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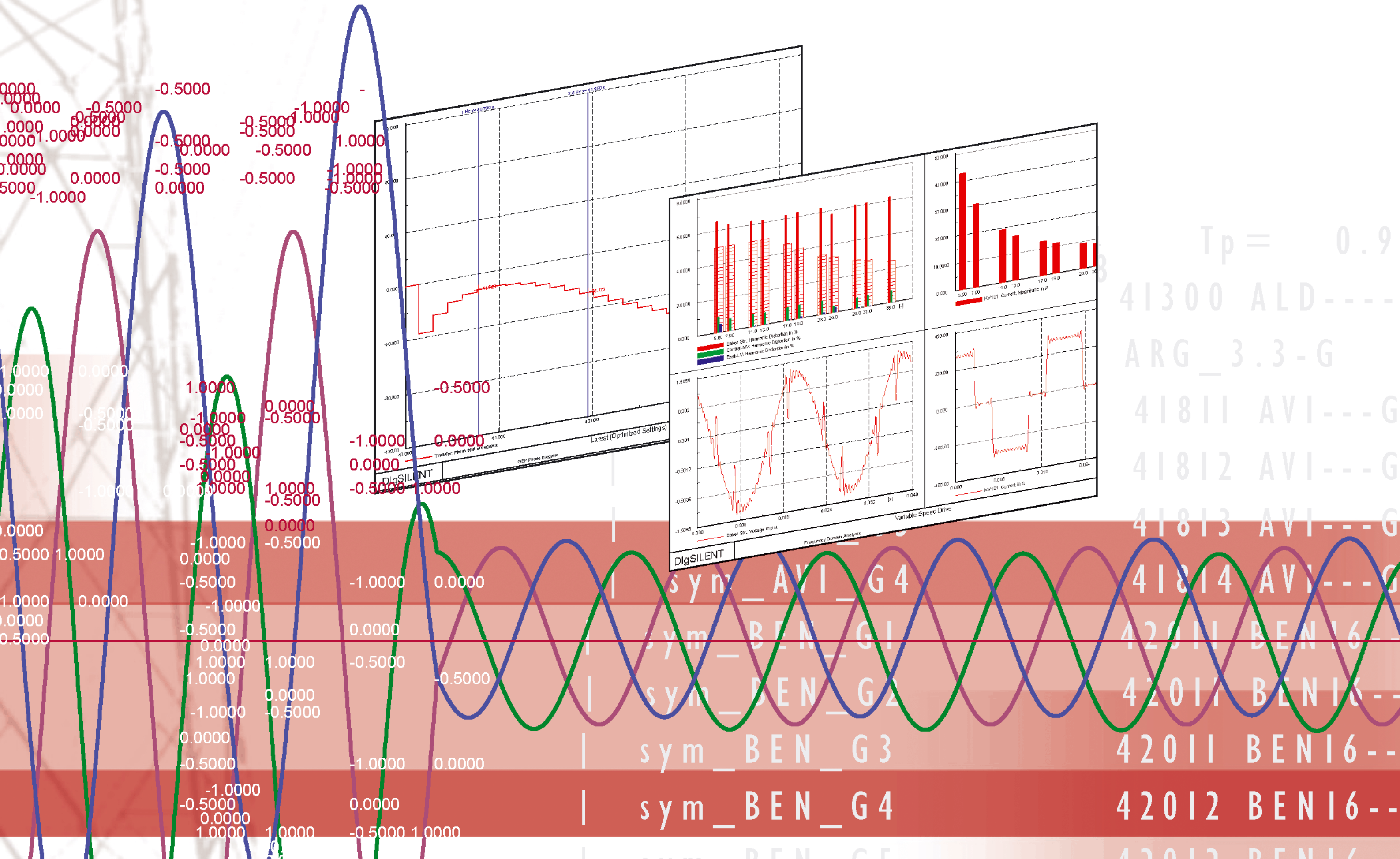
Develop a Proposal of the Methodology for the Determination of the Capacity Credit for Electricity Generated by Renewable and Cogeneration Plants

Final Report - Deliverables 1 and 2

prepared for

GTZ/CRE



DIgSILENT GmbH
Heinrich-Hertz-Strasse 9
D-72810 Gomaringen
Tel.: +49 7072 9168 - 0
Fax: +49 7072 9168- 88
http://www.digsilent.de
e-mail: mail@digsilent.de

Please contact

Markus Pöller
Tel.: +49 7072 916840
e-mail: mpoeller@digsilent.de

Rev.	Prepared by	Date	Reviewed by	Date	Comments
1	Markus Pöller	20.12.2010			Final, Deliverable 1 and 2

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1 Introduction

According to the LAFERTE-law from November 28th 2008, the Mexican Energy Regulatory Commission (CRE) is responsible for defining methodologies to determine the contribution that renewable energy technologies can make to the generation capacity of the National Interconnected System in Mexico. The elaboration of these methodologies shall take into account the information provided by the Suppliers, the researches carried out by specialized institutes as well as the best practices available in the industry and in the national and international level.

For this reason, GTZ has initiated a consultancy for supporting the development of a methodology for the calculation of capacity credit in Mexico to be issued by CRE.

In the context of this consultancy, studies for the calculation of capacity credit of renewable and cogeneration in Mexico have been carried out. Based on international experience and the results of those studies, a simplified methodology for determining the contribution of renewable and cogeneration to the firm capacity of the Mexican system has been derived.

This report summarizes the international experience and practice with regard to capacity credit assessment of renewable generation, presents the results of studies that have been carried out for the SIN and finally presents a simplified methodology for assigning a capacity credit to power plants based on renewable generation or cogeneration.

2 Background: Capacity Credit of Variable Generation

2.1 General Definitions

For ensuring a reliable supply of the load of a power system sufficient generation capacity has to be made available. For defining what actually is “sufficient”, it is necessary to carry out a probabilistic assessment of all generation plants considering their planned and unplanned outage rates and other aspects influencing the availability of generation capacity.

In the case of variable power sources, such as wind or solar plants or even co-generation plants whose availability may depend on other constraints than the requirements of the power system, the question arises if those variable power sources can have a contribution to the required generation capacity at all.

Especially for the case of wind power, this problem has received a lot of attention during recent years. The discussion in this and following chapters has, for this reason, many references to the wind power case, but its concepts can be transferred to the case of photovoltaic solar power, or to any type of power plant with a primary energy source of variable nature.

For assigning a contribution to the required generation capacity to variable sources, probabilistic criteria have to be applied and the contribution of variable generation sources to one or more reliability indices has to be assessed.

