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Analysis of System Stability in Developing and Emerging Countries

Country Chapter: El Salvador

Published by

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

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1 Background

Numerous developing and emerging countries have ambitious plans for the development of renewable generation. Other countries show interest in renewable generation but corresponding plans are pending due to concerns relating to the technological consequences of fluctuating electricity generation.

In both cases, the impact of renewable generation on system reliability and system security needs to be analysed in order to assess related risks and to propose mitigation measures for ensuring a secure and reliable power system operation in the presence of a large penetration of renewable generation.

This report provides an overview on the power sector of El Salvador and identifies potential issues relating to the impact of wind and PV power plants on system security. Based on this initial analysis, a scope of studies for analysing the impact of planned wind and PV plants on system security in El Salvador will be given.

2 The Salvadorian Power Sector

2.1 Overview

Figure 1: Actors in the Salvadorian power sector [1]

The Salvadorian electricity sector consists of different organisations that [2]:

- define politics / policies and the regulatory framework
- manage the electric power market
- operate generation, transmission and distribution of electricity.

Figure 1 provides an overview on the relevant organizations that control the Salvadorian electricity market and the way that they are interacting.

The main organizations and their roles are [2]:

- **Consejo Nacional de Energía (CNE):** CNE is the principal authority to define/establish energy politics / policies and has the objective to establish politics / policies and a strategy to promote the efficient development of the energy sector. (www.cne.gob.sv)
- **Superintendencia General de Electricidad y Telecomunicaciones (SIGET):** SIGET is the responsible authority to implement the provisions contained in international treaties, laws and regulations of the electricity sector. (www.siget.gob.sv)
- **Unidad de Transacciones (UT):** The UT was created by "Ley General de Electricidad (LGE)" ("*General Electricity Law*"). Its objective is to operate the transmission grid and to manage the electric energy exchange market. (www.ut.com.sv)

These organisations define the general framework for the different market actors. Market actors are generally private companies having the following roles [2]:

- Power producers
- The transmission system operator
- Distribution network operators
- Retailers
- Big end-users and customers

2.1.1 Power Producers

Table 1 - Existing power producers [2]

Inversión	Tecnología	Participante de mercado	Capacidad instalada (MW)	Porcentaje (%)
Pública	Hidroeléctrica	Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL)	472	32.0%
Mixta	Geotérmica	LaGeo	204.4	13.8%
Privada	Bagazo	Compañía Azucarera (CASSA)	66	4.5%
Privada	Bagazo	Ingenio El Ángel	22.5	1.5%
Privada	Bagazo	Ingenio La Cabaña	21	1.4%
Privada	Térmico - FO/DO	Duke Energy	338.3	22.9%
Privada	Térmico - FO	Nejapa Power	144	9.7%
Pública	Térmico - FO	Inversiones Energéticas (INE)	100.2	6.8%
Privada	Térmico - FO	Textufil	44.1	3.0%
Privada	Térmico - FO	Cemento de El Salvador	32.6	2.2%
Privada	Térmico - FO	Energía Borealis	13.6	0.9%
Privada	Térmico - FO	Generadora Eléctrica Central (GECSA)	11.6	0.8%
Privada	Térmico - FO	Hilcasa Energy	6.8	0.5%
			1477.1	100%

2.1.2 Transmission System Owner

The company ETESAL owns the entire transmission grid of El Salvador, including the interconnection to Guatemala and Honduras (SIEPAC-line) and is responsible for its maintenance and expansion (Empresa Transmisora de El Salvador) [2].

2.1.3 Distribution Network Operators/Suppliers

Distribution network operators in El Salvador own and operate the distribution grids (voltage levels <115kV) and act at the same time as suppliers that sell energy to the end customers.

Since 1998 the electric energy supply is realized exclusively by private companies [2]:

- Currently 8 companies are registered in the UT as energy suppliers: CAESS, CLESSA, EEO, DEUSEM, DEL SUR, ABRUZZO, B&D, EDESAL.
- The first four companies of this list belong to the AES Group, which provide energy to 77% of the end-user/customers.
- The distributors "DEL SUR" provide energy for 22% of the customers.
- The rest (ABRUZZO, B&D, EDESAL) provide energy to 1% from a total number of more than 1.5 million customers

Figure 2: Distribution network zones [2]

