Power Sector Planning in LAC countries

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POWER SECTOR PLANNING IN LAC COUNTRIES

IDB

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CONTENTS

1

INTRODUCTION: WHY DO COUNTRIES NEED TO PLAN FOR EXPANSION OF THE ELECTRICITY SECTOR?

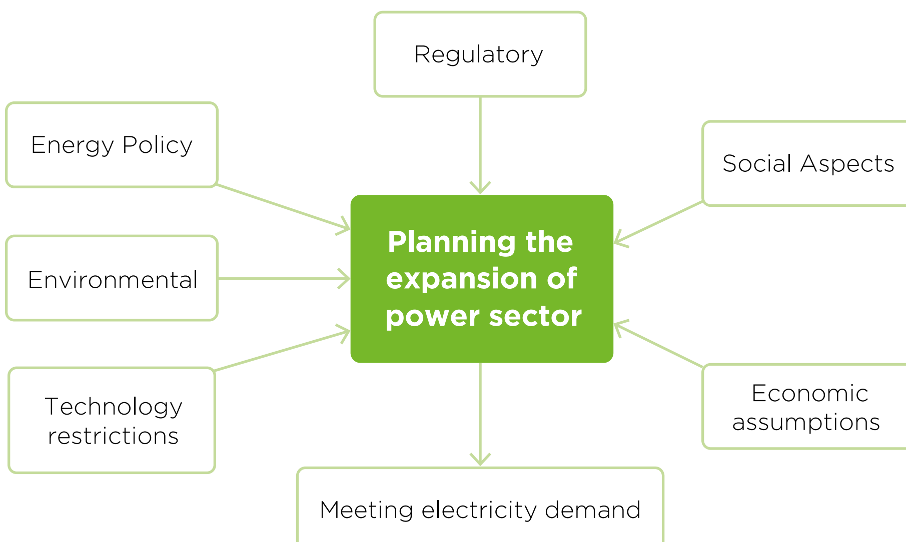
Power system planning is a fundamental activity for the energy sector. It helps to anticipate potential challenges and to identify suitable preventive solutions. Long-term generation plans, over the course of 20-30 years, are central instruments that work with quantitative scenarios and targets for the generation mix that meets a country's policy goals. The way this planning will impact on the investments in each country depends on its market design, the people in charge of planning, and the relation of this agency with those players deciding on the investment. Often these expansion plans are guidelines to private and/or public stakeholders on the decisions of when, where and how to invest in the energy sector.

The expansion plans for an electricity generating system have to take into consideration the energy mix by type of generation, i.e., nuclear, coal-fired, oil-fired, natural gas turbines, renewable energy sources. Moreover, it is important to consider the size (MW) and the schedule of the generating units to be installed in the system, in order to meet the growing demand for power and energy over time.

The power system planning process involves the interaction of different types of information about the electricity industry and the expectation of how the electricity demand will evolve in the future. In order to gather all this information, the planning institution should be able to bring together diverse stakeholders from utility companies, government agencies, industry and academy to discuss the country´s energy future. Thus, it can become a tool that summarizes the nation´s energy goals focused on its energy policy, social aspects and environmental policies, together with technical and economic constraints to meet the forecasted electricity demand[1], see Figure 1.

1. Historically, the electricity demand has been a separate issue from generation. New technologies of small-scale generation have changed this dynamic, increasing the complexity of this historical separation. Besides that, new technologies, such as energy efficiency and demand management has increased the complexity of the separation and the forecast of energy demand.

Figure 1. Planning the expansion of power sector systems



Source: Authors' elaboration.

In this study we will review the characteristics of different Power System Planning Models (PSPM), the input variables that feed the forecasting scenarios, their historical deviation and how these models are adapting to face the uncertainty attached to the new wave of innovative technologies and the intermittency of non-conventional renewable energy power plants.

The technical note proceeds as follows. Section 2 evaluates the deviation of past projections and describes the types of forecasting deviations. Section 3 explores the most used Power System Planning Models in the region and presents the regulatory and institutional frameworks concerning power system planning in the countries of the region. Section 4 analyzes how the energy planners are modeling the new technologies, particularly how they are adapting to face the volatility attached to non-conventional renewable sources, and finally the section of conclusions.

2

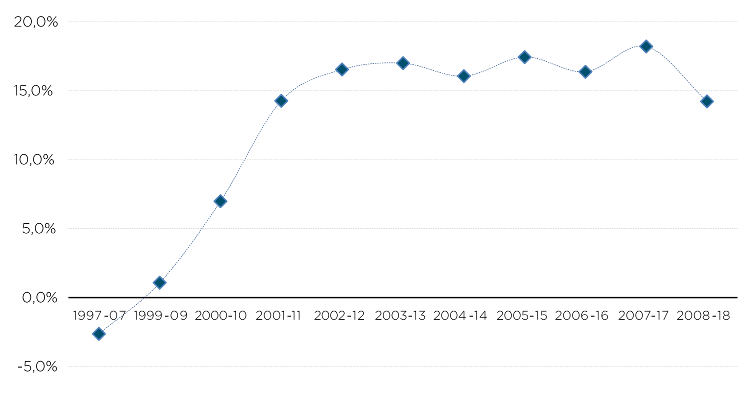
WHY WAS THE HISTORICAL FORECAST OF ELECTRICITY SUPPLY NOT ADJUSTED CLOSER TO REALITY?

Medium-to-long term electricity supply projections play a role in guiding a national power system strategy and policy, but could also lead to serious economic distress when poorly executed. As O'Neill and Desai (2005) have pointed out: "evaluations of the deviation of past projections can provide insight into the uncertainty that may be associated with current forecasts. They can also be used to identify sources of deviation and potentially lead to improvements in projections over time". As an example, this section compares the projections of USA´s electricity supply produced by the Energy Information Administration (EIA) over the period 1997-2018 with the real electricity supply in the same period. We found that electricity supply projections have tended to overestimate future generation demand. Projections 10 years ahead into the future have had an average overestimation error of about 15 %, these errors are much larger when evaluating the generation projection by type of technology.