2.1.1 Reliability Indices

The most important reliability indices used for assessing generation adequacy are the following:

Loss Of Load Probability (LOLP) is the probabilistic measure of the ability of the system to cover the load at a specific moment in time, e.g. under peak load conditions. LOLP is expressed in %. For correctly interpreting a LOLP-figure, it is required to understands its basis correctly. Typical definitions are:

- LOLP at yearly peak load
- LOLP at seasonal peak load
- LOLP at daily peak load

Loss of Load Expectancy (LOLE) is the probabilistic measure of the ability of the system to cover the load: in other words, the expected length of time in the year when the demand exceeds the available generation. It is typically expressed in time units (hours/year). In contrast to LOLP, LOLE considers the complete load duration curve and is therefore the more accurate reliability index. On the other hand, there are much more data required for being able to accurately assess the LOLE of a system compared to LOLP-figures.

Energy not Supplied (ENS) (or Energy not Delivered END) is the energy demand that cannot be supplied by the available generation capacity. ENS is also based on a complete load duration curve. In addition to LOLP or LOLE the ENS also considers the amount of load that couldn’t be supplied in case of a loss of load scenario.

2.1.2 Other Relevant Definitions

Equivalent Firm Capacity (EFC) is the capacity of a power plant with 100% availability that would have the same effect on a selected reliability index as the addition of an actual power plant with limited availability. EFC is expressed in MW.

Equivalent Load Carrying Capability (ELCC) Is the additional amount of load that can be supplied by adding a new power plant to a system while keeping the reliability level constant. ELCC is expressed in MW.

Capacity Credit (CC) is the percentage of the installed capacity of a power plant that can be considered to be "firm". The capacity credit is either defined on the basis of EFC or ELCC. It is expressed in %.

Capacity Factor (also known as Load Factor) is the percentage of the average power production as a fraction of the nameplate capacity of a power plant. In case of a variable generation plant, capacity credit and capacity factor are related to each other when assuming that the variable generation plant always produces the entirely available power.

Penetration Level of Renewable Energy Sources is in this report defined by the amount of installed capacity of renewable energy sources divided by the installed capacity of conventional power plants (dispatchable thermal and hydro power plants).

2.2 Methodology for Assessing Capacity Credit

2.2.1 General Methodology

For assessing the capacity credit of renewable generation and cogeneration plants, probabilistic studies have to be carried out, which calculate relevant reliability indices of a system. Based on these reliability studies the influence of renewable generation and cogeneration plants on relevant reliability indices has to be assessed.

For the definition of capacity credit, two approaches can be found in literature. These are:

- Equivalent Firm Capacity (EFC)
- Equivalent Load Carrying Capability (ELCC)

The EFC criterion assesses the amount of firm capacity (capacity with 100% availability) that would have to be added to a system in order to observe the same improvement of the relevant reliability index as observed by the addition of actual wind generation.

Another approach for defining capacity credit is based on the Equicalent Load Carrying Capability. The ELCC criterion assesses the amount of load that could be added to the system due to the addition of wind generation while keeping the relevant reliability index constant.

The choice of the actual methodology to be applied generally depends on the following aspects:

- Existing capacity planning principles.
- Data availability.
- Type of system.

Generally, it can be stated that in systems having problems with system adequacy an EFC criterion is more relevant because the main purpose of adding generation to the system is the improvement of system reliability.

However, in systems with sufficient generation adequacy levels but heavy load growth, capacity credit definitions based on ELCC are of more interest because it defines the equivalent load that can be added to the system due to the addition of a new power plant.

Besides EFC and ELCC, capacity credit can be based on any relevant reliability index, as defined in the previous section. Data availability and existing capacity planning practice are the most relevant aspects influencing this selection.

Because of the large variety of different approaches and calculation procedures, the results of capacity credit studies highly vary, not only between different countries but also for the same country and the same power system. For this reason, it is important to properly understand the concept and to base the assessment on clear criteria.

2.2.2 Renewable Energy Source of Variable Nature Model

Capacity Credit assessment requires a probabilistic representation of variable energy source. The following description will be based on the case of Wind Power, but can be applied analogously to any variable source to which a probabilistic/stochastic generation function can be associated.

Generally, variable power sources can be modelled by:

- Time series approach
- Analytical approach based on a given probability density function

The advantage of a time series approach is that correlation effects can be considered in a better way. The most relevant correlation effects are:

- Correlation between variable generations from different power plants.
- Correlation between variable generation and load.
- Correlation between variable generation and planned outages of conventional power plants (maintenance).

The main disadvantage of the time series approach is its data requirements. Ideally, time series data over several years with an hourly or even 15-minutes resolution should be available for all considered variable power plants. If insufficient data are available, the randomness of those generation sources is underestimated and it is difficult to predict whether the obtained results are actually representative or whether they overestimate effects that have occurred during the observed period of time.

2.2.2.1 Time Series Approach

The time series approach for modelling variable generation is either based on time series measurements of:

- Power generation or
- Primary energy (such as solar radiation or wind generation)

In the case that time series of power generation are available, the generated power can directly be considered by the reliability assessment algorithm.

In the case that time series of the primary energy source is available, e.g. in case of planned or projected power plants, the primary source first needs to be converted into a power time series.

In case of a wind farm, a wind farm power curve, as for example shown in Figure 1 can be used for converting wind speeds into power. In order to account for shadowing effects and internal losses the manufacturer-power curves for individual wind turbines can be scaled. Also a technical availability factor for the wind generation can also be included in order to build a more realistic wind power probability curve.

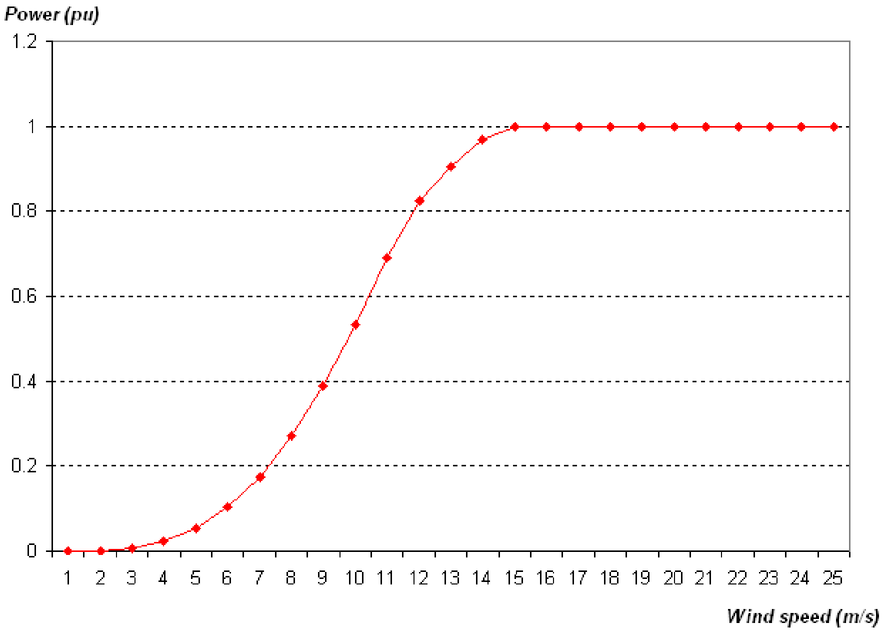

Figure 1: Typical p.u. Power-to-Wind Speed curve

2.2.2.2 Analytical Approach for Wind Generation

In the case that no or only insufficient measurements are available, an analytical approach based on known distribution functions can be taken.