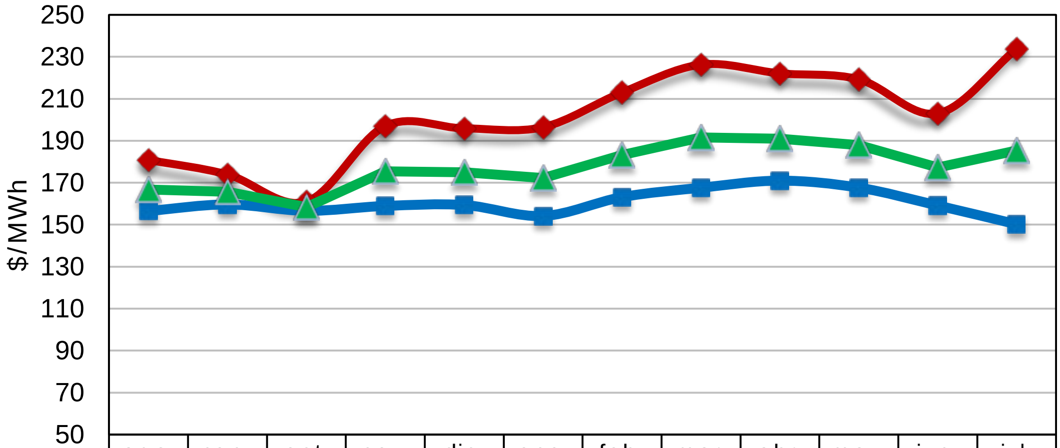
2.2 Salvadorian Energy Exchange

Since August 1st 2011 an electric energy exchange market is in operation, which is based on "production cost". The energy exchange market is regulated in the document "Reglamento de Operación Basado en Costos de Producción (ROBCP)".

The market model realizes the dispatch based on "declared costs" of generation and pays for every produced kWh the marginal cost of operation (CMO).

The cost of power production of each participating unit in the market is reviewed by the administrator and operator of the market, the UT. By law, the cost also can be reviewed by the regulator, the Superintendencia General de Electricidad y Telecomunicaciones (SIGET).

The final price is translated to the end-user tariff and is defined by a weighted average of the spot market price and contracted long term market prices [2].



	ago-2011	sep-2011	oct-2011	nov-2011	dic-2011	ene-2012	feb-2012	mar-2012	abr-2012	may-2012	jun-2012	jul-2012
Spot	181	174	161	197	196	196	213	226	222	219	203	234
CLP	157	160	157	159	159	154	163	168	171	168	159	150
Spot+CLP	167	166	158	175	175	172	183	192	191	188	177	185

Figure 3: Spot market and long term contract prices[1] [2]

[1] CLP = Contratos de Largo Plazo = Long term contracts

3 The Salvadorian Power System

3.1 Present Situation

3.1.1 System Overview

By the end of 2011, the Salvadorian power transmission system had the following key-system parameters [2]:

- 38 lines of 115 kV having a total length of 1,072.48 km (see Figure 4)
- 2 lines of 230 kV, which interconnects the transmission grid of El Salvador with Guatemala and Honduras (see Figure 5). The line to Guatemala has a length of 14.6 km and to Honduras of 92.9 km.
- 23 electric substations with an installed transformation capacity of 2,386.7 MVA.
- Total installed capacity: 1470 MW (2010, see Table 2)
- Peak load: 962 MW (2011)

As shown in Figure 6, the contribution of renewables to the produced electric energy is already now greater than 60%. This contribution mainly comes from hydroelectric plants (36%), geothermal plants (25%) and a much smaller contribution from biomass power plants (3%).

