maximum capacity.

30 *Ministry of Economy, 2006. The methodologies are regulated by Exempt Resolution 54, "Technical Norm of Capacity Transfers between Generating Companies" (CNE (Chile), 2022), as part of Supreme Decree 62 of 2006 and modifications.*

Renewable generators

For solar PV, wind, and other non-conventional renewable source plants, the initial Firm Capacity is obtained by multiplying the plant's maximum capacity by the lowest of the following values:

- lowest annual average plant factor of the last five years (prior to the year of calculation)
- simple average plant factor of the unit during the last year in the 52 hours of higher demand in the system or subsystem.

Hydroelectric generators

For hydroelectric generators, the average of the two hydrological years with the lowest inflows (driest conditions of the system) are used. For plants with regulation capacity, the initial Firm Capacity is determined using the plant's capacity factor corresponding to the average volume of the reservoir. If no regulation capacity is available, the average capacity factor is used.

Thermal generators

In this case, the availability of the main input depends on the hours in which fuel limitations caused the generating unit to be off-line or in which its output was restricted (*i.e.* in service but prevented from injecting its maximum gross power), its resulting power output, and the total number of hours the unit was in operation.

The initial Firm Capacity of thermal units operating with only one fuel is calculated as the product of the maximum capacity and the lowest availability of the main input of the last five years. The initial Firm Capacity does not depend on the type of fuel, only on its availability.

For generating units that can operate with alternative fuel, the initial capacity is determined as the value of the initial capacity without alternative fuel, plus the maximum capacity associated with the alternative fuel weighted by the *factor 1 – availability of the main input*.

Self-generators

To participate in Firm Capacity monthly balance (transfers), a self-generator must be able to offer power surplus on a permanent basis. Power surplus is understood as the difference between the installed generation capacity and its maximum annual demand.

b Preliminary Firm Capacity

The preliminary Firm Capacity is determined by the National Electrical Coordinator (CEN) using a probabilistic model that considers for each generating unit its initial Firm Capacity, unavailability, maintenance period and self-consumption. The model calculates for each unit its expected contribution to the sufficiency.

c Final Firm Capacity

The final Firm Capacity of each power plant is determined using Firm Capacity as a basis, scaled by a single adjustment factor for all units so that the sum of Firm Capacity of all units equals the system's peak demand.[31]

31 Peak demand is defined as the National Electric System gross demand minus the internal consumption of power plants during the 52 highest hourly values of the annual load curve of each system or subsystem for the year of calculation.

If the transmission network cannot transmit the power of any of the units, the Firm Capacity recognition will be reduced in such a way that the restriction disappears, proportionally increasing the Firm Capacity of the remaining units.

3.2.3 Firm capacity contracts, balances and settlements

In Chile, distribution companies must contract their energy and capacity needs in advance. Regulated contracts (those between generators and distributors) are a result of public tenders with fixed energy and capacity requirements.

Generators may sell their Firm Capacity either through PPAs or to the monthly Firm Capacity balance. If a generator sells more than its own sufficiency capacity, it is considered a buyer for the difference and must pay for it though the monthly balance (settled through CEN). Similarly, if a generator sells less than its sufficiency capacity, it automatically sells the excess in the monthly balance and receives the associated payment through CEN; this results in no constraints in the sale or purchase of sufficiency capacity. If a power unit has a firm commitment that exceeds its own sufficiency capacity, that commitment can be backed by all the power units belonging to the same company or by purchases from other generators.

Spot capacity contracts can be freely negotiated, but prices are typically close to the expected regulated prices.

3.2.4 Key findings

The Firm Capacity concept is well defined in Chilean regulations. The methodologies for Firm Capacity recognition are clear and include recognition of VRE generation.

Energy buyers (distribution companies or free users) must purchase their Firm Capacity requirements in advance. Energy buyers do not participate in any of the energy or capacity markets or balances, and all their requirement must be fulfilled through a PPA, resulting in a spot energy market and monthly Firm Capacity balances that are only for generators.

In addition, Chile has implemented a renewable purchase obligation, with a target of 20% by 2025, meaning that by 2025, energy buyers are obligated to purchase 20% of their energy demand from renewable sources (Government of Chile, 2013).

The association of the Firm Capacity concept with the probability that the technology can supply the demand in the critical period is well established in the regulations; however, different methodologies are used for different technologies.

The current discussions in Chile relate to how to implement a new methodology that allows competition among the different technologies for Firm Capacity revenues. This modernisation of the regulatory framework is in progress and will focus on improving the market signals to correctly assign risks and benefits to the different agents.

A future challenge will be the introduction of a Firm Capacity market in which the Firm Capacity price will be the result of a competitive market.

3.3 MEXICO

In Mexico, the Capacity Balancing Market (Mercado para el Balance de Potencia, in Spanish) is an annual, ex-post market that aims to promote investment in new capacity. For this purpose, the National Energy Control Centre (CENACE) estimates a capacity requirement for consumers and acknowledges it to those generators that were available during the 100 critical hours of the system.

3.3.1 Definition of Firm Capacity

Within the Electricity Market Basis, basis 11 establishes the general provisions for the capacity market and the methodology of calculation of Firm Capacity, known as physical available capacity (*disponibilidad de producción física* in Spanish) in the Mexican regulation (CENACE, 2015).

Firm capacity is a commercial product that generators can trade and through which they acquire the obligation to guarantee the availability of physical production and offer the corresponding energy in the day-ahead market and the real-time market.

3.3.2 Calculation of Firm Capacity

A generator's physical available capacity is subject to the generator's average availability during the 100 critical hours of the pertinent power system.[32] The 100 critical hours are defined at the end of each year as the 100 hours with the minimum generation reserves in the power system.[33]

The physical available capacity calculation depends on the type of generator (firm or intermittent):

- **Thermal generation:** average available capacity during the 100 critical hours.
- **Hydro, solar or wind generation:** average real production during the 100 critical hours.

The difference in calculation method between thermal and renewable generation is due to the contribution provided by each of these technologies to the reserve margin and, correspondingly, to achieving certainty of supply of the energy demanded.

Thermal generation can supply the energy demanded during critical hours, when available, although it may not be dispatched.

In contrast, the real availability of the renewable generation depends on the availability of its primary natural resource (water, wind, sun), which is dependent on weather conditions. For this reason, the capacity of renewables during critical hours is measured with the real generation during such hours; the annual energy production of renewables also depends on weather conditions. The correlation between total annual energy production and actual energy production during the 100 most critical hours is not direct. It is possible that in years in which the annual energy production is lower than the average (P50) value, the actual production during the 100 most critical hours is greater than the average. The opposite is also possible.

32 National Electric System or the Baja California or South Baja California systems.
33 Total reserve (for each capacity zone) will be calculated as follows:
a For each hour, generation availability is equal to the maximum capacity of firm generation units (net of any reductions ordered by CENACE), plus actual generation of intermittent plants, plus available transmission import capacity into the capacity zone.
b Firm demand for each hour is equal to actual demand (including exports), minus the maximum capacity of guaranteed controllable demand, plus the actual dispatched controllable demand.
c Total reserve for an hour is the generation availability minus the firm demand.
Historically, critical hours have been more frequent between 15:00 and 20:00. It is expected that with increased addition of solar PV plants to the energy matrix, the critical hours occur more during non-solar hours, when the system reserve margin will be minimum.

3.3.3 Firm capacity contracts, balances and settlements

The Capacity Balancing Market aims to facilitate the activities of market participants when buying or selling the required capacity to cover imbalances that exist between their capacity requirements and the amounts registered in their bilateral capacity transactions. The market takes place in February each year and contemplates real generation data from the previous year.