In case of wind generation, only the average wind speed and possibly the so-called Weibull shape factor at a given site may be known. Based on these data, the complete wind speed distribution curve can be calculated und used by the reliability assessment algorithm.

Obviously, the consideration of correlation effects is much more difficult in an analytical model than in a time series model. For overcoming this problem, wind farms that are in a similar region can be considered to be fully correlated whereas wind farms that are in different regions can be considered to be fully uncorrelated.

The correlation of load and wind generation can only be considered if additional information is available, e.g. seasonal average of wind speeds.

To assess the frequency of wind speeds at a particular location, a probability distribution function is often fit to the observed data (different locations will have different wind speed distributions).

Experience has demonstrated that the Weibull distribution function is the best suited to represent the actual distribution of hourly wind speeds at many locations. The wind speed probability density (distribution) function is defined as:

$$P(u) = \frac{k}{A}\left(\frac{u}{A}\right)^{k-1} \exp\left(-\left(\frac{u}{A}\right)^{k}\right)$$

Where:

- P(u): Frequency of the wind speed u
- A: Scale parameter, which has the units of wind speed
- k: Form Parameter, which has no units

A Graphical representation of a wind speed Weibull distribution function is given in the following figure.

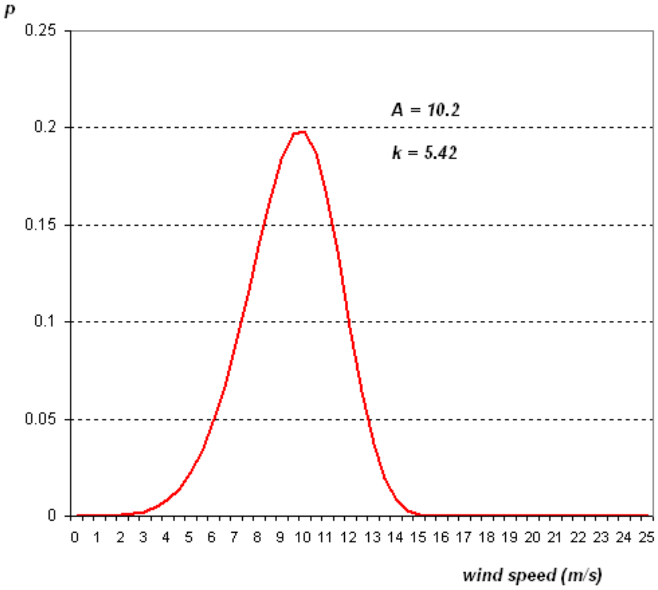

Figure 2: Weibull Probability Density Function

Parameters A and k will be used to fit the curve to the actual wind data, and of course will vary from case to case. This wind speed distribution curve will be combined with a wind farm power curve, as described in the previous section related to the time series approach (see Figure 1).

2.2.3 Conventional Generation Model

The Capacity Credit concept involves stochastic models not only of the uneven/random source power generation, but also of conventional generation. Such stochastic models are well known in literature and widely used for generation planning purposes. Generators are modelled by two-state generators (on/off), or as multi-state generators, when de-rated states need to be included. The capacity-out-of-service and availability indexes are obtained from forced outage rates (FOR) in the simplest case, but can include also planned outages.

2.2.4 Load Model

The load model that is required for carrying out capacity credit studies depends on the reliability index on which the capacity credit concept will be based.

2.2.4.1 Capacity Credit Based on LOLP

The loss of load probability index implies that probability of occurrence of individual loss of load events is assessed and their probability is evaluated. Consequently the analysis is typically carried out on peak load events during which the likelihood of a loss of load situation is the highest.

The simplest approach that requires the minimum amount of information related to the load is the LOLP at yearly peak load. In this case only the yearly peak load is required and the LOLP simply provides a probability with which the load can be covered in case of a peak load situation.

Because the load level is constant in this case, it is sufficient to evaluate the generation availability curve only. The LOLP of a given load level is represented by the confidence level of the generation availability curve.