All predictions are made upon the basic assumptions of several major drivers, including economic and population growth, energy prices, technology advancements and government policies. Liao et al. (2016) found that forecasting errors are driven by three major assumptions. First, using IEA's energy demand projections, the authors found that GDP projections alone account for a 13.1% projection bias in energy demand forecast. Second, oil price projections have a negative relationship with forecasting errors, which means that an overestimation of oil prices will lead to underestimate energy demand in the future. Third, the authors found that population projections fail as a major prediction factor, leading to errors in forecast demands.

The Annual Energy Outlook is published by the Energy Information Agency (EIA) of the United States of America (USA) and provides long-term energy projections of electricity demand and supply for the USA. In order to quantitatively measure the deviation of EIA's historical projections, we calculated the percentage error which measures the proportional error (difference between projected electricity supply and actual energy supply as a ratio of the observed value) at a point in time. Figure 2 shows the percentage error of 10-year electricity supply projections. For instance, the marker in 2000-10 indicates that 2000's projection of 2010 electricity supply was 7% larger than the current value in 2010. We observed that EIA's projections have tended to overestimate the future electricity generation 10 years ahead.

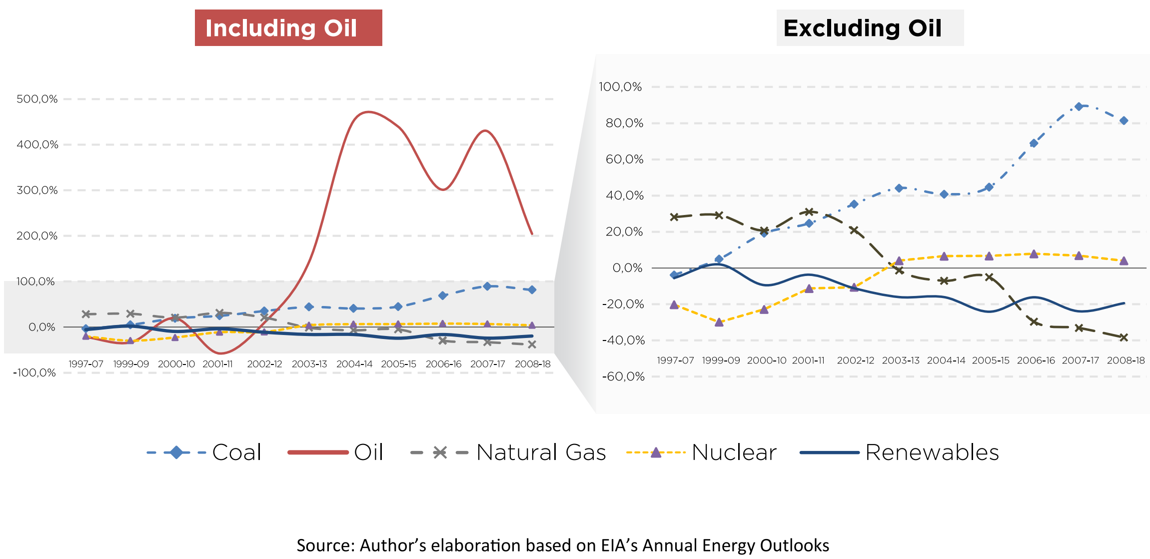
Figure 2. Percentage error in projected electricity supply



Some findings were astonishing when comparing the different percentage errors by type of technology. EIA calculated long-term electricity supply by type of technology, when the generation of oil power plants was consistently overestimated after 2002, (see Figure 3). In many cases, this error is explained by an overestimation of the electricity demand, but it is also related with the expected technological choice of electricity supply. In a following section, we explore how policymakers have emphasized the aftermaths of overestimating and underestimating input variables of an expansion plan. Concerning the rest of the technologies, we observed different patterns: electricity generation from cleaner sources such as renewables and natural gas were underestimated during the analysis period. About this fact, we observed an inflexion point at 2003-13, since projections before 2003 had always overestimated the so-called "transition energy source", but later it became an underestimation. The electricity generation from coal power plants tended to be overestimated, which means that EIA always expected to use more coal in the future. Finally, the percentage error estimated for nuclear power plants is the smallest among all technologies and remains constant over time [2].

2. When comparing the projections with the observed values, the literature has recognized different types of errors. The most relevant to users is the visible error, in our case the percentage error, which indicates the difference between the expected participation of a technology in the energy mix and the observed value. But to understand the source of the visible error, it is useful to examine invisible errors, i.e. components of the visible error whose combined effect produces the net visible error (Bulatao, 2001). The invisible error has three components: i) baseline error; ii) trend error; iii) and variability. The baseline error captures errors in the initial estimates for energy consumption in the base year. Projections that begin with inaccurate estimates of consumption in the base year are likely to project future consumption inaccurately, even if the model is otherwise very accurate. The trend error measures the deviation of the projection from the historical trend. Models used to project consumption or electricity supply are designed to project longer-term trends in consumption, not inter-annual variability. The variability error captures the deviation of actual electricity supply from the historical trend. This error is independent of the projection, it is determined only by the difference between actual consumption and the historical trend.