The purpose of this market is to set price signals that represent the conditions of shortage or surplus in the generation capacity of the National Electric System. The objective is to create signals to promote the contracting of capacity in the medium and long term and to encourage the development of new generation capacity that fulfils the demand.

Market participants may contract their capacity demand under bilaterally negotiated terms and can register those transactions with CENACE as bilateral power transactions.

3.3.4 Key findings

The Firm Capacity concept is well defined in the Mexican electricity market. The methodologies for Firm Capacity recognition are clear and include recognition of VRE generation. Thermal and non-thermal generation methodologies are not treated alike.

Energy buyers must purchase their Firm Capacity requirement through bilateral agreements or through the Capacity Balancing Market. In addition, energy buyers have the obligation to purchase 5% of their demand from renewable sources.

The association of the Firm Capacity concept with the probability that the technology can supply the energy demand during the critical period is well established in the regulations. Critical hours are associated with the hours of lower reserves, which are a good indication of the critical moment of the system. The estimation of the critical hours using an ex-post methodology creates additional uncertainty and may require further study.

The main challenges observed are related to the modernisation of the regulatory framework, aiming to increase the competition between technologies to supply Firm Capacity. A unique methodology that allows competition between technologies under similar conditions may be achievable.

In addition, a methodology that increases the certainty of future Firm Capacity revenues may provide stable signals for the development of new generation. Ex-post calculations reduce the opportunities for generators to manage risk.

3.4 PERU

In Peru, the concepts of firm energy and Firm Capacity apply, and their calculation depends on the technology of the power plant. Generators cannot contract to supply free users and distributors more Firm Capacity (and firm energy) than their own plus what has been contracted through third parties. Since 2019, renewable energy power plants ("renewable energy sources" in Peruvian regulations) can contract with free and regulated users without the need for a back-up Firm Capacity purchase agreement with another generator.

3.4.1 Definition of firm energy and capacity

In Peru, regulations define two different concepts:

- **Firm energy**, which is the expected production of electricity, determined for hydroelectric generation units through a probabilistic simulation and, for thermal generation units, considering forced and planned unavailability. The annual calculation of firm energy for each generating unit is used to verify that it can meet its contractual obligations.
- **Firm capacity**, which is the capacity that can be supplied by each generating unit with a high level of certainty (depending on its technology). This value is calculated monthly, based on the effective capacity of the power plant and its unavailability rate.

The System Economic Operations Committee oversees the calculation of Firm Capacity and firm energy for each generating unit, following specific technical procedures.[34]

3.4.2 Calculation of firm energy

The methodology to calculate firm energy depends on the technology of the power plant.

a Hydroelectric power plants

The firm energy of a hydroelectric power plant is determined by simulating its operation for a 12-month period, with the objective of maximising its annual generation. For this purpose, the annual hydrological study of the previous year is used, applying parameters such as initial volume of the year,[35] irrigation restrictions, drinking water and ecological flow, minimum volume of reservoirs, losses due to filtration and evaporation, and unavailability due to major maintenance and forced outages.

b Thermal power plants

The firm energy for a thermal power plant is determined based on its effective capacity and its forced and planned unavailability.

c Wind and solar power plants

In the case of wind and solar power plants, firm energy is equal to the arithmetic average of the last five years of production.[36]

3.4.3 Calculation of Firm Capacity

Firm capacity recognition of each generating unit is calculated monthly with the following distinctions by the type of technology:

34 Technical Procedure 13: Determination of firm energy and verification of annual committed energy coverage. Technical Procedure 26: Firm capacity calculation. Technical Procedure 30: Valuation of capacity transfers to the main system and guaranteed transmission system. Technical Procedure 36: Firm capacity available and minimum Firm Capacity available for long-term bids.

35 From the "Seasonal regulation reservoirs" document as the average of the measured volumes on each 1 January over the last ten years.

36 For new plants awarded through a contract tender, the awarded energy is used as Firm Capacity; for new projects not awarded through tender, the previous year's capacity factor is used, or – when the required history is unavailable – the average factor of all the power plants of the same technology is used.

a Thermal power plants

The Firm Capacity of a thermal unit is calculated based on its effective capacity, discounting unavailability due to forced outage and planned maintenance.

b Hydroelectric power plants

The calculation of Firm Capacity for hydroelectric power plants accounts for the energy that each plant can guarantee, based on the hydrological series, the characteristics of the basins involved, and the number of hours of regulation, as defined by the guidelines.

The yearly optimal operation of the plants is simulated with the objective of maximising the plant's annual generation. For this purpose, the hydrological series; natural inflows to the seasonal reservoir; natural intermediate inflows; filtration and evaporation volumes; volumes for irrigation and drinking water; maximum capacities of tunnels, canals and floodgates; and scheduled maintenance are considered.

The guaranteed energy for hydroelectric power plants is obtained for each of the 12 months of the year considered, based on the total discharged volumes, the intermediate input volumes and the maximum generable energy.

There is a different calculation for hydroelectric power plants that have seasonal and hourly reservoirs (refer to Annex II for more detail on this methodology).

The final guaranteed capacity is calculated based on the total energy guarantee in those reservoirs and the total number of hours of regulation offered by the total reservoir capacity.

c Wind and solar generation plants

The Firm Capacity of solar and wind generators is determined based on the energy production during peak demand hours.[37]

d Readjustment of Firm Capacity

If the sum of the Firm Capacity for thermal and hydro units does not cover the maximum demand of the system (with a surplus probability defined by the Ministry of Energy and Mines), norms regarding reservoir regulation hours, excess probabilities and unavailability are relaxed until supply and demand are equalised, as follows:

- **Regulation hours:** progressively reduced in intervals of one hour from the initial regulation hours down to the one-hour limit in order to increase the guaranteed capacity of hourly regulation reservoirs.
- **Probability of exceedance:** progressively reduced in intervals of 1%, from the initial probability of exceedance up to 70%.
- **New availability factors:** determined for thermal and hydraulic units, assigning 1% reduction to the unavailability rate of the thermal units if the established parity is not satisfied, with a limit of unavailability equal to 0%. If parity is not yet achieved, the unavailability for scheduled maintenance will be reduced in successive periods of ten days for hydroelectric power plants. If parity is still not achieved, then Firm Capacity will be equal to the effective capacity of each unit.

37 17:00 to 23:00 (OSINERGMIN, 2019).

3.4.4 Firm capacity contracts, balances and settlements

The wholesale spot market in Peru is open to generators, distributors and large users.[38] Energy buyers are obligated to purchase their Firm Capacity requirement.

The market for long-term contracts is characterised by some basic conditions for generators and distributors:

- Generators cannot contract to supply free users and distributors more Firm Capacity (and firm energy) than the Firm Capacity of their own facilities plus the Firm Capacity that has been purchased from third parties.
- Sales of electricity from generator to distributor, destined for the public electricity service, are made through non-bid contracts[39] and contracts resulting from public auctions.

The available Firm Capacity of an applicant company for long-term bids is determined monthly, for the entire accreditation or verification period requested, as follows:

- For existing generation, the sum of the Firm Capacity of all the applicant's existing generation units, plus the amount contracted with third parties, minus the power committed in peak hours by its contracts, is determined.
- For new electric generation, the declared Firm Capacity of the applicant's new electric generation project, minus the peak hour power committed by the contracts of the project, is determined.
- The minimum available Firm Capacity is determined based on the lowest available Firm Capacity calculated for each month within the requested time horizon.

The System Economic Operations Committee calculates the Firm Capacity and energy recognition for each generation unit.[40]

4.4.5 Key findings

The Firm Capacity concept is well defined in the Peruvian regulations. The methodologies for Firm Capacity recognition are clear and include recognition of VRE generation. Regulations define two different concepts: firm energy and Firm Capacity. The first one relates to the annual energy that can be assured, and the second one relates to the critical hour of the year.