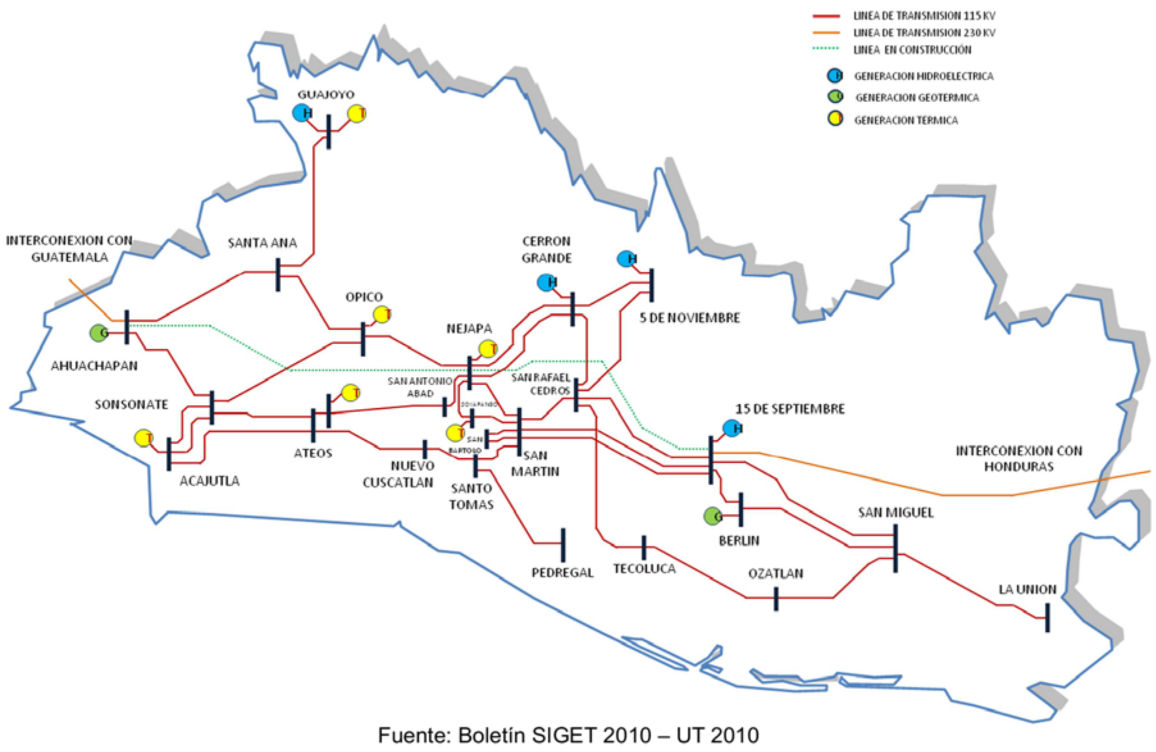


Figure 4: Power plants and transmission grid of El Salvador (2010) [2]

Figure 5: Regional interconnection of Mesoamerica [3]

Table 2 - Installed capacity per source 2010 [4]

Tipo de Recurso	Capacidad Instalada		Capacidad Disponible	
	MW	(%)	MW	(%)
Hidroeléctrico	472.0	32.1	472.0	33.8
Geotérmico	204.4	13.9	183.8	13.2
Térmico*	691.2	47.0	657.5	47.1
Biomasa	103.5	7.0	82.0	5.9

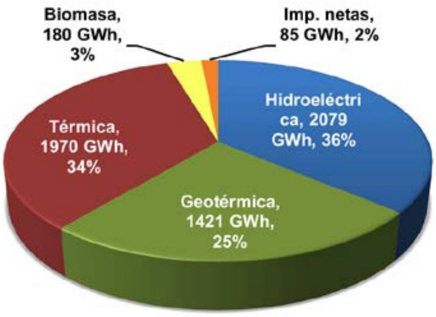


Figure 6: Generation per energy source 2010 [4]

3.1.2 Operational Aspects

Peak demand in the system of El Salvador is very flat over year and does not show very high seasonal variations.

More important than seasonal load variation is the seasonal availability of hydro power, which contributes by more than a third to the electrical energy production of El Salvador.

As shown in Figure 8, hydro availability is high during August/September/October (peak in September), medium in May, July, November and almost zero during the dry season (November to April).

Hence, seasonal variations are mainly defined by hydro availabilities and consequently, load flows in the transmission grid of El Salvador will be substantially different for the wet and the dry season.

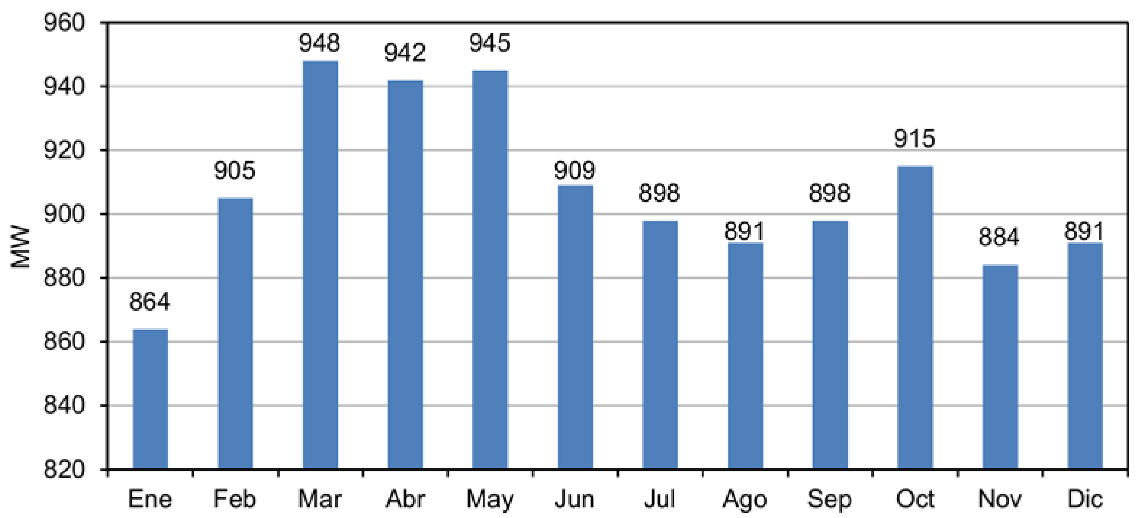


Figure 7: Monthly Net Peak Demand (2010) [4]