Figure 3. Percentage error in projected electricity supply by technology



Source: Author's elaboration based on EIA's Annual Energy Outlooks

Many scholars have also found similar results in other energy variables projected by EIA. O'Neill and Desai (2015) analyze EIA's energy forecasts between 1982 and 2000 and prove that 10 to 13 year forecasts have an average error of about 4%, while shorter time horizons are half as much. Fischer et al. (2009) found an average of 2% per year underestimation of total energy demand based on EIA's Energy Outlook. Using EIA's projections, Auffhammer (2007) provides empirical evidence that forecasts of oil, coal, natural gas consumption, energy intensity and gas prices are shown to be consistent with highly asymmetric loss functions.

3

POWER SECTOR PLANNING IN LATIN AMERICAN AND CARIBBEAN (LAC) COUNTRIES

This section explores the most used Power Sector Planning Models in the region and presents a critical view of the performance of each of them. Also, the section presents the legal and institutional framework in charge of the elaboration of the expansion plans in each country. The main objective is to identify which countries have a regulatory framework that support the energy planning process, the local institutions responsible for making the expansion plans, and the frequency and planning horizons established in it.

3.1 Regulatory and Institutional Framework in LAC countries

A good international benchmark, for example, is the Annual Energy Outlook (reviewed in the last section), published according to the Department of Energy Organization Act of 1977, which requires the EIA to prepare annual reports on trends and projections for energy use and supply in the USA.

In the LAC region the reality is different: on one hand, there are still several countries that do not have a power system planning unit or, even if they have one, it was recently created and lacking experience. Based on this, the Ministry of Energy must initiate a process of long-term expansion plan with a horizon of at least thirty years.

Table 1 depicts the regulatory framework and the institutions in charge of issuing the expansion plans for each country in the region. Most of them are energy units inside the Ministry of Energy or the Ministry itself who elaborate the expansion plan.

A common characteristic of all the issued laws was the creation of a specialized unit in charge of power system planning; for example, in Nicaragua the 12th article of the Electricity Industry Law enforces the National Energy Commission (CNE) to design the sector´s policy and planning. This leads the CNE to prepare, review and periodically evaluate the strategic plan of the energy sector. In Argentina, the law stipulates that the Energy Planning Unit has the objective of: i) assisting the Minister of Energy and Mining in the design of strategic planning of energy resources, ii) evaluating the energy balance of the country and the projections of demand, supply, and other factors that make possible an adequate planning of the use of energy resources, iii) developing policies aimed at improving the country's energy balance, diversifying the supply or optimizing the demand for the different primary sources available, iv) participating in the development, economic evaluation and construction of energy projects that are defined by the National Government. However, the law does not mention how often the forecasts should be published or updated. In other cases, as in Chile, Article 83 of the General Law of Electricity Services, in matters of power system planning, states that every five years the Ministry of Energy must initiate a process of long-term expansion plan with a horizon of at least thirty years.

Table 1. Regulatory and legal framework

Country	Institution	Regulatory / Legal Framework	Issuing Date
Argentina	Subsecretaria de Planeamiento Energético Estratégico (MEM)	Decreto 231/2015 (Modificación al Decreto 357/2002)	2015
Bahamas	X		
Barbados	X		
Belize	X		
Brazil	Secretaria de Planejamiento e Desenvolvimiento Energetico	Ley n ° 10.847	2004
Bolivia	Ministerio de Energía y Minas	Ley No. 1604	1994
Chile	Ministerio de Energía	Ley General de Servicios Eléctricos Reglamento Núm. 134	2016
Colombia	Unidad de Planeación Minero-Energética	Ley 143	1994
Costa Rica	Instituto Costarricense de Electricidad	Ley General de Electricidad	2010
Dom. Rep	X		
Ecuador	Ministerio de Energía y Recursos Naturales No Renovables	Ley Orgánica del Servicio Público de Energía Eléctrica	2015
El Salvador	Consejo Nacional de Energía	Ley de Creación del Consejo Nacional de Energía	2007
Guatemala	Ministerio de Energía y Minas	Reglamento del Administrador del Mercado Mayorista (Acuerdo Gubernativo No. 69-2007)	2007
Guyana	X		
Haiti	X		
Honduras	Empresa Nacional de Energia Eléctrica	Ley General de la Industria Eléctrica / Reglamento de la Ley General de la Industria Eléctrica	2015
Jamaica	X		
México	Secretaría de Energía (Subsecretaría de Planeación y Transición Energética)	Ley de la Industria Eléctrica	2014
Nicaragua	Instituto Nicaragüense de Energía	Ley No. 272 Reglamento (Decreto No. 42-98)	1998
Panamá	Empresa de Transmisión Eléctrica S.A.	Ley No. 6 Decreto No. 22	1998
Paraguay	Administración Nacional de Electricidad	Ley No.966	1964
Perú	Ministerio de Minas y Energía	Ley General de Electricidad N. 23406	2006
Suriname	Ministry of Natural Resources	Electricity Act	2016
TTO	X		
Uruguay	Ministerio de Industria, Energía y Minería (Recientemente se asignó a la Dirección Nacional de Energía)	Ley No. 16.832	1997
Venezuela	Ministerio para el Poder Popular para la Energía Eléctrica	Ley Orgánica del Sector Eléctrico	2010

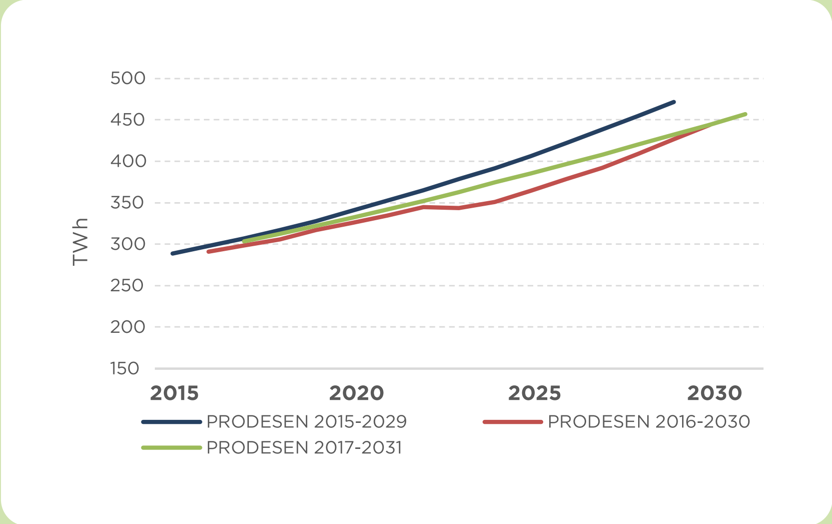
Source: Author's elaboration based on regulatory and legal schemes