Energy buyers (distribution companies or free users) must purchase their Firm Capacity requirements in advance.

The association of the Firm Capacity concept with the probability that the technology can supply the demand in the critical period is well established in the regulations; however, different methodologies are used for different technologies.

The main challenges observed are related to the modernisation of the regulatory framework, aiming to increase the competition for supplying Firm Capacity by creating a capacity market.

38 Currently, distributors and large users can participate in the wholesale spot market, but only for purchases up to 10% of their energy needs (hence, in practice, the wholesale spot market is mostly a market of generators).
39 Prices may not be higher than the bar prices referred to in article 47 of the Electric Concessions Law.
40 Since Resolution OSINERGMIN No. 144-2019-OS/CD in 2019 (Firm Capacity recognition for RER), RER power plants can celebrate contracts with free and regulated users without the need to enter into a backup contract with other generator to purchase Firm Capacity.

4 COUNTRY CASE: EL SALVADOR

Under the regulatory component of IRENA's Clean Energy Corridor of Central America initiative, IRENA developed a financial model to assess investment for wind and solar PV projects and developed a simulation with a focus on PPAs and Firm Capacity recognition.

Using this tool, a modelling exercise was performed to analyse Firm Capacity recognition for wind and solar projects in El Salvador currently operating under PPA contracts, in order to assess the financial implications of Firm Capacity recognition. The complete methodology and assumptions used for the exercise can be consulted in **Annex III**.

Below is a summary of the findings and observations from the simulation:

- The replicated projects are expected to be able to deliver reasonable returns on investment (around 9%), feasible for the El Salvadorian market. Potential PPA prices seem to represent an opportunity for El Salvador to reduce the power cost.
- As expected, the recognition of Firm Capacity for solar PV and wind may lead to lower energy prices in the PPAs offered by the developers. Due to an expected higher Firm Capacity recognition for wind projects, the potential PPA energy price is more sensitive to the Firm Capacity recognition methodology for wind projects than for solar projects.
- Based on the available or assumed wholesale price trends, load following PPAs in general showed the necessity of a marginally higher PPA price to cover the spot exposure of the projects.
- A more stable source of revenues (generator energy PPA with commitment linked to generation) provided benefits for the potential development of variable renewable technology projects. However, in an energy market with increasing shares of renewable energy, high wholesale prices are bound to increasingly correspond to periods of lower production from renewable sources.
- Given the lifetime of renewable energy projects and the uncertainty of long-term wholesale price trends, any strategy relying on a large exposure outside the PPA contract would imply a higher project risk.

CONCLUSIONS

This analysis has focused on the methodologies applied in the Central American countries plus the benchmark analyses of Brazil, Chile, Mexico and Peru (four countries that have implemented wholesale electricity markets, in the case of Chile one of the first ones in the world).

The Firm Capacity product aims to provide stable signals for the development of new offers, with a long-term focus on the security of supply in the system. One of the main characteristics of Firm Capacity is that it generates a stable source of revenues that help the development of new offers and prevent the system from deficit conditions.

In general terms, the Central American countries' electricity sectors are designed with a wholesale electricity market model (a market in which energy is traded), except for Belize and Costa Rica, which are still under a single buyer model (a vertically integrated model, with a utility in charge of supplying the final demand that signs PPAs with a generator or independent power producer that it is not owned by the utility). In the countries that created a wholesale electricity market, a mechanism to trade Firm Capacity has been implemented (a market or a balancing mechanism), but in Belize and Costa Rica the concept of Firm Capacity is not defined, other than under the specific conditions of each PPA signed with the independent power producer.

Countries with a wholesale electricity market have, in general, set an obligation for energy buyers to purchase their Firm Capacity requirements. Typically, energy buyers acquire their requirement through contracts (freely negotiated or by public auctions), and a mechanism to purchase or sell the surpluses and deficit is implemented.

In general, the mechanisms designed to trade Firm Capacity are characterised by:

- A Firm Capacity methodology designed by each country regulator and typically applied by each country system operator (the system operator recognises a level of Firm Capacity that can then be traded). The methodologies are different for each technology: thermal, hydroelectric and VRE.
  - Belize and Costa Rica do not have a methodology to calculate Firm Capacity.
  - Nicaragua has implemented a methodology but does not include VRE as a potential source of Firm Capacity.
  - Guatemala and Panama have defined a methodology for solar PV (Panama) and wind (Guatemala and Panama), but the recognition by the system operator is zero due to the restrictive methodology.
  - El Salvador and Honduras have implemented a methodology that includes VRE generation.
  - Honduras has taken the methodology one step forward by unifying the methodologies for all technologies and allowing open competition between technologies.

- The creation of a Firm Capacity trading mechanism or market (except for Belize and Costa Rica) in which the agents can trade the Firm Capacity or deficit:
  - A reference capacity price is calculated by the regulator as the fixed cost of the peak unit (unit required to supply the hours of higher demand in the year). The reference price is calculated as the fixed price that is required by the peak unit (typically open cycle) to repay its capital expenditure and its fixed operating expenses plus a rate of return.
  - A balancing mechanism (daily or monthly) in which the system operator estimates the Firm Capacity surplus or deficit for each agent. Surplus or deficit are calculated as the difference between the agent's Firm Capacity (own generation plus purchases) minus Firm Capacity commitments (contracts).
  - The balancing mechanism includes an adjustment process to adjust the amount of money paid by the purchasers to the amount of money collected by the sellers. The adjustment is performed by adjusting the recognised Firm Capacity (megawatts) or adjusting the price for the sellers.
  - In Panama, two Firm Capacity markets have been implemented, in which the generators bid a price for their Firm Capacity offers (limited to the regulated price calculated by the regulator).

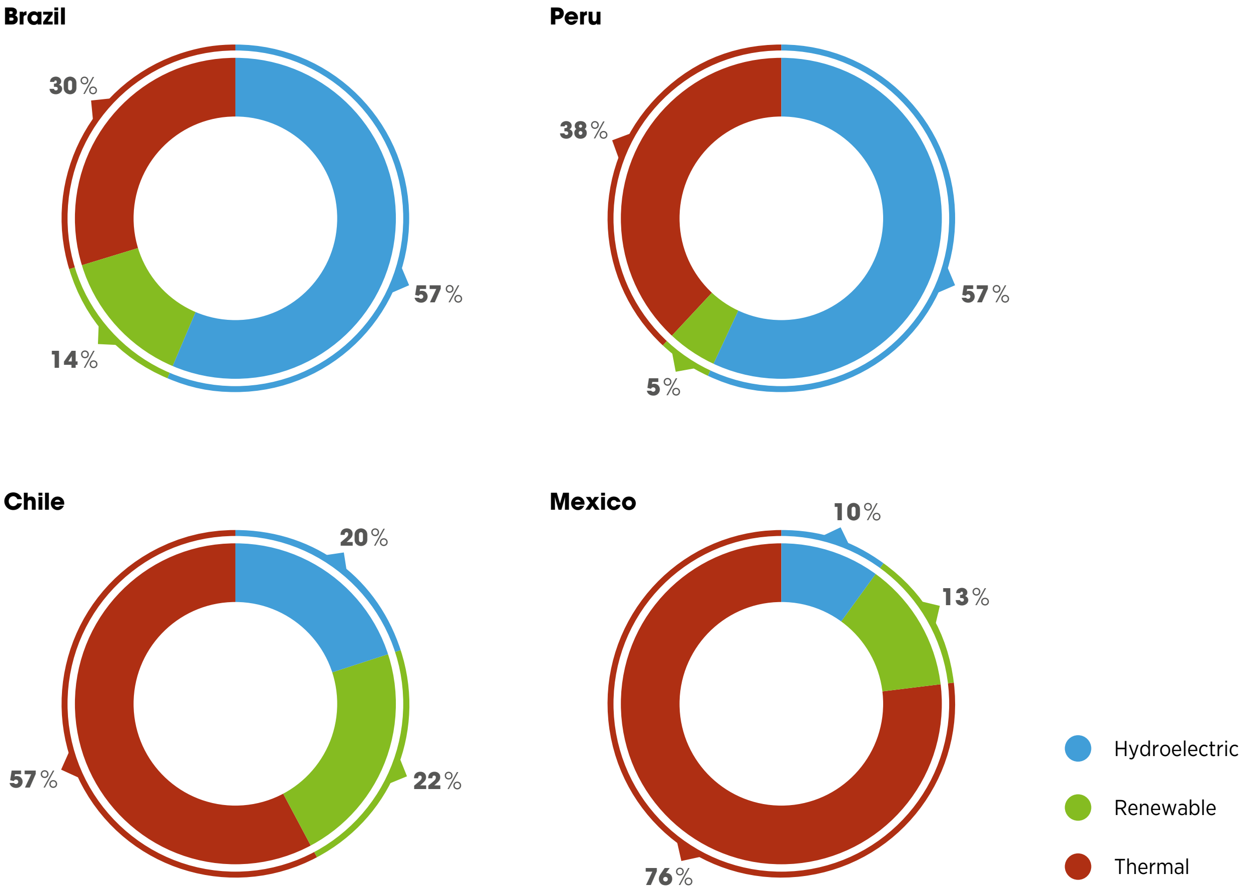
Spot energy markets in countries with a high share of renewable generation (conventional and non-conventional) have shown high levels of volatility in energy prices. This is a challenge for the development of new power generation, especially from renewable sources. This is one of the reasons power sector designs have usually implemented other more stable sources of revenue, like contracts and/or Firm Capacity payments.