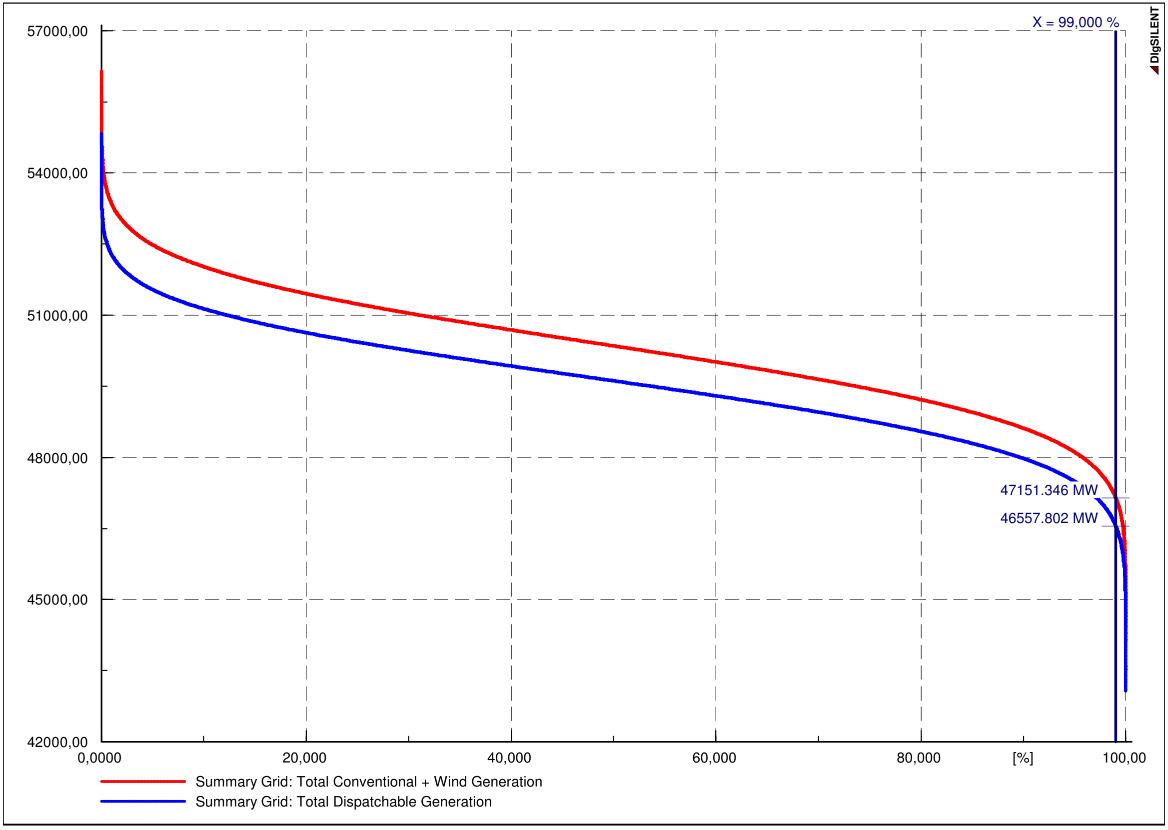

Figure 3: Generation Availability Curve

An example for such an approach is given in Figure 3. Here the generation availability curve is calculated for the total generation including renewable and cogeneration (red curve) and for conventional generation only.

For a given load of 46557,8MW, the LOLP would be equal to 99%. When adding renewable generation and wind generation a load of 47151,3MW could be covered at a LOLP of 99%. Hence the ELCC of this example would be equal to 593MW.

When considering more than one load level simultaneously, e.g. by considering daily peak loads, the capacity credit assessment cannot be carried out based on the generation availability alone but needs to consider all different load levels. In this case, the average loss of load probability can be calculated based on a probability curve for the Reserve Capacity, which is equal to the available generation capacity minus the load. All situations, in which the Reserve Capacity becomes negative will count for the average loss of load probability.

2.2.4.2 Capacity Credit Based on LOLE or ENS

For calculating LOLE or ENS, the consideration of individual peak load scenarios is not sufficient but the complete load duration curve, e.g. on the basis of hourly or even 15 minutes samples has to be taken into account.

An example for such an assessment is depicted in Figure 4. In this case, the LOLE for the system with wind generation would equal to around 5% or 18,25 days. For calculating the Energy Not Supplied (ENS), one would have to calculate the area between the red line and the solid blue curve.

Based on this approach, the equivalent firm capacity (EFC) can be evaluated by considering that the addition of Firm Capacity (capacity with 100% availability) would simply shift the the Reserve Capacity upwards by the amount of firm capacity that is added to the system. This means that EFC is represented by the little green line, which represents the value of the Reserve Capacity curve of conventional generation only at the give LOLE of 5%.

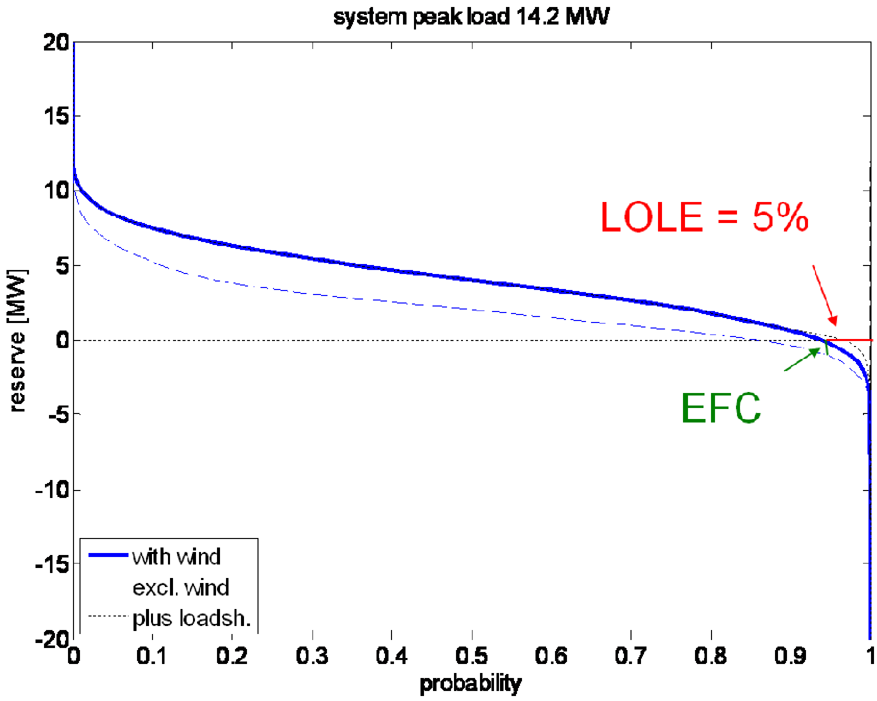

Figure 4: Reserve Capacity for assessing LOLE

The assessment of Capacity Credit based on ENS would be more complex and would require to calculate the area between the red line and the blue solid curve and to execute several reliability assessment simulations in order to identify the amount of firm capacity that one would have to add to the system for obtaining the same ENS as the system with the actually installed wind generation capacity.

2.2.5 Analysis of Capacity Credit

2.2.5.1 Capacity Credit and Incremental Capacity Credit ICC

The capacity credit of variable generation describes the contribution of existing variable generation to the firm capacity of a system.

Capacity credit is typically expressed in %, e.g. by rating the ELCC to the installed variable generation:

$$CC = {ELCC}/{P_{inst}}$$

In the case of mini-hydro and co-generation units, the maximum power output has been taken as basis instead of the installed capacity.

For evaluating the benefit of newly installed variable generation with regard to capacity, the incremental capacity credit is a better definition. It is based on the increment of the ELCC in ration to the increment of installed capacity (or maximum power output in case of mini-hydro and co-generation) between two scenarios (e.g. scenario i and j):

$$ICC_{ij} = {(ELCC_i - ELCC_j)}/{(Pinst_i - Pinst_j)} = {\Delta ELCC}/{\Delta Pinst}$$

2.2.5.2 Allocation of ELCC and CC (Capacity Credit) to Individual Power Plants

The capacity credit of renewable generation of cogeneration depends on the following main factors:

- Average production of the source
- Probability density of the source
- Correlation of the production with the load
- Penetration level
- Other system related parameters, such as load properties, availability of conventional generation etc.

For being able to work out a formula that allows to assign a capacity credit to every individual power plant, the nonlinear dependence of capacity credit on all of the above aspects can be decomposed into

- System-wide component
- Power plant specific component

It can further be shown that a good approximation of capacity credit can be obtained by lumping all nonlinear components into the system-wide aspect and to approximate all power plant specific aspects by a linear formula. With this approach, it is possible to assign a capacity credit (or ELCC) to each variable energy source of a system.

$$ELCC = R(cp) \times Pav$$

The different variables are defined as follows:

- ELCC: Equivalent Load Carrying Capability
- Cp: Penetration level: Installed renewable capacity/Installed conventional capacity
- R(cp): Reduction factor, which is a system-wide parameter that depends on the penetration level
- Pav: Average power production of all power plants. If correlation aspects shall be considered, only the average during e.g. peak load hours shall be considered.