As we saw in the previous section, the electricity supply projections in each expansion plan are not predictions of what will happen, but rather modeled projections of what may happen given certain assumptions. Therefore, the technicians should keep in mind that electricity forecasts are susceptible to variations in GDP growth, fuel costs and technological changes, which may have an impact on the investment requirements and economic choices. Planning the expansion of the electricity system should be an exercise frequently updated. In the following box we will review the case of Mexico and Brazil, two countries with a long history in power sector planning.

Box 1. Power System Planning in Mexico and Brazil

Mexico and Brazil are two countries with a long history of power system planning. Both countries have a specialized unit in charge of modeling and forecasting electricity generation needs for the whole economy. Nevertheless, the current generation matrix of each of them is completely different. In the case of Brazil, it required the development of its own energy model to fit its context. In Mexico, the Ministry of Energy (SENER) is responsible for forecasting and updating the electricity supply year by year and publishes the outcome in an annual publication (PRODESEN), which serves as a guide for investment in energy for the next 15 years. (See Figure 4).

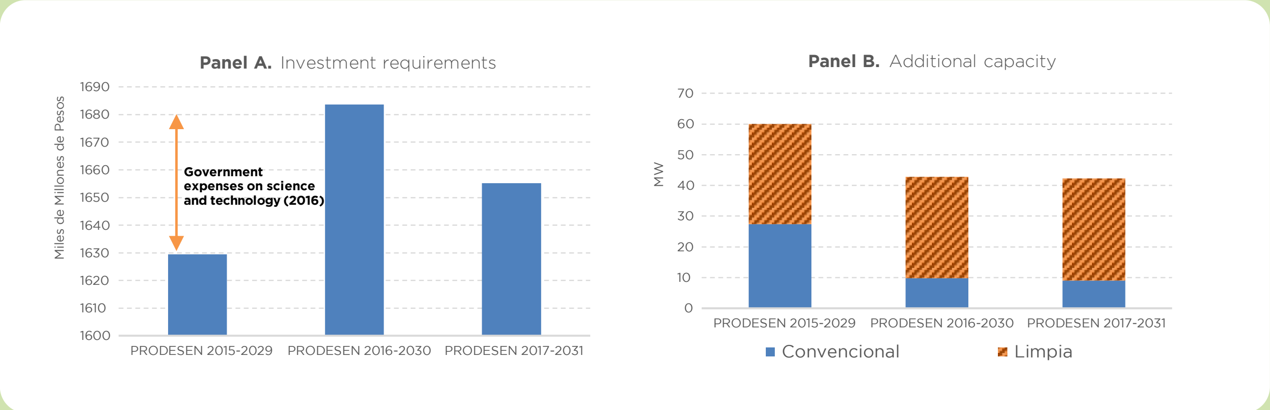
Figure 4. Mexico's electricity supply forecast



Source: Author's elaboration based on information from SENER.

Updating expansion plans in shorter time periods helps to anticipate potential challenges. Based on recent data, the amount of investment requirements from one year to another, PRODESEN 2015 to PRODESEN 2016, is comparable to the size of what government spends on science and technology in 2016. In terms of installed capacity, the difference between supply projections is about 20 MW. (Figure 5).

Figure 5: Year-by-year difference in each expansion plan

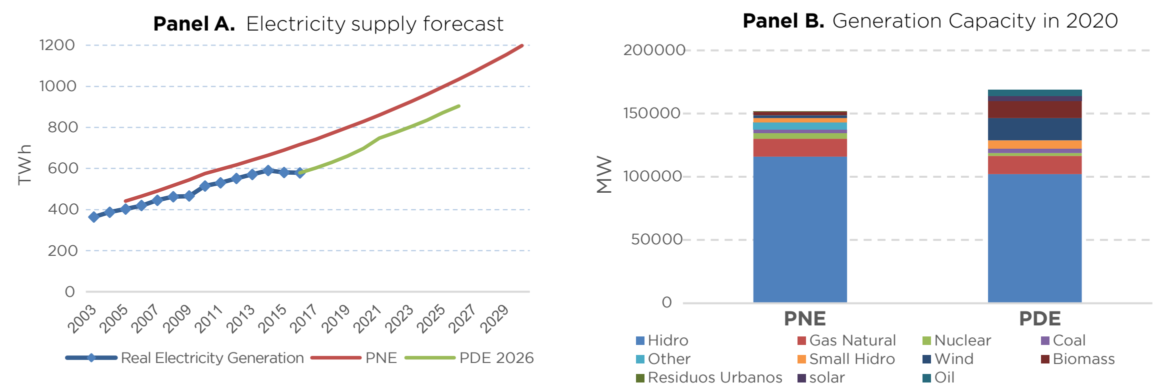


Source: Author's elaboration based on information from SENER

Box 1. Continued

On the other hand, Empresa de Pesquisa Energética (EPE) in Brazil publishes a ten-year energy plan (PNE) which updates every two years in a short terms energy plan (PDE). In Figure 6, Panel A shows the comparison of both projections with the real electricity generation (blue line). One advantage of constantly reviewing energy projections is the possibility of adapting these projections to the needs of the country.