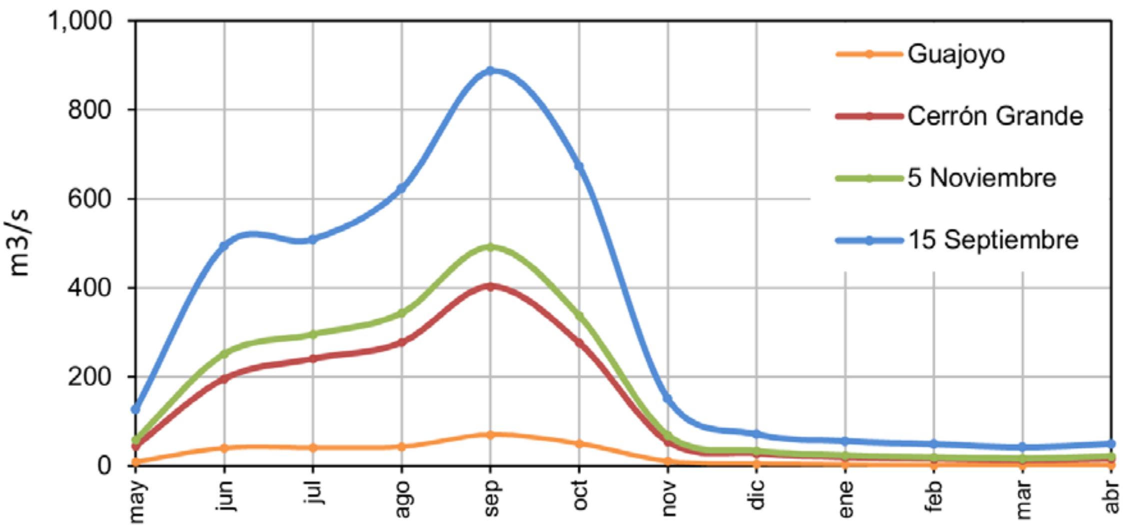


Figure 8: Hydro availability: Average volume per second of main hydroelectric power stations in El Salvador [2]

3.2 Expansion Plans

The legal base to develop an „INDICATIV generation capacity expansion plan“ is the „Reglamento de Operación del Sistema de Transmisión y del Mercado Mayorista basado en Costos de Producción (ROBCP) [4].

The fundamental conceptual aspects of this „reglamento“ is to define a „sistema marginalista“ to

- cover generation costs (transacciones de energía a nivel de generación) and
- „firm capacity“ of each power plant.

Like any emerging country, El Salvador expects a considerable load growth for the coming years, as shown in Figure 9.

According to Figure 10, the increasing load shall mainly be covered by new resources; hence wind and PV generation will have an increasing importance in El Salvador.

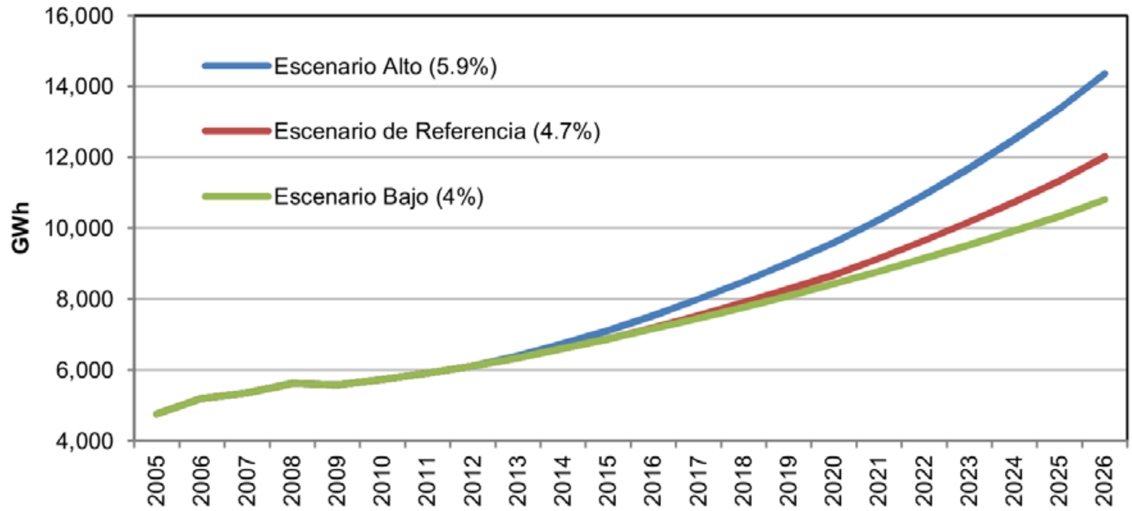


Figure 9: Load forecast scenarios 2012 – 2016 [4]