The parameters R and cp are system-wide parameters, whereas Pav is specific to each power plant. With this approach, there is a linear relationship between ELCC and Pav, which means that it is possible to assign an ELCC to each individual power plant with index “i”:

$$ELCC_i = R(cp) \times Pav_i$$

The total ELCC of all power plants can be calculated by:

$$ELCC = \sum_i ELCC_i = R(cp) \times \sum_i Pav_i$$

The only approximation of this formula is the assumption that the reduction factor R only depends on system properties and is the same for all variable power sources in a system.

This assumption is valid as long as all variable power sources of a system show similar properties with regard to their probability distribution, correlation effects etc.

This is generally the case if there is only one renewable technology to be considered in a system, e.g. wind generation.

2.2.5.3 Variable Generation of Different Technologies

In the case that several generation technologies have to be considered, the assumption of a constant reduction factor R for all variable generation sources is generally not valid. In this case, technology-specific reduction factors have to be calculated.

A suitable procedure for assigning an ELCC to each technology can be based on the following two-step approach:

- In a first step, the ELCC for all technologies is calculated by considering all power plants in the system.

- In a second step, ELCC is calculated for each technology independently by only considering power plants of one technology together with conventional power plants during one simulation run.

Based on these simulations, technology-specific scaling factors can be defined:

$$s_{tech} = ELCC_{techonly} \Big/ \sum_{Alltech} ELCC_{tech\_only}$$

And the ELCC of each technology is calculated as follows:

$$ELCC_{tech} = s_{tech} ELCC_{all}$$

Based on technology-specific scaling factors, technology-specific reduction factors can be calculated as follows:

$$R_{tech} = ELCC_{tech} \Big/ Pav_{PLtech}$$

These technology-specific reduction factors can then be used for assigning a capacity credit figure to each individual power plant.

2.2.6 System Boundaries/Transmission Constraints

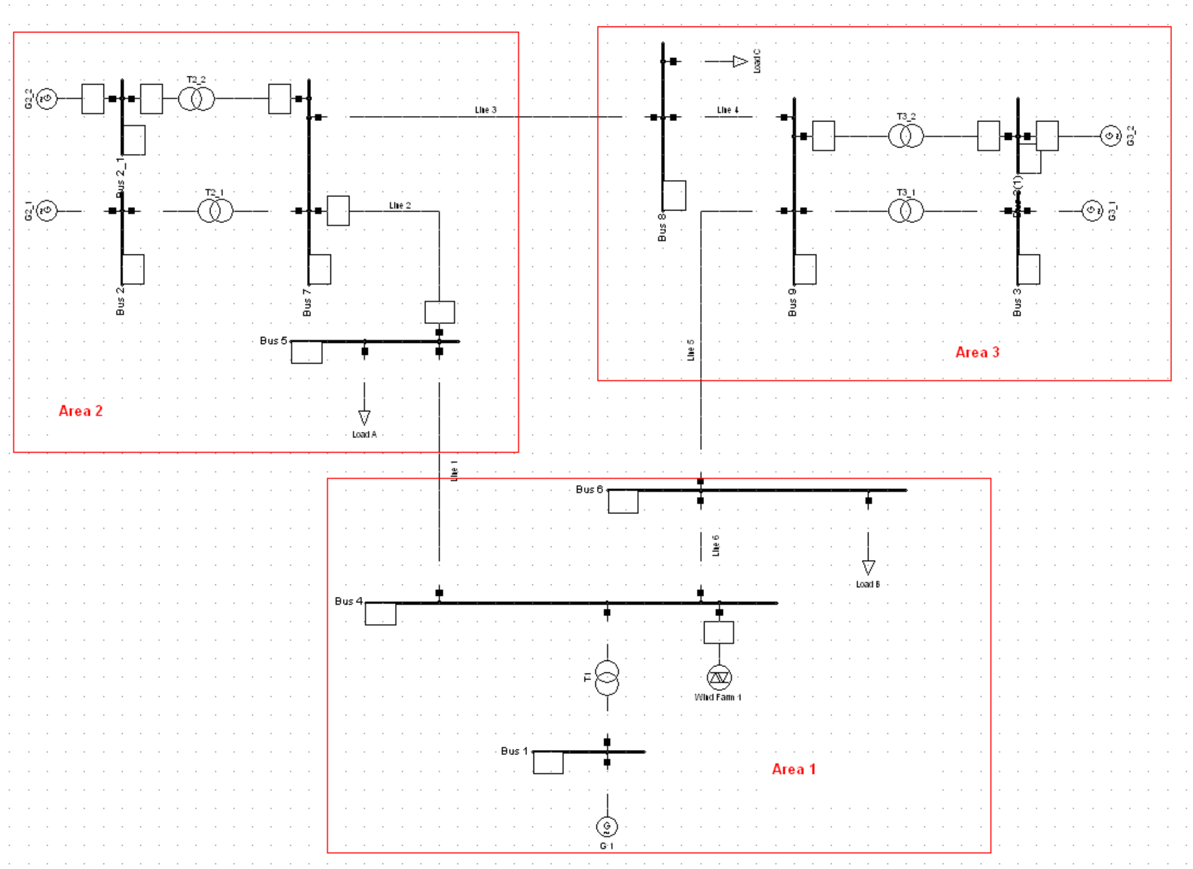

Figure 5: Simple Example System

Especially in the case of interconnected systems the question about system boundaries is of high relevance. System boundaries are typically be defined by the load that is in the responsibility of one transmission system operator. Connections to other systems are usually considered by their transmission capacities and forced and planned outage rates of the tie lines.

The contribution of generation to the load outside the area of responsibility is typically not considered.

Constraints on interconnectors inside the area of responsibility of the transmission system operator are usually not considered in capacity credit calculations because it can usually be assumed that the grid will be strengthened with the addition of generation in order to accommodate the additional generation sources.

In this case, grid reinforcement expenses are considered as additional costs, which are necessary for the grid integration of wind generation but not seen as part of the capacity credit of wind generation.

Only in cases, in which it has to be assumed that it will be impossible to reinforce the grid, either because of economical reasons or because of other aspects such as long planning time frames, grid constraints are explicitly taken into consideration in the capacity credit assessment.