Firm capacity recognition and Firm Capacity revenues have been shown to be a stable source of revenues that help to develop new non-conventional generation. The same can be said about long-term PPAs. A lack of recognition reduces the potential for the development of these technologies.

Also, the lack of a standard definition of Firm Capacity has acted as a barrier between countries and restricted the possibility of Firm Capacity transactions between generators and demand in different countries within MER. The lack of recognition for solar PV and wind in several countries has affected these technologies in particular. Harmonisation of the different definitions and methodologies is key to strengthening the operation of MER in the future.

Between the "benchmark" countries, we can observe structural differences between Brazil, a country with very large hydroelectric resources in the generation mix, and Mexico, a country in which the generation mix is based on thermal generation (see *Figure 11*. These structural differences imply different challenges and risks in each country. Hydroelectric generation shows high levels of flexibility in hourly or even seasonal generation but depends on the natural resource conditions, which may be very different between years.

Figure 11 Generation mix (2021) in the benchmark countries



Based on: (CCEE, 2021; COES, 2021; CEN, 2021; CENACE, 2021).

These differences in the generation mix create different environments for the development of electricity sector regulations.

In Brazil, which has a large share of hydroelectric generation in the mix, the critical conditions of the system are always linked to the moments of high demand and dry conditions. Typically, hydroelectric reservoirs act as a storage facility with very fast response, so the hourly variations of the load or natural resources are less critical because the hydroelectric generation can quickly compensate for the difference. This is the main reason the Firm Capacity concept in Brazil in more linked to a firm energy concept (an amount of energy that the power plant can secure in the period) than to an actual Firm Capacity.

In general, hydroelectric provides an important share of the generation mix in the Central American countries, so the best practices of Brazil can be considered.

In contrast, the hydroelectric generation in Mexico is very low, and the more critical conditions of the system are linked to the hours of lower thermal reserves, including the very short-term restrictions of the thermal units (ramps).

The development of new large hydroelectric generation in the Central American countries will be mostly limited (due to the relatively high cost of hydro and the environmental and social problems observed). Furthermore, the expansion plans associated with each country will require high levels of investment in VRE technologies. Therefore, the problems associated with the short-term balance of offer and demand are expected to increase in the future. In this sense, the experience and best practices observed in Mexico can be considered.

Some of the key lessons we can conclude from the analysis are as follows:

- The definition of Firm Capacity must consider the structural conditions of the power sector in each country as well as its projected evolution, new generation capacity and new technologies. It is expected that VRE generation will increase its share in the generation mix of all countries in Latin America, as the RELAC (Renewables in Latin America and the Caribbean) Initiative aims to achieve at least 70% renewable energy participation in the region's electricity matrix by 2030.

  Countries with a high share of hydroelectric generation and strong transmission grids have the possibility of absorbing high levels of variable generation and compensate the variability by optimising the use of the energy stored in the reservoirs.

  Countries with a low share of hydroelectric generation or with weak transmission grids may face increasing operative problems with the additional variability.

- The definition of Firm Capacity has to consider that the system can face critical annual problems (*e.g.* a dry year in Brazil) or a critical short-term problem (*e.g.* the conditions of hydropower in Mexico and the short-term restrictions to compensate the variability of the load and natural resources). So, the definition of Firm Capacity should include a clear view of the critical conditions of the system.

  For instance, the physical guarantee in Brazil is a clear example of a critical annual condition (a dry season), but Brazil is analysing regulatory changes to include a short-term critical signal because of the projected high increase of VRE generation. It is expected that in the future Brazil will have a physical guarantee both for energy and for capacity.

- The definition of Firm Capacity must consider the real contribution of VRE generation to the sufficiency of the system (the possibility that the system can supply the demand in the critical hours).

  The fact that a technology has an injection that is not manageable for the system operator of a country and depends on the natural resources must not be a barrier to the recognition of Firm Capacity for that technology. As an example, the solar PV injection during daytime hours in a system with an important storage capacity (hydroelectric reservoirs) has the option to store water during the day and inject it during the night, increasing the reliability of the whole system.

- The critical period in which the Firm Capacity will be evaluated should align with the real critical period, usually the hours with lower reserve margins.

- The methodologies for Firm Capacity calculation should aim to allow all the technologies to compete for Firm Capacity recognition (as happens for energy) and not include external barriers.

  The Firm Capacity recognition for each technology should depend only on the contribution of the technology to the security of the system.

- The methodologies for Firm Capacity recognition should be prepared for the future new technologies (*e.g.* storage) and for the participation of all the agents (demand management).

- The definition and methodologies should keep being a signal for the development of new generation and the security of supply in the long term.

KEY GUIDELINES FOR USE OF FIRM CAPACITY

There are many important elements in a PPA that define the characteristics of the economic transaction and impact how a power system is expanded. PPAs provided a stable source of revenue that supports the development of new generation projects in the different countries under study.

In general terms, establishing energy and Firm Capacity obligations, terms and prices for the transactions and penalties, in terms of underperformance of any of the parties, has reduced the risk associated with the purchase of energy and Firm Capacity (typically two products that energy buyers – distributors and qualified consumers – are legally obligated to acquire).

PPAs have been able to provide stable prices for energy and Firm Capacity to the participants of the demand group (energy buyers) without being affected by the volatility of the prices in the spot market. Regulatory authorities have been using the PPA mechanism as a way to increase efficiency in the energy acquisition process and to support the development and availability of the generation required to supply the energy demand.

Firm capacity purchases through PPAs have been one of the drivers for securing the demand supply in the long term. Both Firm Capacity spot transactions and Firm Capacity contract transactions aim to provide long-term signals for the development of the required offer.

Particularly, long-term PPAs with a Firm Capacity requirement have been shown to be an efficient way to provide stable conditions for new generation development by reducing the volatility risk of spot transactions. For the purpose of this guide, the focus is on Firm Capacity and its elements that interact with PPAs.