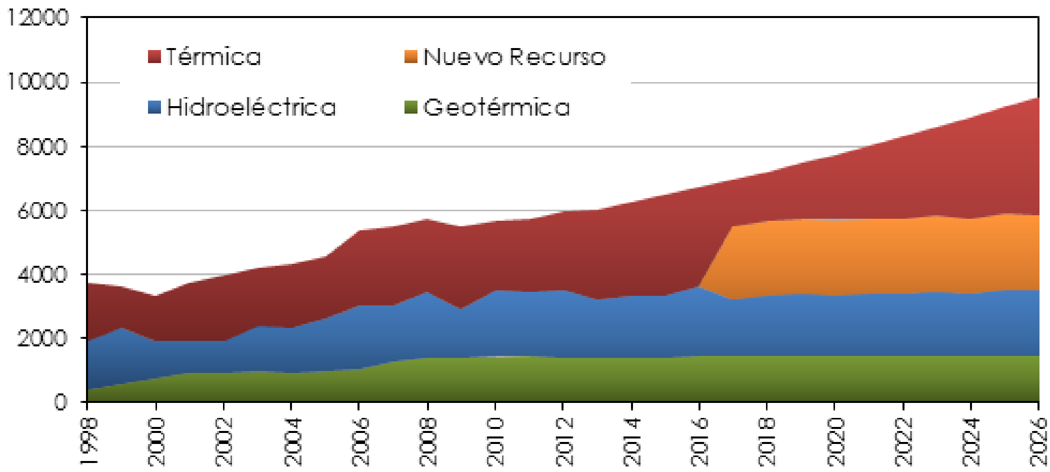


Figure 10: Net generation forecast by energy source (GWh) [2]

4 Renewable Energy Sources

4.1 Current Situation

In the present power system of El Salvador, renewable generation already contributes by more than 60% to the overall electric energy production.

Renewable energy is mainly generated by large hydro power plants and geothermal power stations.

Main technical and economical parameters of the largest hydroelectric and geothermal power plants are depicted in Table 3 and Table 4.

Their geographical location is shown in Figure 4.

Table 3 - Technical and economic information of existing hydropower plants [4]

Descripción	Unidad	Guaj U1	Cgra U1	Cgra U2	5nov U1	5nov U2	5nov U3	5nov U4	5nov U5	15se U1	15se U2
Potencia Máxima Neta	MW	19.8	86.4	86.4	20	20	20	18	21	92.76	92.76
Cota máxima de operación	m.s.n.m.	430.3	243	243	180	180	180	180	180	49	49
Cota mínima de operación	m.s.n.m.	419.5	228.5	228.5	176	176	176	176	176	46	46
Costo Variable No combustible (CVNC)	US$/MWh	7.056	2.204	2.204	2.88	2.88	2.88	3.1	3.3	2.445	2.445
Caudal mínimo turbinable	m3/s	14	84	84	20.7	20.7	20.7	20.7	20.7	130	130
Caudal máximo turbinable	m3/s	46	175	175	40.5	40.5	40.5	35	47.8	370	370
Factor de producción promedio	MW/m3/s	0.397	0.473	0.473	0.491	0.491	0.491	0.469	0.474	0.265	0.265

Table 4 - Technical and economic information of existing geothermal power plants [4]

Descripción	Unidad	AHUA-U1	AHUA-U2	AHUA-U3	BERL-U1	BERL-U2	BERL-U3	BERL-U4
Límite superior generación	MW	28	28	37	27.5	28.2	41.3	8.0
Límite inferior generación	MW	15	15	20	24.5	24.5	35	4
Costo Variable No Combustible (CVNC)	US$/MWh	4.079	4.079	3.464	2.280	2.280	2.189	1.886
Costo de Arranque Variabilizado	US$/MWh	0.014	0.012	0.004	0.007	0.005	0.058	0.107

4.2 Solar and Wind Resources

There are significant solar and wind resources in El Salvador. The geographical location of areas with high solar and wind potential are depicted in Figure 11 and Figure 12.

As shown in these figures, wind resources are mainly in the north-west and south-west of El Salvador, whereas areas with high solar irradiation can be found in the centre of the country.