Figure 6: Brazil's electricity supply forecast



Source: Author's elaboration based on Expansion Plans.

3.2 Power system planning models and computer tools used in LAC countries

The main objective of an expansion plan is to determine how the country will be able to provide affordable and reliable electricity in the future. According to Battle and Paredes (2014), a planning process consists of the following stages. First, the definition of a candidate plan : in this stage the energy planner defines a candidate plan, setting dates when investments are to be made and when generation and transmission equipment is to become operational. Second, the supply reliability analysis and reliability criteria, where the energy planner estimates the energy supply which would result from the implementation of the candidate plan. Subsequently, the acceptability of reliability indexes is checked against the planning criteria. Third, the energy planner should run an operational analysis of the candidate plan. In this step, the operation of the generation-transmission system is simulated for several scenarios, and equipment failures as well as operational indexes are calculated. Last, the planner compares his results against the reference plan. In this step, the energy planner compares the overall costs of the candidate plan against the reference plan.

Power sector planning is thus framed as an investment selection problem, from the point of view of the planner considering a set of restrictions. Energy planners have been using different tools to solve it. Bhattacharyya and Timilsina (2010) provide a comparative overview of existing power system models in terms of modeling approaches (supply and demand modules), input data requirements, flexibility to incorporate new end-uses, fuel and technology. However, most of these models were developed in industrialized countries to analyze a problem within a specific context, so their application in the context of developing countries could be fraught with difficulties. The authors argue that existing energy system

models inadequately capture the characteristics of developing countries, such as the extensive use of traditional energy sources, the transition of the population from traditional to modern markets, and the existence of multiple barriers to capital flow.

The scope of a power system model can vary due the diversity of the technologies and the complexity of the energy sector. Therefore, the following section aims to provide a brief review of different tools used by the countries of the region to plan the expansion of their energy system. For this purpose, first we categorized different energy models depending on their level of aggregation, planning horizon and computational procedure. Second, we explored the models used by the countries in each expansion plan and analyzed how the energy planners are adapting these models to the regional context.

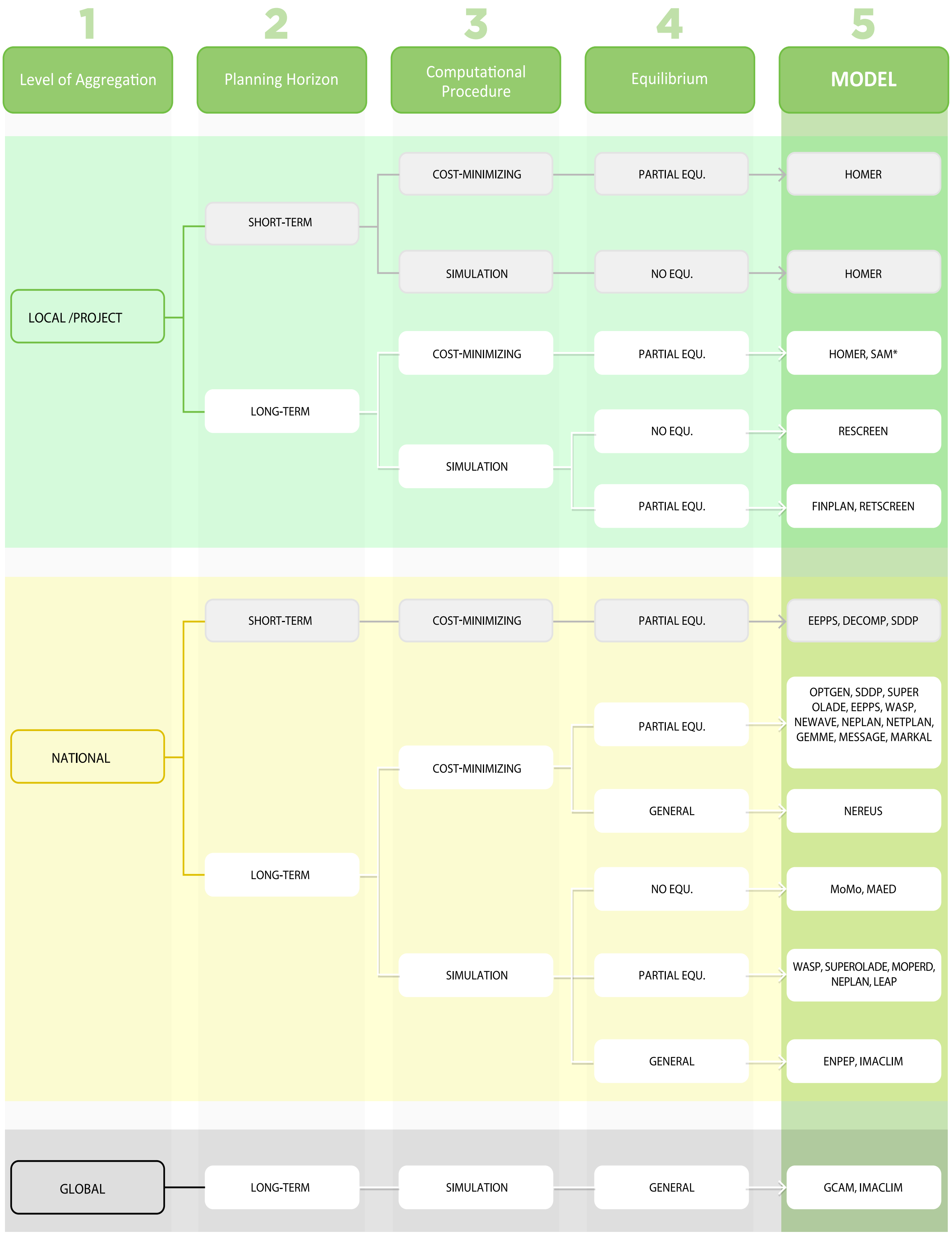
3.2.1 Electricity Planning Model Classification

Planning the expansion of a power system has traditionally been a field of intense work for researchers, due to the complexity of the mathematical programs that arise in this context. Least-cost approaches have been the mainstay of electricity planning in most countries. The underlying idea is that by adding least-cost incremental capacities, planners will maintain a minimum cost generating system. Least-cost probably worked sufficiently well in a previous technological era, marked by relative certainty and low rates of technological progress (Awerbuch, 2003). The introduction of competition and the new wave of technological innovations in the power generation business have altered how models address this power commitment problem.