As observed in the country case, the recognition of Firm Capacity for wind and solar PV generation increases the competitiveness of the projects by reducing the price of energy per megawatt-hour and lowering the risk for wind and solar PV development.

The concept of Firm Capacity associated with PPAs can determine the firm offer requirement that energy buyers need to cover and can have an impact on the potential development of the different projects and technologies. The possibility of selling Firm Capacity through a PPA can affect the competitiveness of the different technologies in supplying the demand.

Therefore, according to best practices in the region and in the world, it is important to have a clear definition of the concept of Firm Capacity and clear methodologies to recognise Firm Capacity in different technologies.

This section will provide some key guidelines for the commercial use of Firm Capacity. This applies for countries with wholesale electricity markets in place and countries with a single buyer model.

The definition of Firm Capacity should include or consider:

- How to represent the capacity of the offer to secure the supply of the demand during critical conditions of the power system.
- How the system's critical condition is defined. This critical condition must represent the moments in which the system's security of supply shows a higher risk (lower firm margin).
- How the structural condition of the country's power sector is incorporated. Systems with large amounts of flexible generation (hydroelectric, storage, etc.) but high dependency of meteorological conditions are different from systems with high shares of dispatchable generation (manageable) but with strong technical operative constrains (ramps). The definition of Firm Capacity must include these characteristics of each system.

In regional markets, like MER, a standard and uniform definition within the different countries is critical to facilitate international transactions.

Nowadays, practices show methodologies in which each technology should have a specific calculation. Specifically for wind and solar PV, it is important to take into consideration the following elements to assign an adequate Firm Capacity value:

- The critical period (time during the year when the system is the most constricted due to the availability of the sources used to generate electricity) is a key element to consider in the methodology. In a system with a high share of optimisable flexible generation (like hydroelectric), the injection of solar PV and wind provides the system the possibility to store energy for the critical conditions, allowing a higher contribution from hydroelectric generation that would not be possible without the contribution of solar PV and wind.
- The variability of solar PV and wind generation in terms of the energy production within a year is low in comparison with alternative renewable technologies like hydroelectric. The differences between a P99 and a P50 (probability of exceedance) for solar PV and wind are typically lower than for hydroelectric. In a system with high levels of hydroelectric generation, this contribution is high because it increases the security of supply during critical conditions (dry years).

As of late, discussions are shifting from a specific calculation for each technology to a single methodology for all technologies that aims to capture the real contribution of each technology (and the synergies between them) to the reliability of the energy supply. The benefits of a unique single are:

- Allows the competition of different technologies under similar conditions.
- Does not discriminate against any technology. Once the critical conditions are defined, with the proper modelling tools the methodology can capture the real contribution of each asset to the sufficiency of the system (by comparing the capacity for supplying the demand with and without the asset).
- Captures the specific characteristics of each system by representing the flexibility of the generation mix and the operative restrictions of the generation fleet.
- Allows harmonisation of the methodologies within the regional market, which can incentivise Firm Capacity transactions between markets.

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ANNEX I: CENTRAL AMERICA LEGAL FRAMEWORK AND INSTITUTIONAL LANDSCAPE

Table A1 Energy sector institutions by country

COUNTRY	POLICY MARKER	REGULATOR	SYSTEM AND MARKET OPERATOR
Belize	Ministry of Energy, Science & Technology and Public Utilities	Public Utilities Commission	No market; Belize Electricity Limited (BEL) as system operator
Costa Rica	Ministry of Environment and Energy (Energy Sector Directorate)	Public Services Regulatory Authority (ARESEP)	No market: Energy Control National Centre (CENCE, owned by Costa Rican Institute of Electricity [ICE]) as system operator
El Salvador	Energy National Commission (CNE (ES))	Electricity and Telecommunications General Superintendency (SIGET)	Transactions Unit (UT)
Guatemala	Ministry of Energy and Mines	Electricity National Commission (CNEE)	Wholesale Market Administrator (AMM)
Honduras	Secretary of State in the Energy Dispatch	Electricity Regulator Commission	Independent System Operator (ODS), shifting to National Electricity Energy Company (ENEE)
Nicaragua	National Energy Commission	Nicaraguan Energy Institute (INE)	National Dispatch Centre (CNDC)
Panama	National Energy Secretariat	Public Services National Authority (ASEP)	Dispatch National Centre (CND, owned by Electricity Transmission Company [ETESA])

Table A2 Main characteristics of the power sector structure in Central America countries

COUNTRY	GENERATION	TRANSMISSION	DISTRIBUTION & RETAIL	ELECTRICITY MARKET	MODEL
Belize	State owned plus IPP	State owned	State owned	None	Single buyer model
Costa Rica	State owned plus IPP	State owned	State owned	None	Single buyer model
El Salvador	Liberalised	State owned	Private (regulated segment); traders in the free segment	Energy market; Firm Capacity regulated payment	• Wholesale electricity market model • Bilateral and regulated contracts • Cost-based power pool
Guatemala	Liberalised	Mix of state owned and private (regulated segment)	Private (regulated segment); traders in the free segment	Energy and Firm Capacity markets	• Wholesale electricity market model • Bilateral and regulated contracts • Cost-based power pool
Honduras	Partially liberalised	State owned	Private	Energy market; Firm Capacity regulated payment	• Wholesale electricity market model (under revision) • Bilateral and regulated contracts • Cost-based power pool
Nicaragua	Partially liberalised	State owned	Private	Energy market (with cap prices); Firm Capacity regulated payment (government intervention)	• Wholesale electricity market model (with government intervention) • Bilateral and regulated contracts. • Cost-based power pool
Panama	Liberalised	State-owned	Private	Energy and Firm Capacity markets	• Wholesale electricity market model • Bilateral and regulated contracts • Cost-based power pool

Table A3 Existing regulatory framework for variable renewable energy in each country

COUNTRY	ELECTRICITY LAW	SPECIFIC REGULATIONS FOR VRE
Belize	• Law 13 (1992) Electricity Law • Law 40 (1999) Creation of the Public Utilities Commission	N/A
Costa Rica	• Law 449 (1949) Creation of ICE • Law 7200 (1990) Contracts with ICE • Law 7508 (1995) Contracts with ICE BOT scheme • Law 7593 (1996) Creation of ARESEP	N/A
El Salvador	• General Electricity Law (1996) • Joint Agreement N°. 1/2007/SC/SIGET Transition period. Price calculation mechanism. • Agreement N°. 232-E-2008 Design of the Cost Based Pool Wholesale Electricity Market; Introduction of ROBCP rules • Decree 88 (2010) Electricity Law regulations	Decree 462 (2007) Incentives for VRE generation
Guatemala	• Decree 93 (1996) General Electricity Law	Decree 52 (2013) VRE incentives
Honduras	• Decree 404 (2014) Electricity Industry General Law • New Electricity Law (2022) approved by the Congress	• Decree 70 (2007) Promotion of VRE energy • Decree 138 (2013) Promotion of VRE energy; Modification of Decree 70
Nicaragua	• Law 272 (1998) Electricity Industry Law • Law 531 (2005) Market reform	• Law 532 (2005) Promotion of VRE Generation • Law 911 (2015) Assigned the Ministry of Energy and Mines to establish the list of reference prices for new power generation contracts from renewable sources • Resolution N°2-DGERR-002-2017 (maximum prices for VRE generation)
Panama	• Law 6 (1997) Electricity sector regulatory framework	• Decree 45 (2009) Promotion of hydroelectric and new clean energies • Law 44 (2004) Promotion scheme for renewables • Law 18 (2013) Incentives for wind • Law 37 (2013) Incentives for solar

Note: ARESEP = Public Services Regulatory Authority; BOT = Build, Operate and Transfer; ICE = Costa Rican Institute of Electricity; N/A = not available; ROBCP = Operative Regulations for the Transmission System and Wholesale Market Based on Productions Costs; VRE = variable renewable energy.