With the consideration of grid constraints, capacity credit calculations become much more complex than without. Practically, such an assessment can be carried out using a Monte Carlo Simulation Algorithm, in which the state of every generator (conventional or renewable) is determined by a random number generator. Each scenario is then analyzed by an optimisation algorithm that assesses if a dispatch scenario exists that allows supply of the entire load. If no solution can be found, the corresponding scenario is marked as infeasible and it counts as a loss of load situation. An infeasible solution can either be caused by:

- Insufficient total generation
- Grid constraints

In the example according to Figure 5, such a situation can occur in the case that the generators in Area 3 fail. In this case, the total generation in Area 1 and Area 2 may still be sufficient for covering the total system load but the line capacity linking Area 3 to Area 1 and Area 2 may be insufficient and a part of the load in Area 3 has to be shed.

This problem can be mitigated by expanding the tie-lines linking Area 3 to the rest of the system, which would possibly increase the capacity credit of wind generation in Area 1. However, as this example shows, it is questionable if the capacity credit of wind generation in Area 1 has to be reduced because of insufficient interconnection capacity.

For this reason, it is common practice not to consider the grid inside the system boundaries of a study and to calculate required grid expansion costs separately from the capacity credit aspect.

2.2.7 Example

For illustrating the concepts of formulas presented in this section an example based on Scenario 3 of the Mexican system studies is presented in this section (see also chapter 0).

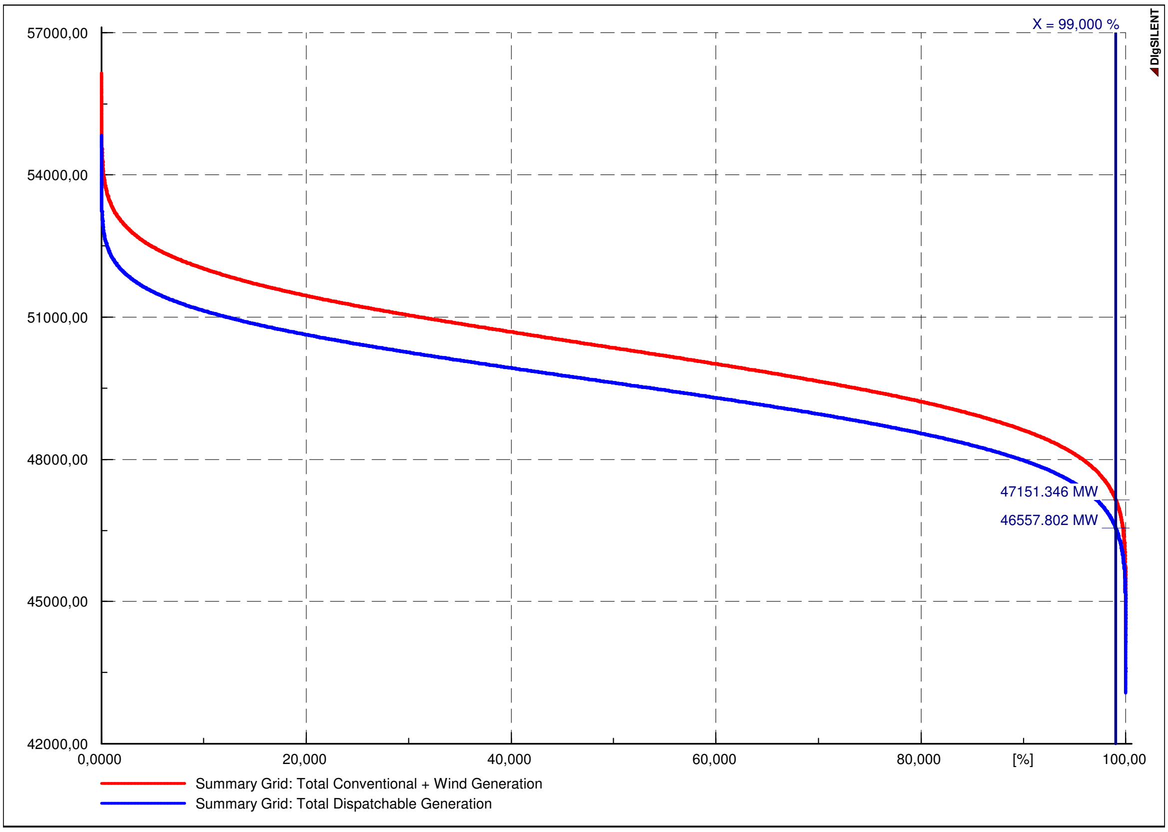

Figure 6: Example for the definition of the Equivalent Load Carrying Capability (ELCC)

In this example, four different variable generation sources will be considered:

- Wind generation
- Solar generation
- Mini-hydro generation
- Cogeneration

The ELCC of all variable generators together (wind, solar, mini-hydro and co-generation) is defined by the difference between the available generation at a confidence level of 99% with and without variable generation.

For obtaining the ELCC of different variable generation technologies individually, the same type of calculation is repeated just by considering one variable generation technology only, e.g. only wind, only co-generation or only mini hydro.

A corresponding example, which corresponds to Scenario 3, is depicted in Figure 3:

At a confidence level of 99%, the equivalent load carrying capabilities of the system are as follows:

- Total (including all variable generators):	48 308,7 MW
- Conventional + wind generation:	47 151,3 MW
- Conventional generation only:	46 557,8 MW

The resulting ELCC figures are the following:

- ELCC for all variable generators: 48 308,7 MW - 46 557,8 MW=1 750,2 MW
- ELCC for wind generation only: 47 151,3 MW - 46 557,8 MW= 593,5 MW

Analogously to the assessment of "wind generation only", an analysis for a case with "mini-hydro only" and "co-generation only" has to be carried out. In Scenario 3, these values are:

- ELCC for mini-hydro only: 316 MW
- ELCC for co-generation only: 881 MW

Based on the "technology-only" ELCC values, scaling factors for each variable generation technology are calculated by applying the following formula:

$$s_{tech} = ELCC_{techonly} \Big/ \sum_{Alltech} ELCC_{tech\_only}$$

In a next step it is possible to assign an ELCC to each technology by multiplying the technology-specific scaling factor by the ELCC of all variable generators together:

$$ELCC_{tech} = s_{tech} \cdot ELCC_{all}$$

In the above example, ELCC for wind generation can be calculated as follows:

$$s_{wind} = 593MW \Big/ (593MW + 316MW + 881MW) = 0{,}331$$

$$ELCC_{wind} = s_{wind} \cdot ELCC_{all} = 0{,}33 \cdot 1763{,}4MW = 584{,}2\mathrm{MW}$$

This value is slightly below the value obtained by considering wind generation only. In cases, in which the total penetration of variable generation is small, the ELCC calculated for only one technology represents a good approximation of the ELCC of this particular technology.

2.2.7.1 Capacity Credit CC

The capacity credit of variable generation is generally defined by its contribution to the firm capacity of a system, e.g. defined by the ELCC at a given confidence level, rated to the installed capacity.