Moreover, the addition of distributed generation into power systems adds a new complexity, as a least-cost approach (from a single point of view) no longer represents the objectives of all the stakeholders in the power system. Distribution generation owners have their own cost minimization objectives, which can contrast with the system's cost minimization objective — this turns the problem into a multi-objective problem (Alarcon, 2010).

The modeling of power generation units comes with a set of challenges, such as: i) operational constraints (i.e., minimum and maximum power outputs, limited available energy, ramping limits, minimum number of hours of continuous operation), ii) non-convex cost functions (i.e., no-load costs, start-up costs), iii) uncertainty and the economics of the primary source of energy (i.e., the cost of fossil fuels, the availability of hydroelectric , wind or solar energy), and iv) unforeseen outages (Cerisola et al., 2009). Thus, when choosing a model, energy planners should consider these preceding factors, as well as the planning horizon and the level of aggregation. Figure 7 tries to classify the energy and power system models depending on the level of aggregation, planning horizon, and computational procedure.

Figure 7. Electricity planning model classification



Source: OLADE (2017), own translation

3.2.2 Modeling input variables: Electricity demand and energy prices

Most of the generation expansion models consider electricity demand, energy prices and new technologies as input variables and exogenously determined. Therefore, policymakers and researchers have emphasized the aftermaths of overestimating or underestimating these input variables. For example, Steinbuks (2017) explains that "overestimating electricity demand may result in an overinvestment on generation capacity and ultimately even higher electricity prices. On the other hand, underestimating electricity demand could cause supply shortages and forced power outages, which have detrimental effects on productivity and economic growth".

In terms of the time horizons of the forecast, in the short-run, high quality forecasts allow the utility companies to optimize the amount of generated power, thus maximizing their revenue and minimizing operational costs; whereas, over the long run, accurate forecasts help to reduce inefficiencies. In addition, electricity demand is affected in the medium and long term by several other factors including electricity price, availability of supply, the development of new technologies, population and economic growth, and even weather conditions (seasonality).

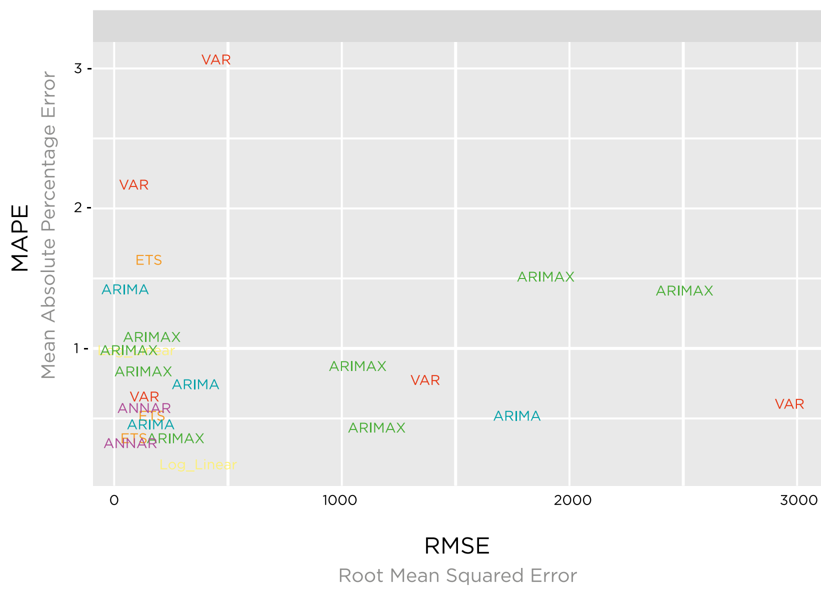
Table 2 shows the most common models used to forecast energy demand and highlights their pros and cons. Linear regression, ARIMA, ARIMAX and VAR normally assume that the Data Generating Process (DGP) is linear. This linear assumption makes it more intuitive to interpret the components of the model and its corresponding causality, but it might be susceptible to errors as an appropriate representation of the GDP in electricity demand. Moreover, Steinbuks (2017) argues that econometric methods significantly outperform the simple heuristic rules used by technicians, who frequently assume that electricity demand grows at some exogenous rate or is proportional to real GDP growth. It is also important to notice that econometric forecasts of electricity demand are challenging for developing countries which are in the process of rapid economic and structural transformations, or are prone to conflicts and environmental disasters. For those countries, a more rigorous forecasting approach using a combination of micro-econometric and computational modeling methods would be preferred. Therefore, in an attempt to include nonlinearity in demand modeling, more innovative methodologies as ETS (Exponential Smoothing) and ANNAR (Artificial Neural Network with Lagged Inputs) are also used for energy demand forecast. These purely statistical methods are designed to process non-linear model specifications and thus are sometimes more aligned with practical data.