Table A4 Main characteristics of Firm Capacity in analysed countries

COUNTRY	CONCEPT	TYPE OF TECHNOLOGY	PERIODICITY	REGULATION
Belize	N/A	N/A	N/A	No norm
Costa Rica	N/A	N/A	N/A	No norm
El Salvador	Firm final capacity	All technologies	Yearly	Norm ROBCP
Guatemala	Firm efficient offer	Thermal, hydroelectric, geothermal and wind power	Yearly	Commercial Coordination Norm N°2
Honduras	Firm capacity	All technologies	Yearly	Technical Norm for Firm Capacity
Nicaragua	Maximum contractable capacity	Dispatchable generation	Yearly	Operation Normative
Panama	Long-term Firm Capacity and commercial maximum capacity	All technologies	Yearly	Operation Rules Detailed Methodologies
Brazil	Physical guarantee	All technologies	Yearly	Portaria MME Nº 101 Portaria MME n ° 41 EPE Procedures
Chile	Sufficient final capacity	All technologies	Yearly	Supreme Decree 62 Technical Norm of Power Transfers between Generating Companies Exempt Resolution 54
Peru	Firm energy	All technologies	Yearly	Technical Procedures 13, 26, 30 and 36
	Firm capacity	All technologies	Monthly	
Mexico	Capacity	All technologies (classified in firm and intermittent)	Yearly	Electricity Market Rules

Source: AMM, 2022a; CENACE, 2015; CND, 2022a; CNDC, 2022; CNE, 2022; COES, 2022; CREE, 2021; EPE, 2022b; UT, 2022.
Note: N/A = not available; ROBCP = Operative Regulations for the Transmission System and Wholesale Market Based on Productions Cost; EPE = Energy Research Office

Table A5 Summary of existing Firm Capacity definitions

COUNTRY	DESCRIPTION
Belize	As a vertically integrated system, there is no Firm Capacity nor capacity market.
Costa Rica	As a vertically integrated system, there is no Firm Capacity nor capacity market.
El Salvador	Firm capacity is the capacity that a power plant can guarantee in critical supply. It is calculated using the process described in the Operative Regulations for the Transmission System and Wholesale Market Based on Productions Cost (ROBCP), including an initial recognition, provisional and definitive Firm Capacity, adjusted to fit the demand curve. The definitive Firm Capacity is the capacity that can be negotiated with distributors or traded in the spot capacity market.
Guatemala	The Firm Capacity of a generating unit is the maximum net capacity, discounting internal consumption, that a power plant can generate, based on its technical characteristics, maximum capacity, availability and considering the restrictions of the transmission grid. The efficient Firm Capacity is the maximum Firm Capacity that can be sold to cover the Firm Capacity demand of an agent. Firm capacity can be traded through contracts or through the capacity deviations balance mechanism.
Honduras	Firm capacity is the capacity that a power plant can guarantee during the critical period of the system. It can be traded though contracts or through the monthly deviation settlement.
Nicaragua	Firm capacity is the effective capacity, discounting the average unavailability of the power generator, and the recognition is limited only to dispatchable generation. It can be traded through contracts or through the capacity deviations balance mechanism.
Panama	Firm capacity (long term) is the capacity that a power generation unit or plant is able to guarantee during the critical period (maximum offer requirement). It can be traded through contracts, the annual Long-Term Reserve Service tender or the daily deviations market.
Brazil	Firm capacity (physical guarantee) can be defined as the maximum demand that the power unit can supply with a certain probability of exceedance during critical conditions (dry year). It defines the maximum energy that a power plant can trade through contracts. There is no formal Firm Capacity market, but generators can trade physical guarantee through bilateral agreements.
Chile	Firm capacity (sufficiency capacity) is defined as the capacity to supply the peak demand, considering for each generating unit their unavailability, the unavailability of the natural resources and the unavailability of the unit's fuels (main and alternative). Generators may sell or buy sufficiency capacity either through contracts or to the capacity regulated balance.
Peru	Firm capacity is the capacity that can be supplied by a generator with high probability. Since 2019, variable renewable energy has been recognised with Firm Capacity. Generators may buy or sell Firm Capacity either through contracts or to the capacity regulated balance.
Mexico	Firm capacity refers to a commercial product that generators can trade and generates an obligation to secure the availability of physical production and offer the corresponding energy to the short-term energy market. Generators may trade Firm Capacity through contracts or in the capacity market.

Source: AMM, 2022a; CENACE, 2015; CND, 2022a; CNDC, 2022; CNE, 2022; COES, 2022; CREE, 2021; EPE, 2022b; UT, 2022.

ANNEX II: EQUATIONS

Guatemala

$$OF = \min\left(PP \cdot coefdisp, \frac{EF}{NHRM}\right)$$

Where:

OF = Firm Capacity

$\boldsymbol{PP}$ = Maximum power of the generating unit.

$\boldsymbol{Coefdisp}$ = Availability factor of the generating unit.

$\boldsymbol{EF_i}$ =Energy that can foreseeably be produced by the power plant in the stage of maximum thermal requirement. The generator shall supply and substantiate this foreseeable energy with a 95% exceedance probability.

$\boldsymbol{NHRM}$ =Number of hours of the stage of maximum thermal requirement. The duration of the stage shall be the same as that used as the basis for determining the long-term planning.

$$OF = PP \cdot coefdisp$$

Where:

$\boldsymbol{PP}$ =Maximum power of the generating unit.

$\boldsymbol{Coefdisp}$ =Availability factor of the generating unit.

$$OF = PPR \cdot coefdisp$$

Where:

$\boldsymbol{PPR}$ =Power that the generating unit guarantees will be able to supply to the grid throughout the seasonal year based on the minimum availability of the renewable fuel declared by the agent.

$$coefdisp = \frac{HD + HMP - HED}{HD + HIF + HMP}$$

Where:

$\boldsymbol{HD}$ = Hours of availability.

$\boldsymbol{HMP}$ = Hours of scheduled maintenance, including minor and major maintenance.

$\boldsymbol{HIF}$ = Hours of forced outage.

$\boldsymbol{HED}$ = Equivalent hours per degradation when the unit is available (regardless of the availability of water in the case of hydroelectric plants), calculated as follows:

$$HED = \sum_{i=1}^{N} \frac{PP - PD_i}{PP}$$

Where:

$\boldsymbol{PP}$ = Net maximum power.

$\boldsymbol{PD_i}$ = = Net available power in hour $\boldsymbol{i}$ (regardless of the availability of water in the case of hydroelectric power plants and without considering the operation requirements that the Wholesale Market Administrator may have).

$\boldsymbol{N}$ =Number of hours in the calculation period.

Honduras

$$F = D \times K$$

Where:

$\boldsymbol{F}$ = Firm capacity of the power plant.

$\boldsymbol{D}$ = Annual availability factor of the power plant.

$\boldsymbol{K}$ = Effective capacity of the power plant in **kW** or **MW**. The effective capacity is the maximum power that a power plant can supply to the grid considering the local temperature and pressure conditions, the plant's self-consumption and any other restriction of its generation units.

The System Operator determines the availability factor as:

$$D = 1 - \Delta D$$

Where:

$\boldsymbol{\Delta D}$ = Reduction of availability of the power plant during the year in study.