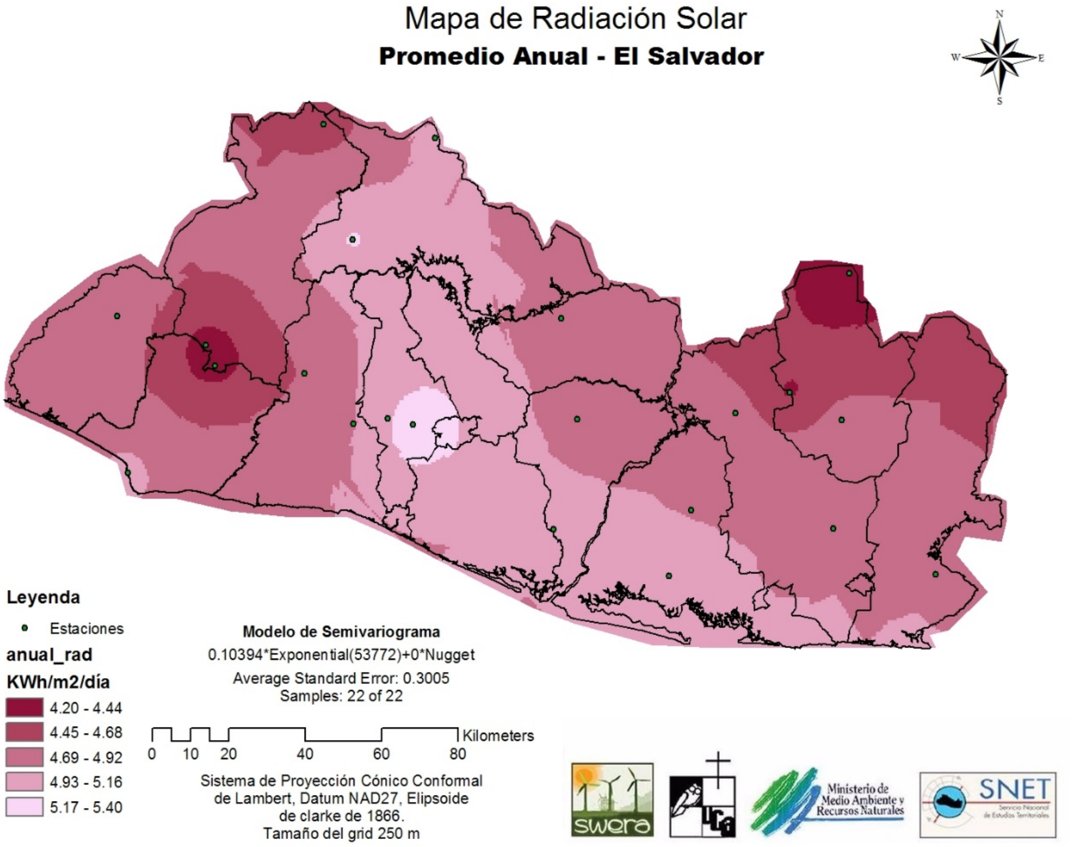


Figure 11: Solar radiation map [5]

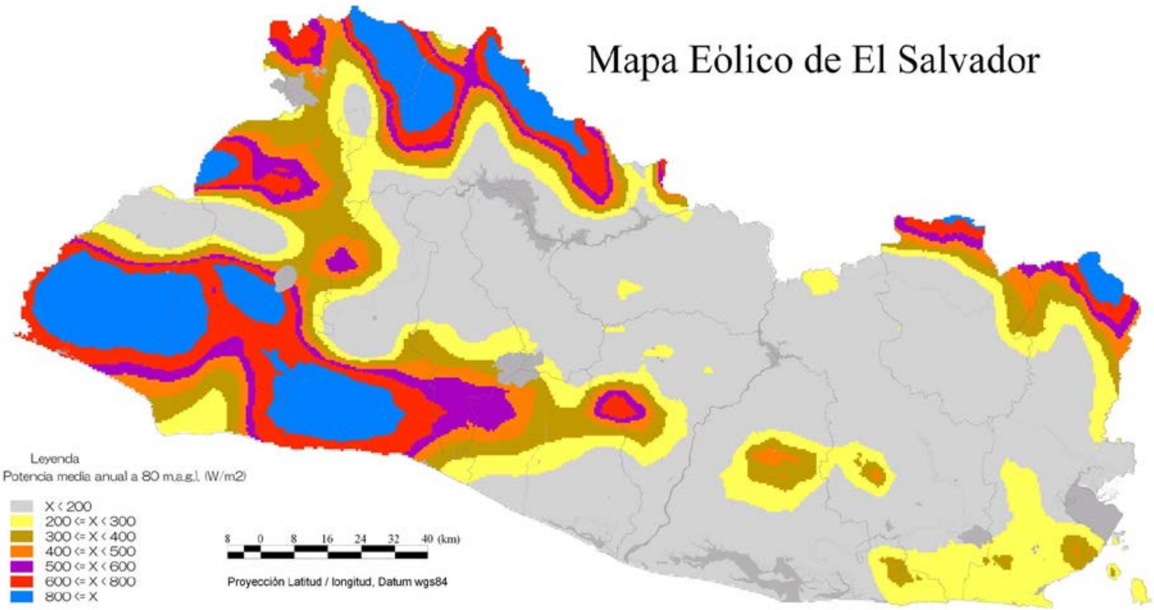


Figure 12: Wind resources [5]

4.3 Planned Wind and PV Projects

Planned wind generation and PV generation projects (according to Consejo Nacional de Energia and SIGET) are depicted in Table 5 and Table 6. The commission of these projects will not be before 2016.

According to these tables, the planned wind generation capacity is 72 MW and the planned PV capacity is around 123 MW.