Capacity credit of wind is therefore defined as follows:

$$CC_{Wind} = ELCC_{Wind} \Big/ Pinst_{Wind}$$

In case of mini-hydro and co-generation plants, the model used for these studies is based on time series reflecting the generation excess minus the locally supplied load of these generating sources. Hence, only generation excess is considered and not actual generation. For this reason it has been decided that using the maximum generation excess as basis of the capacity credit definition represents a more realistic approach than using installed capacity. For this reason, capacity credit of mini-hydro and co-generation plants is defined as follows:

$$CC = ELCC \Big/ P\max$$

In case of Scenario 3, the capacity credit of wind generation can be calculated as follows:

$$CC_{Wind} = ELCC_{Wind} \Big/ Pinst_{Wind} = 584{,}4MW \Big/ 3428{,}4MW = 0{,}17$$

2.2.7.2 Allocation of ELCC and CC (Capacity Credit) to Individual Power Plants

The objective of the studies of the Mexican case is to allocate an ELCC or a CC to each individual power plant based on a variable generation technology such as wind generation, solar generation, co-generation or mini-hydro.

Because it is too complex to carry out a detailed capacity credit study for each new plant, an approximate formula is required that allows allocating a plant-individual ELCC or CC. This approach is described in this section:

As shown in literature, the ELCC of variable generation approaches the average production for very small penetration levels of variable generation. For higher penetration levels, the actual ELCC will be below the average production during the considered time interval but still strongly depends on it. For this reason, the reduction factor R is introduced as being the ration between ELCC and the average production during peak load hours:

$$R = {ELCC}\big/{Pav_{PL}}$$

This reduction factor is calculated on a per technology basis for each scenario:

$$R_{wind} = {ELCC_{wind}}\big/{Pav_{PLwind}}$$

$$R_{cg} = {ELCC_{cg}}\big/{Pav_{PLcg}}$$

$$R_{mh} = {ELCC_{mh}}\big/{Pav_{PLmh}}$$

The allocation of a power-plant specific contribution to ELCC is the following

$$ELCC_i = R_{tech} \cdot Pav_{PLi}$$

The power plant specific capacity credit can be calculated by rating the ELCC of this particular power plant to its installed capacity (or maximum power excess in case of co-generation plants and mini-hydro power plants):

$$CC_i = {ELCC_i}\big/{P_{rated_i}}$$

This approach for allocating ELCC to individual power plants ensures that the sum of all ELCCs of all power plants is equal to the total ELCC contribution of all variable power plants:

$$ELCC_{tech} = \sum_{tech} ELCC_i = R_{tech} \sum_i Pav_{PLi} = R_{tech} Pav_{PLtech}$$

Because this reduction factor R depends highly on the penetration level of each variable generation technology, sensitivity studies will be carried out showing the dependence of R against the penetration level for a given specific distribution of variable generation.

3 Assessment of Capacity Credit of Wind Generation – International Experience

In this section some of the approaches used to evaluate the wind capacity used today in different parts of the world will be surveyed. These methods come from a variety of entities, such as Transmission Organizations, Public Utility Commissions, Utilities et al., or studies carried out on behalf of such organizations.

3.1 United States

3.1.1 Pennsylvania-New Jersey-Maryland Regional Transmission Organization

The capacity credit for wind in PJM RTO is based on the wind generators capacity factor during the peak hours (from 3 p.m. to 7 p.m., from June 1 to August 31). The capacity credit is calculated as a rolling 3-years average, with the most recent data replacing the oldest data. Because of insufficient wind generation data, PJM RTO has applied a capacity credit of 20% for new wind projects, to be replaced by the wind capacity credit as defined earlier once the new plant is in service for at least one year.

3.1.2 GE/NY State Energy Research and Development Authority

A study commissioned by this organization to examine the impact of 3300 MW of wind on the New York system assessed the capacity credit of wind using ELCC. The study used simulated wind data from more than a 100 sites, matched to the year of load data, accounting this way for any underlying correlation between wind and load.

3.1.3 Minnesota Department of Commerce

The MN/DOC examined the impact of 1500 MW of wind capacity distributed at various locations, representing approximately 15% wind penetration. The study used a time-sequential Monte Carlo method, which performed repeated samplings of an annual state transition function based on the wind data. The intent of this approach is to capture the inter-annual wind variations in the estimates of the ELCC.

3.1.4 PacifiCorp

PacifiCorp used for their Integrated Resource Plan the same Monte Carlo approach as MN/DOC

3.1.5 Electric Reliability Council of Texas

ERCOT evaluated the operating wind plants to determine the capacity contribution of wind. The analysis was based on wind generation from 4 p.m. to 6 p.m. during July and August, the peak period for ERCOT. During this period, the average output of the wind was obtained. Because of the variability of wind, the inclusion of a 2% confidence factor is being considered.

3.1.6 Mid-Continent Area Power Pool

The MAPP approach is a monthly method that calculates wind capacity value based on the wind power delivery relative to peak loads. Up to 10 years of data is used when available. Wind data for 4 hour periods around the peak load occurrence are selected for the analysis. The wind generation from that 4 hour periods in all days of the month is then sorted, and the median value is calculated. Such median value is the wind capacity for the month.

3.1.7 Portland General Electric

PGE assumed a 33% capacity credit for the wind generation in its 2002 Integrated Resource Plan.

3.1.8 Idaho Power

IP calculates the capacity credit based on a 100 MW wind plant projected output that would occur 70% or more of the time between 4 p.m. and 8 p.m. during July, IP peak month.

3.2 Chile

The contribution of firm power (or capacity credit) of a non firm generation to the total system capacity, which is part of the tariff scheme for generators in Chile, is calculated in the Chilean system according to a procedure established in the Electrical Sector Regulations, and is based on the outage probabilities of the individual generators. Since the capacity credit of renewable generators is not part of the tariff scheme at the moment, the conventional generation model described in an earlier chapter is used and the procedure is applied to obtain a firm capacity for each conventional generator in the system. As for Regulations, the capacity credit is calculated relative to the peak load condition.

The procedure is mathematically described, for a system with a maximum demand "D" comprising a number "N_c" of two-state units each one with maximum capacities $G_1,\ldots,G_i,\ldots,G_{Nc}$ and unavailability factors $U_1,\ldots,U_i,\ldots,U_{Nc}$, as follows:

From the individual unavailability factors of each unit, the generation states individual and cumulative probabilities are obtained by combining the individual unavailability factors. Then a "Preliminary Firm Capacity" *PFP* is calculated for each unit as:

$$PFP_i = G_i \cdot \Pr(\sum_{j \neq i}^{Nc} X_j > D - G_i) \cdot \Pr(X_i = G_i)$$

Where $X_1,\ldots,X_i\ldots X_{Nc}$ are the maximum powers corresponding to each generation state, and Pr indicates the probability. In other words, the Preliminary Firm capacity of a unit is the product of the maximum capacity of such generator, times the probability of having such maximum capacity available, times the cumulative probability of having a generation available in all other units exceeding the residual demand obtained by subtracting the unit maximum capacity from the total demand.