The reduction of availability is finally calculated as:

$$\Delta D = \sum_{i=1}^{4} \Delta D_i = \sum_{j=1}^{n_1} \frac{H_{1j} \times \frac{R_{1j}}{K}}{HT} + \sum_{i=2}^{4} \sum_{j=1}^{n_i} \frac{H_{ij} \times \frac{R_{ij}}{K}}{2 \cdot HT}$$

Where:

$\boldsymbol{\Delta D_i}$ = Reduction of availability due to situation $\boldsymbol{i}$.

$\boldsymbol{n_i}$ = Number of times that there will be power capacity reduction due to situation $\boldsymbol{i}$.

$\boldsymbol{H_{ij}}$ = Number of hours that there will be power capacity reduction in the $\boldsymbol{j-th}$ occasion due to situation $\boldsymbol{i}$.

$\boldsymbol{HT}$ = Total number of hours in the year.

$\boldsymbol{R_{ij}}$ = Power capacity reduction in the $\boldsymbol{j-th}$ occasion due to situation $\boldsymbol{i}$.

Peru

$$Ef_{CT} = \frac{\sum_{i=1}^{N}[\sum_{k=1}^{12}(Pe_i \cdot T_k)\,(1 - IM_{ik})(1 - IF_{ik})]}{1000}$$

Where:

$\boldsymbol{Ef_{CT}} =$ Annual firm energy of the thermal power plant in $\mathbf{GWh}$.

$\boldsymbol{Pe_i} =$ Effective capacity of generating unit $\boldsymbol{i}$ in $\mathbf{MW}$.

$\boldsymbol{T_k} =$ Number of hours in month $\boldsymbol{k}$.

$\boldsymbol{If_{ik}} =$ Forced unavailability of generation unit $\boldsymbol{i}$ in month $\boldsymbol{k}$.

$\boldsymbol{IM_{ik}} =$ Planned unavailability for maintenance of generation unit $\boldsymbol{i}$ in month $\boldsymbol{k}$.

$\boldsymbol{N} =$ Number of units that constitute the thermal power plant.

$$PF_T = P_{eft} \cdot (1 - FIF)$$

Where:

$\boldsymbol{PF_T}$== Firm capacity

$\boldsymbol{P_{eft}}$== Effective capacity of the unit.

$\boldsymbol{FIF} =$ Monthly incidental unavailability factor of the unit.

$$EG_i = min\{R \cdot (VDT_i + V_i), EMG_i\}$$

Where:

$\boldsymbol{R} =$ Production factor in MWh/m3.

VDTi = dispatch water volumes (m3)

Vi = intermediate discharge (m3)

EMGi = Maximum energy that can be generated

The methodology to calculate guaranteed energy is different for seasonal reservoirs and hourly reservoirs.

ANNEX III: EL SALVADOR CASE STUDY

In order to analyse the financial implications that recognising Firm Capacity has on PPA contracts, El Salvador was selected as a basis to develop a modeling exercise. The outcomes of this analysis have been previously described, with more details on the related calculations provided in the following segment.

METHODOLOGY

These are the actions implemented to compare investment opportunities based on Firm Capacity recognition for wind and solar projects:

1. Assessment of generic solar photovoltaic (PV) and wind projects based on the national planning process, with inputs including location, technology, estimated selling price, and committed energy level.

2. Estimation of the potential energy production of selected projects, with an hourly resolution, using TSL Series data.

3. Further inputs, such as:

    - hourly balance between potential power production and committed energy through the power purchase agreement (PPA)
    - project finance assumptions, including operating costs, investment costs, the weighted average cost of capital and the loan structure
    - energy market assumptions, such as future wholesale electricity prices
    - potential PPA specifications, such as awarded tariff level, balancing requirements and penalties
    - contractual strategies for the PPA, in line with the current regulatory framework, which requires generators to deliver all energy at the price established in the PPA to the off-taker (in this case, the distribution company), without engaging with the wholesale market.

The financial model evaluated each project, drawing on key financial performance indicators such as internal rate of return (IRR), economic internal rate of return (EIRR), debt-service coverage ratio and payback period, to determine overall investment incentives.

a Site and energy production

For the exercise in question, two projects (presented in *Table 1*), were selected for replication.

Wind and solar case study projects

Data on the available wind and solar resources were obtained from the TSL Series hourly data by PSR (2022) for each site location and adjusted according to the conclusions of IRENA's "Utility scale solar and wind projects – El Salvador" report.

Table A6 Study case projects characteristics

	SOLAR	WIND
Source	TSL Series 2.0	TSL Series 2.0
Resolution	Hourly	Hourly
Inclination / height	15°	120 m
Longitude	–87.9°	–89.4°
Latitude	13.3°	14.4°
Avg. resource	Global incident irradiation on the tilted coll. plane: ~2 100 kWh/m²	Mean wind speed: ~7.7 m/s
Model	Monocrystalline 1-Axis	V136-3.45
Nominal capacity	30 MW	30 MW

Figure A1 Solar PV project – average hourly profile

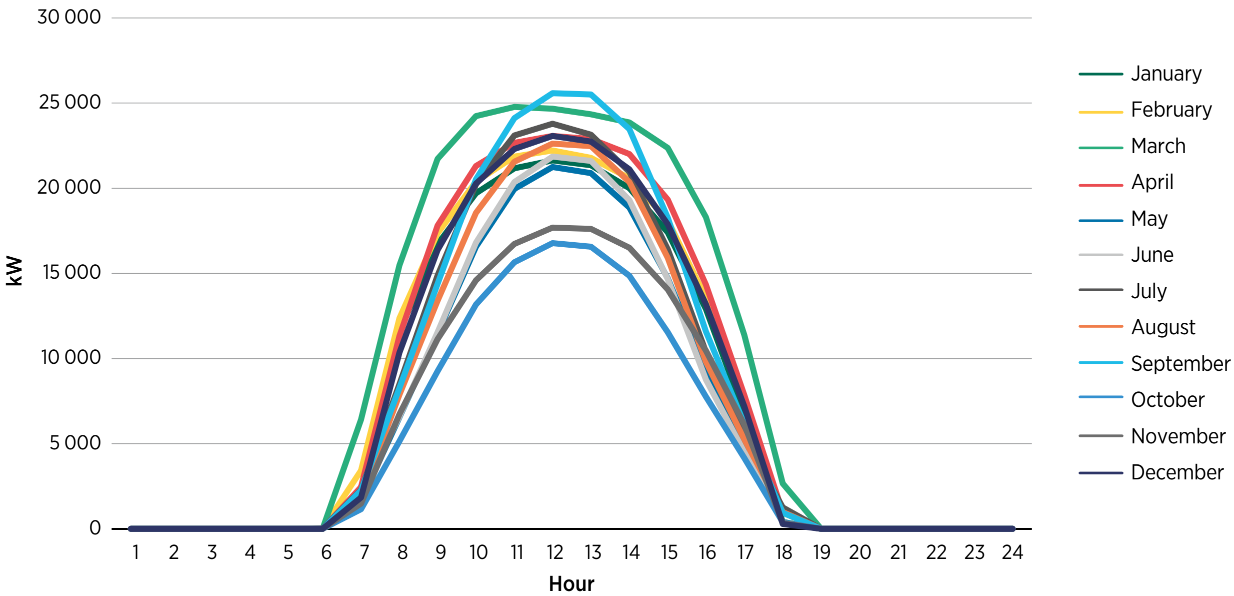
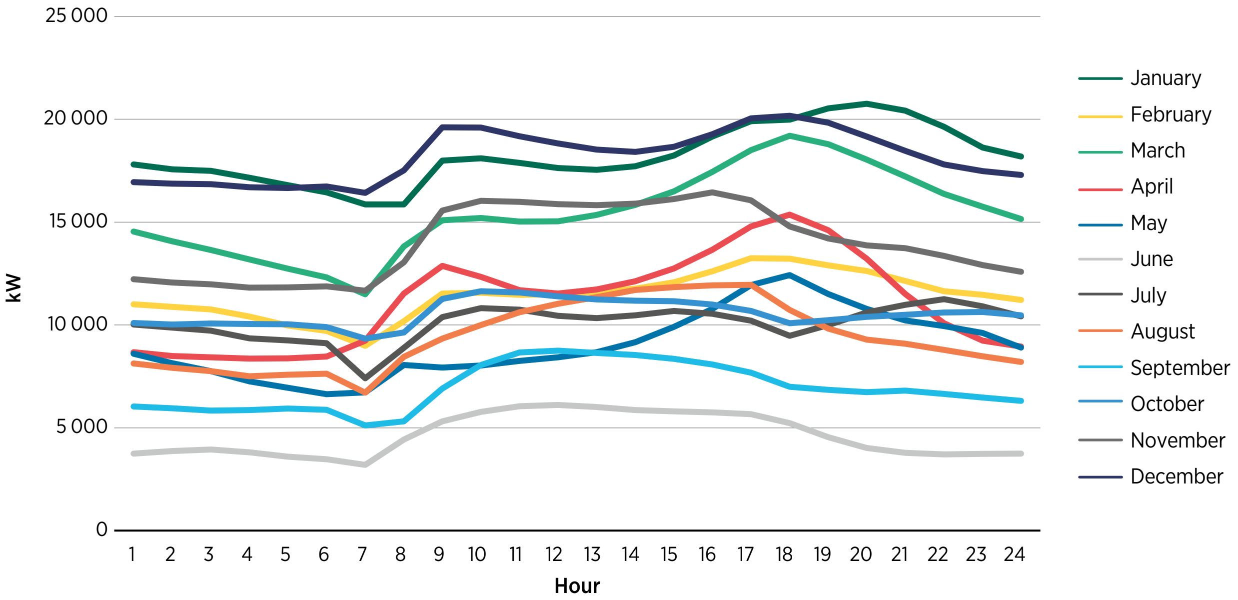