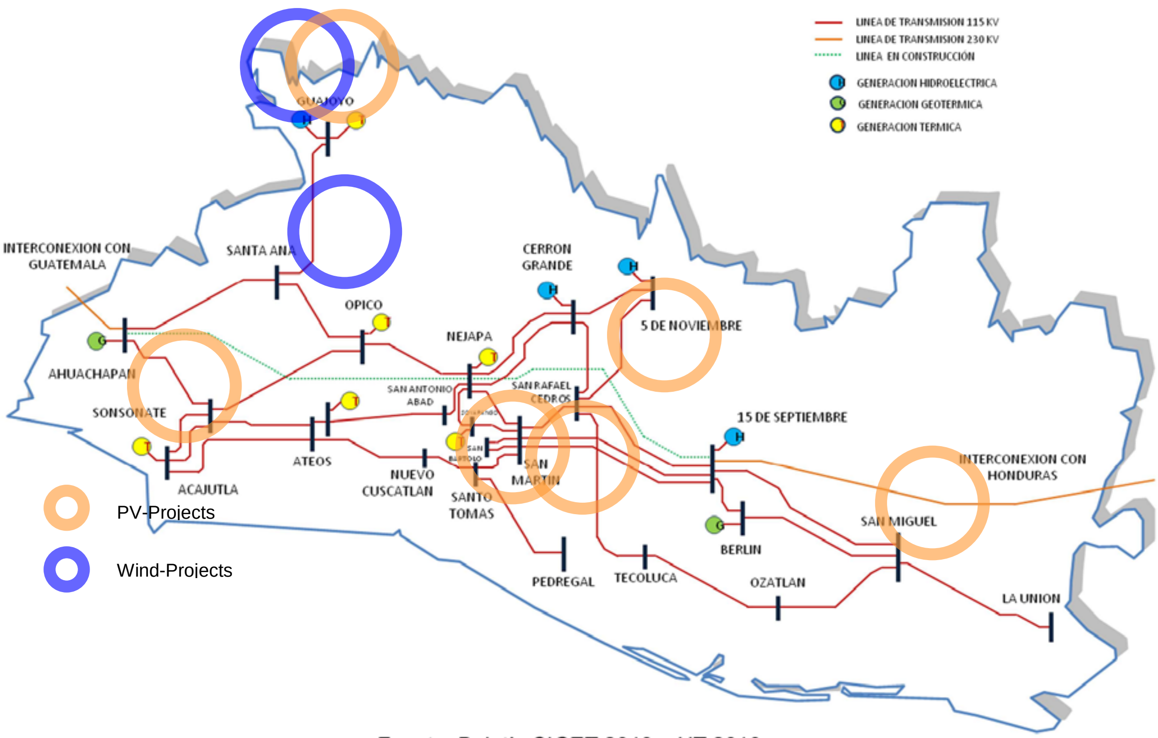
The locations of substations to which these wind and PV power plants will be connected are depicted in Figure 13.

Table 5 - Planned Wind-Projects [6]

Interconnected wind projects		
Project	**Capacity**	**Substation**
Proyecto Metapán	42.0 MW	Subestación de Guajoyo
Proyecto San Julián	30.0 MW	Subestación de San Matias

Table 6 - Planned PV-Projects [6]

Interconnected photovoltaic projects		
Project	**Capacity**	**Substation**
Proyecto 15 de Septiembre	14.2 MW	Subestación de 15 de Septiembre
Proyecto Guajoyo	3.0 MW	Subestación de Guajoyo
Proyecto La Unión	15.0 MW	Subestación La Unión
Proyecto Zona Central	10.0 MW	Subestación Tecoluca o en Subestación de Ozatlan
Proyecto American Park	6.0 MW	Subestación OPICO (San Mateas)
Proyecto Isofoton	50 MW	Subestación la Unión
Proyecto Abantia	20 MW	Subestación Acajutla
Proyecto Termopuerto	5 MW	Subestación PEDREGAL



Fuente: Boletín SIGET 2010 – UT 2010

Figure 13: Power System of El Salvador including the location of planned wind and PV plants [2], [6]

5 Potential Issues and Recommendations for System Impact Studies

5.1 Potential Issues and High Level Recommendation

According to the Renewable Energy Scenarios, defined by the Consejo Nacional de Energia and SIGET (see Table 5 and Table 6) there are plans to connect two wind farms having a total rating of 72 MW to the 115 kV system of El Salvador and PV plants having a total rating of 123 MW. The totally planned production will sum up to around 195 MW.

Considering a worst case coincidence factor of 100%, there will be situations, in which the total of wind and PV production will reach around 32.5 % of the load at day time and around 26 % during the night time.

Because the system of El Salvador is not an isolated system, but supported by the electricity grids of other Central American Countries, it can be expected that the 115 kV electricity grid will represent the dominant limiting factor for the integration of the planned wind and PV plants.

For this purpose, it is proposed to carry out a grid impact study in the first place for evaluating the feasibility of the planned projects.

Because the maximum temporary penetration levels of RE plants are still moderate, studies relating to the impact of the planned RE projects on system balancing, reserve allocation, etc. can be carried out at a later stage.

The proposed grid impact study will focus on a relatively short time frame between 2013 and 2019 and will be based on the assumption that the grid expansion will follow existing expansion plans and that no major grid reinforcements (additional transmission lines) can be realized within the analyzed time frames. However, minor network upgrades, like the installation of additional reactive power compensation devices will be considered to be feasible.