Table 2. Most common models to forecast energy demand

Models	Time - series?	Pros	Cons
Log -log	No	Allows for more data volatility, suitable for emerging economies.	Relies on the accuracy of exogenous forecast
ARIMA	Yes	Widely applied, depicts well of data's historical trend.	Only historical evolution lacks expectation
ARIMAX	Yes	Allows for events that did not happen before by including exogenous variables.	Relies on the accuracy of exogenous forecast
VAR	Yes	Multi-variate, allows for cross-variable dynamics.	Only historical evolution lacks expectation
ETS (Exponential Smoothing)	Yes	Allows non-linearity in the construction of parameters, and non-stationarity.	Only historical evolution, lacks expectation
ANN (Neural Network)	Yes	Allows fornon-linearity in parameters, perform better with multicollinearity.	Relies on the accuracy of exogenous forecast

In Latin American and Caribbean countries, the most used models to forecast the electricity demand are: 1) Log-Log; 2) ARIMA; and 3) VAR. To demonstrate the performance of each methodology, we took historical data and applied two widely used measures of accuracy: Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE). Figure 8 below shows the result in each of the 26 countries of the region. The models and count that appear in the graph are indicators of good performance, x-axis depicts the Root Mean Squared Error (RMSE) and y-axis shows the Mean Absolute Percentage Error (MAPE). In both axes, dots that are closer to zero indicate a better model with less error. In this sense, ARIMAX appears to be the model that fits the best in most of the countries (33%), and Log-log has a nice balance between the two mostly applied error measures (X and Y axis) for being very close to the zero-error origin.

Figure 8. Comparison of forecasting methods



MODELS	COUNT
LOG - LOG	2 (8%)
ARIMA	4 (17%)
ARIMAX	8 (33%)
VAR	5 (21%)
ETS	3 (13%)
ANN	2 (8%)

A second important element to be considered when making expansion plans is the volatility of energy prices. Variability in future fuel and renewable energy prices could have a greater impact on the selection of the combination of units to be installed in the system in future years. As fuel prices and technology costs change over time, some energy sources become more economical to use than others. EIA (2012) analyzes the competition between coal, natural gas and petroleum oil used for electricity generation by estimating the elasticity of substitution among the fuels. The elasticity of substitution measures how the use of these fuels varies as their relative price change. In terms of modeling, usually the uncertainty in fuel prices is reflected by their joint probability distribution, with the classical breakeven point analysis model (Levin et al., 1985).

A third important element that policymakers must consider when planning the power system is the availability and continuous disposal of energy resources. The expansion plans assume the importance of a continuous supply of primary fuel for electricity production, but fail to list measures to be taken to ensure adequate supply of coal/oil/natural gas or alternative fuels to meet the growing demand for electricity.

Other factors besides fuel prices and fuel availability that must also be included are the generators' nonfuel variable operating costs, startup/shutdown costs, emission rates and allowance costs, transmission constraints on the electricity grid and reliability requirements. Nevertheless, most of the top-down models are not able, unfortunately, to process precisely how consumer behavior may change in the future. It is challenge, for instance, to incorporate

expected impact on energy efficiency with the idea of the "prosumers", i.e. those consumers that may themselves generate energy. Furthermore, these models focus on general statistics and demand trends, but they do not incorporate elements describing the energy load (which may be a key for transformation of the energy industry and adaptation of potentially variable energy mixes).

3.2.3 Most used power system models in selected LAC countries

When choosing a planning model, the first thing that needs to be considered is the current energy matrix. For example, in the LAC region many countries have a large number of hydroelectric plants in their generation matrix, which varies according to the season of the year and has strong variations associated to El Niño phenomenon. In these cases, the recommendation is to use planning models that represent this hydrological variability adequately, because if the model only considers a median hydrological value, there is the risk of not supplying the demand in drought situations. On the other hand, if only the worst episodes are considered, the risk will be over-sizing the generator park. Therefore, for a better modeling the technicians need to consider a set of hydrological series, and optimize the system to find the best plan for the expected values, subject to established rationing risk conditions.

Another point which must be considered when choosing the planning model is the participation of the Non-Conventional Renewable Energy (NCRE) in the generation matrix and the level of detail with which it should be modeled. With an increasing integration of NCRE in the generation matrix, it is necessary to model the electric power system in very detailed time blocks, passing from weeks to hours. Historically, energy planners used to work with monthly or weekly time blocks when planning hydrothermal systems; nevertheless, given the complexity of NCRE a more detailed time structure modeling is needed.

Table 3 shows the energy models used in selected countries in the region. Most countries in Latin America and the Caribbean have received technical training from the International Atomic Energy Agency (IAEA) to use the following models: i) WASP IV for electrical planning models, ii) MESSAGE for energy planning, iii) MAED for demand projection and iv) FINPLAN for power project financing.

Particularly, WASP IV is a very well-known model developed in Fortram by Argonne in the 70´s. The advantage of using WASP IV is the good performance when modeling hydroelectric and thermal power plants, the model can consider up to 5 different hydrological conditions. However, an important drawback is that NCRE should be modeled as thermal or hydroelectric plants, and it is not possible to model the transmission network.

Another widely known software is MESSAGE, where it is possible to model the whole energy system—not just the power sector. The deficiency of the MESSAGE is that the hydrological conditions are modeled in a deterministic way with a production curve. This characteristic makes it impossible to use in several Latin American and Caribbean countries. Nevertheless, some countries like Brazil have made some improvement in the MESSAGE model for use in some energy sectors.

Some countries of the region, due to the large hydrological participation in their generation matrix, have seen the need to develop their own energy/electricity planning model that fits their current generation mix. For example, the model SDDP and OPTGEN, which were created by the Brazilian company PSR, are perhaps the most used across the region. The SDDP model is used for economic dispatch, while the OPTGEN for planning the expansion of generation system. To solve the optimization problem, the model uses Dynamic Dual Stochastic Programming which does not present limitations in the number of states of the system—that's why it can be used in hydrothermal systems with many reservoirs. Nevertheless, the model is still structured in monthly and weekly-block time format, which may not be very suitable for systems with a large integra-

tion of NCRE. The Super OLADE model is a model of hydrothermal systems that was presented by OLADE in several training courses in the region, both on-site and online, although in the field it has not been practically used.