Figure A2 Wind project – average hourly profile



b Economic and financial modelling

The following sections present the main inputs, assumptions and results from the financial returns of solar and wind projects under various PPA scenarios.

i Main inputs and assumptions

Table A7 Case study inputs

	WIND	SOLAR
Installation		
Construction time	1 year	1 year
Technical lifetime	30	30
Interest during construction	15%	15%
Investment and operation and maintenance		
Investment costs	1.583 USD m/MW	1.1 USD m/MW
Operation costs	55 USD/kW-year	9.5 USD/kW-year
Equity financing		
Cost of equity	12%	12%
Financing share	30%	30%
Senior loan financing		
Financing share	70%	70%
Interest rate	7%	7%
Resulting weighted average cost of capital (WACC)		
WACC	8%	8%
Taxes		
Corporate income tax	30%	30%
Deduction in interest	100%	100%
Depreciation		
Method	Straight line	Straight line
Rate	10%	10%
Cash reserves		
Interest on cash	2%	2%
Minimum cash	USD 1 000 000	USD 1 000 000
Required debt service reserve account	12 months	12 months

ii PPA contract types

Evaluated PPA contract structures:

- **Load-following PPA contracts:** Balancing risks are absorbed by the developer.
- **Monthly power curves bidding:** The supplier commits to delivering the energy described by a power curve that specifies the energy delivered for each hour in a 24-hour cycle. To capture seasonal variation, a unique power curve is determined for each month of the year. Balancing risks are absorbed by the developer.
- **Annual power curve bidding:** The supplier commits to delivering energy that correlates to a predetermined power curve specifying the amount of energy delivered for each hour in a 24-hour cycle. The same power curve is applied for the entire year. Balancing risks are absorbed by the developer.
- **Time block bidding:** The 24-hour cycle is divided into three blocks: night, day and peak. This is similar to the annual power curve bidding strategy; however, "block bidding" is a contract scenario where the focus is on three individual blocks of hours, which is beneficial to resources that produce more energy during sunlight hours (such as solar PV). The supplier commits energy for each hour in active time blocks and balancing risks are absorbed by the developer, but only for a specific block of hours.
- **Minimum guaranteed price bidding:** The supplier sells all energy on the wholesale market, but the PPA provides a minimum guaranteed price. If the wholesale price is lower than the guaranteed price, the PPA pays the difference between the wholesale price and the guaranteed minimum price. If the wholesale price is higher than the guaranteed minimum price, the PPA does not pay. This PPA type removes the balancing risk from the developer.

iii Firm capacity recognition types

Firm capacity recognition methodologies evaluated:

- No recognition.
- **Current methodology:** Current Salvadorian methodology.
- **Peak demand contribution methodology:** Injection during the hours of higher demand (similar to the Chilean methodology).
- **Critical hours contributions:** Injection during the hours of higher demand (similar to the methodology used in Mexico).

iv Main outcomes of the implementation of different PPAs and Firm Capacity recognition methodologies

The following tables present the main results through IRR, EIRR, break even and potential PPA energy price for different combinations of technologies, types of PPA and Firm Capacity recognition methodologies.

Table A8 Wind projects – case results

TECHNOLOGY	WIND TURBINE							
PPA Strategy	**PPA Type**	**Firm Capacity Recognition**	**Firm Capacity Firmness** %	**IRR** %	**EIRR** %	**Break Even** years	**PPA Energy Price** USD/MWh	**% of Revenues from PPA** %
Sell all at PPA price	100% production	No recognition	0.0%	9%	12%	10.3	78.4	100%
Always deliver 100%	Load-following PPA	No recognition	0.0%	9%	12%	10.3	78.0	53%
Sell all at PPA price	100% production	Salvadorian methodology	20.1%	9%	12%	10.3	72.8	100%
Always deliver 100%	Load-following PPA	Salvadorian methodology	20.1%	9%	12%	10.3	70.5	49%
Sell all at PPA price	100% production	Peak demand	33.6%	9%	12%	10.2	69.0	100%
Always deliver 100%	Load-following PPA	Peak demand	33.6%	9%	12%	10.3	65.5	46%
Sell all at PPA price	100% production	Critical hours	40.0%	9%	12%	10.2	67.2	100%
Always deliver 100%	Load-following PPA	Critical hours	40.0%	9%	12%	10.3	63.1	45%

EIRR = economic internal rate of return; IRR = internal rate of return; PPA = power purchase agreement.

Table A9 Solar PV – case results

TECHNOLOGY	SOLAR PV							
PPA Strategy	**PPA Type**	**Firm Capacity Recognition**	**Firm Capacity Firmness** %	**IRR** %	**EIRR** %	**Break Even** years	**PPA Energy Price** USD/MWh	**% of Revenues from PPA** %
Sell all at PPA price	100% production	No recognition	0.0%	9%	12%	10.1	75.5	100%
Always deliver 100%	Load-following PPA	No recognition	0.0%	9%	12%	10.3	77.1	35%
Sell all at PPA price	100% production	Salvadorian methodology	14.7%	9%	12%	10.1	68.6	100%
Always deliver 100%	Load-following PPA	Salvadorian methodology	14.7%	9%	12%	10.3	67.9	29%
Sell all at PPA price	100% production	Peak demand	21.6%	9%	12%	10.1	65.4	100%
Always deliver 100%	Load-following PPA	Peak demand	21.6%	9%	12%	10.3	63.5	25%
Sell all at PPA price	100% production	Critical hours	11.0%	9%	12%	10.1	70.3	100%
Always deliver 100%	Load-following PPA	Critical hours	11.0%	9%	12%	10.3	70.2	30%

Note: EIRR = economic internal rate of return; IRR = internal rate of return; PPA = power purchase agreement; PV = photovoltaic.

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