5.2 Objectives and Contents of Proposed Studies

5.2.1 Objectives

The main objectives of the proposed studies are the following:

- Analyze if the proposed RE projects can be integrated into the electricity grid of El Salvador without any major grid upgrades while maintaining the existing system security level (reference: 2013).
- Propose minor network upgrades, such as additional reactive power compensation devices that can be realized within the analyzed time frame allowing the integration of the planned projects.
- In the case that the integration of the planned projects turns out to be infeasible, identify the maximum installed capacity of wind and PV plants that can be integrated at the current state of the grid.
- Define most relevant connection conditions for wind and PV generation that ensure the required system security level.

5.2.2 Contents

5.2.2.1 Grid Studies

For the purpose listed in the preceding section, the following grid studies are proposed:

- Load flow studies for relevant worst-case operational scenarios for the years 2013, 2016 and 2019 (2013 is used as a reference).

  Load flow studies will mainly look at thermal line loadings and voltages under normal operating conditions.

- Contingency analysis studies for relevant worst-case operational scenarios for the years 2013 (reference), 2016 and 2019. Contingency analysis will focus on a list of credible contingencies (N-1 line outages, credible N-2 outages, generator outages, reactive compensation plant outages).

  The results of contingency analysis studies will be verified against maximum permitted line loadings and voltage bands under contingency situations.

- Voltage stability studies:

  The impact of planned RE plants on voltage stability limits of critical network corridors will be assessed using load variation studies. Voltage stability studies will consider critical line and generator outages.

- Transient stability studies:

  Dynamic simulation studies will be carried out for assessing the impact of the planned RE plants on critical fault clearing times and transient stability constraints transfer limits on critical transmission corridors.

- Short-term Frequency stability studies:

  Dynamic simulations drawing attention to the impact of renewable generation on the inertia of the system in El Salvador and hence on the frequency rate of change following an islanding situation of the system of El Salvador. The studies are limited to short-term frequency stability aspects only. The impact of variability on frequency stability during islanded operation is out of the scope of the studies.

  However, it is recommended to carry out corresponding studies if islanding events represent a credible contingency and a credible operational situation, which will occur during several hours per year.

For the proposed grid studies, it is recommended to consider at least the following study years and operational scenarios:

- Study years: 2013 (reference), 2016 and 2019
- Seasons: 2 seasons (e.g. dry season, wet season)

It is further proposed to consider three load/generation dispatch scenarios per season

- peak load
- minimum load during day time (e.g. a Sunday during a low load season)
- minimum load during night time

Additional load scenarios will have to be defined as appropriate for analyzing operational situations (e.g. maximum line transfers etc.) that are critical to specific stability issues.

With regard to the planned wind and PV projects it is recommended to consider at least two different RE generation scenarios per load scenarios. These are:

- Day time: Max. PV and wind production/No RE production
- Night time: Max. wind production/No RE production

5.2.2.2 Other Studies

With increased penetration levels of wind and PV generation, operational aspects, such as generation – load balancing, reserve allocation, wind and PV forecast etc. will become increasingly important, especially in situations, in which the interconnection to Guatemala and Honduras will not be available.

It is therefore recommended to carry out studies relating to the variability of solar and wind generation in El Salvador with the aim of assessing the following aspects:

- Impact of wind and solar variability on (residual) load variations
- Impact of wind and solar variability on load following reserve
- Impact of wind and solar variability on dynamic performance requirements of conventional (thermal and hydro) power plants.

These studies will require time series data of wind speed and solar irradiation with a resolution of 15min (ideally) or 1 hour (minimum) and load data having the same resolution.

Time series data of wind speeds and solar irradiation should ideally be available over a period of several years (e.g. 10 years).

6 Summary and Overall Recommendations

The electrical power system of El Salvador, with a peak load of around 1000 MW, is an area within in the interconnected power system of Central America.

With regard to the installation of renewable generation plants, there are very detailed plans for the coming years.

Due to frequency support from other Central American Countries, mainly grid studies that focus on the following issues should have highest priority:

- Load flows under contingency scenarios
- Short-term stability and
- Long-term stability

Also important, but slightly less urgent are studies relating to active power balancing aspects in the system of El Salvador.

Those studies should look at active power variations in a time frame of several minutes, during which wide-area solar and wind variability is relevant. Those studies can help identifying the additional active power reserves that will be required for balancing active power variations caused by increased penetration of renewable generation.

The proposed studies will look at renewable generation in El Salvador only and will model the other Central American countries according to their official grid expansion plans (which do not foresee many renewable power plants), as it is common practice in all Central American Countries.

However, it has to be pointed out that at some stage in the near future, studies will require to consider the impact of renewable generation in all Central American countries on network performance and stability simultaneously.

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Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
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As at
Eschborn, August 2013