Figure 9. Power system models used by country

Source: Author's elaboration based on the energy expansion plans in each country

4

THE FUTURE OF THE GLOBAL POWER SECTOR

In this context, the complexity that energy planners need to tackle has increased. First, because there is a greater variability of generation sources. Electricity generation capacity from renewable energy sources is increasing across the world. This large insertion of renewable sources has been based on wind and solar energy production, which are by their nature intermittent, unpredictable on a day to day basis and unevenly geographically distributed. Second, the sector uncertainty increased; on one hand the innovation process behind the transition has opened new possibilities and dropped costs, while on the other hand climate effects are transforming natural conditions, such as hydro, solar and wind conditions.

4.1 Incorporating non-conventional renewables to power sector planning

As discussed by IRENA (2017) the massive introduction of renewables increases the relevance of an accurate analysis of certain variables, such as firm capacity, flexibility, transmission capacity and stability.

Due to the lack of fit-all energy models that capture the nature of Non-Conventional Renewable Energy (NCRE), some countries have developed their own model that adequately represents the characteristics of these types of technologies[4]. For example, in Uruguay where NCRE dispatches 45% of power supply and a high variable participation of hydroelectrical production ranging from 30% in drought periods up to 85 %[5] in rainy seasons, the energy planners created their own power system model called SimSEE (Simulation of Electric Power Systems). SimSEE is a free open source model that is object-oriented programmed and uses classic stochastic dynamic programming. With SimSEE it is possible to model in extreme detail the NCRE and the correlations between them (solar with wind). Also, it allows the use of NCRE under different hydrological conditions and transmission networks. The energy planner can include different reservoirs and all types of storage. The main problem is that the use of this Classic Stochastic Dynamic Programming suffers from Bellman's curse, which means that it cannot be used in systems with many country variables. Moreover, Paredes et al. (2014) explained the different impact of NCRE in the energy system. With higher levels of intermittent generation, it will become necessary to invest in more flexible technologies, and back-up generation will be important for periods where availability of resources is low. In terms of transmission networks, the integration of NCRE will lead to a significant increase in energy flow between areas of the same electric power systems that could be highly diverse. In the distribution systems, an increased presence of NCRE has a heavy impact in the investment required to connect these generation facilities to the distribution network.

4. For best practices references around the world see IRENA (2017).

5. Based on data collected from ADME.

All these planning models in LAC have faced important challenges in incorporating new technologies. Although NCRE has already been incorporated in most expansion plan models in LAC, the challenge is still really important when it comes to how to include uncertainty and the decision-making process in the face of uncertainty. New technologies and potential changes in their tendencies are rarely incorporated, and some of them may play a crucial role for example in energy distribution, the role of consumers in changing the energy load and the different scenarios of technological change. Most of the models which include these variables use exogenous and ad-hoc models to deal with these elements.

4.2 Decision under uncertainty

There is a series of models (decision making under deep uncertainty - DMDU) being developed that try to include processes to account for deep uncertainties, such as technological disruptions and climate disturbances.

"Deep uncertainty occurs when parties to a decision do not know or cannot agree on (1) models that relate the key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes" Hallegate et al. (2012, page 3). In this context, we cannot define the probability to the expected conditions or events, as a consequence methods of decision making under deep uncertainty attempt to identify strategies that perform well under a broad range of future scenarios rather than first predicting a most likely future and optimizing for one given metric for success (such as net present value) Vogt-Schilb and Hoffmann (2019)[6].

It increases the importance of more complex analysis beyond the traditional optimization models, it should include several scenarios and also to take into account the costs associated with choices that could lead to locked in situations and stranded assets. Vogt-Schilb and Hoffmann (2019) discuss further the challenge of using this kind of tools in LAC and argue that electricity planning in the region are lagging behind on this kind of analysis (if compared with other sectors such as water).

6. The final document will be published as chapter of the Development in Americas 2020.

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CONCLUDING REMARKS

Power system planning is a forecast, based on a type of investment-decision problem commonly regarded as a cost minimizing problem where institutional factors, market structure, environmental concerns and social aspects play an important role. It is worthwhile to emphasize that the dispatching model is an important element when considering how power plants will run, and thus what are the cost/benefits associated with the different technologies. Moreover, this optimization problem is based on assumptions about energy demand, fuel prices and technological innovation that are barely constant in the long run. Therefore, energy planning should be an exercise constantly updated.

Planning power generation has traditionally been a field of intense work for researchers due to the complexity of the mathematical programs that arise in this context. Because of this, planning and simulation models have been created and specially made to respond to specific contexts, based on geographical conditions, planning horizon, computational procedure, and equilibrium (partial/general equilibrium). Nevertheless, and based on the literature reviewed, few of them can model with the incorporation of new technologies. For this reason, technicians in each country have developed and adapted models for their own current energy mix. In a context of the necessary transition to deal with climate change, renewable energy is becoming an increasingly important electricity source. Its impact on the design and planning of the energy power system is still a subject of study among energy planners. On one hand, the inclusion of new dispatching profiles has already been incorporated in the most updated models, and this has been an important effort in LAC. On the other hand, these models have been struggling to deal with dynamic methodologies adapted to work with uncertainty and system dynamics. In other words, the results of the current planning models should be interpreted as a representation of the current technology, and scenarios where technology disruptions may happen should add a new layer of sophistication among policy maker tools to tackle new situations.

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