The Firm Capacity *FC* of the unit is then defined as the product of the maximum demand times the rate of the preliminary firm capacity of the unit to the summation of all the preliminary firm capacities. Mathematically:

$$FC_i = \frac{PFP_i}{\sum_{j=1}^{Nc} PFP_j} \cdot D$$

This procedure does not, as said before, consider variable renewable power sources. To include them, the formula should be expanded as to consider multi-state units in the generation model, and represent the variable power generators as such.

However, because the contribution of generators to the equivalent firm capacity is part of the remuneration scheme in the highly liberalized Chilean power market, this approach, which can be easily extended to variable generating sources has been included into this report.

3.3 Germany – DENA-Study

3.3.1 Results of Capacity Credit Calculations

In the German dena study (see [14]), the capacity credit of wind generation was calculated based on

- Measured wind generation data of existing wind farms.
- Measured and estimated wind speed of planned wind farms.
- Availability and unavailability indices of thermal and hydro power plants
- Equivalent load carrying capability (ELCC) using the loss of load probability at seasonal peak loads.

The purpose of capacity credit calculations in the German dena study was to assess the amount of conventional power plant capacity that can entirely be replaced by wind generation.

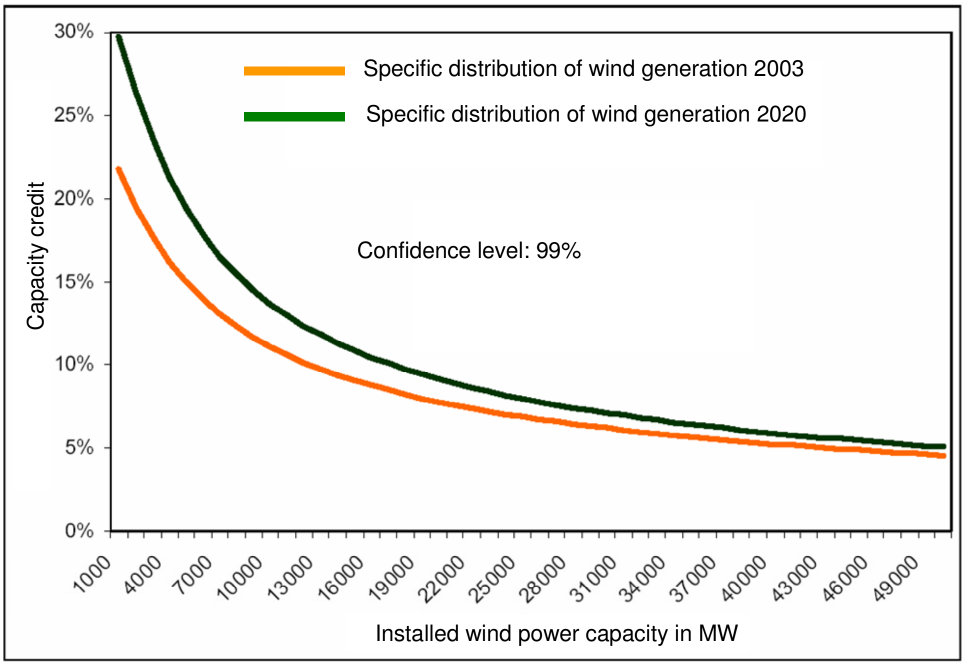

Figure 7: Capacity Credit of German Wind Farms vs. Installed wind generation capacity (Source: [14])

The result of capacity credit calculations according to the dena study [14] is depicted in Figure 7. The results highlight that capacity credit of wind generation depends on two main factors:

- Wind penetration level (Installed wind generation capacity)
- Specific distribution of wind generation

The "specific distribution" reflects two important aspects:

- Wind conditions at the planned sites (weak/strong wind sites)
- Spacial distribution of wind generation

In the dena study [14], capacity credit calculations have been carried out based on the following two assumptions:

- Same specific distribution as in the reference year 2003 (when the studies started)
- Specific distribution of the year 2020 when a high amount of offshore wind generation is foreseen to be grid connected.

The reasons for which the Capacity Credit of wind generation in Germany will be higher when assuming a specific contribution according to the year 2020 are the better wind conditions that will be found offshore compared to German onshore sites.

The results further confirmed that for very low wind penetration levels, the Capacity Credit approximates the Capacity Factor of wind generation.

4 Simulation Studies for the Mexican Case

4.1 System Model Criteria and Methodology

Capacity Credits calculations will require the calculation of system reliability indexes, which in turn will demand the definition of appropriate models for the Variable Power Sources, Conventional Generation, System Load, and their integration in a single system model.

4.1.1 General Approach and Definitions

The approach to be used in this study is based on the loss of load probability criterion (LOLP) at system peak load. For considering correlation effects and for being able to include transmission constraints, a Monte-Carlo based method will be applied. The LOLP will be calculated for different peak load vs. installed generation scenarios, and for each one of them the capacity credit will be calculated using the ELCC (Equivalent Load Carrying Capability) criterion. Because of the particular conditions of the study, the ELCC calculations will be performed for a design-LOLP criterion of 1% (design confidence level of 99%). In this first stage of the study, transmission constraints will not be considered.

With reference to section 2.2, the following modelling approaches are taken:

- Time series model for variable generation (see also section 4.1.2.2)
- Two-state Marcov model for conventional generators (see also section 4.2.2.2)
- Relevant reliability index: ELCC at yearly peak load (see also section 4.1.3.
- Simulation method: Monte Carlo Simulation
- No consideration of transmission constraints.

The example described in section 2.2.7 further illustrates the study approach.

4.1.2 Modelling of Generation

4.1.2.1 Conventional Generation

Conventional generators such as hydro generators, thermal generators, gas turbines, combined cycles units will be modelled as two-state generators (on/off). The criteria used to obtain such availability indexes for each conventional generator in the system are as follows:

- No differentiation is made between forced outages and planned outages.
- The availability index for each generator considered in the system will be obtained as the weighted average of its historical monthly availability covering the period from January 2004 to March 2010 [16].
- De-rated states and un-availabilities of hydraulic units due to water management (when the machine is actually available to be connected to the system) has not been considered.
- Whenever the individual units availability in a plant is not given, but the average availability for the plant is given, then the individual availability will be assigned based on the plant average availability.
- If no unit availability or plant average availability is given for some intervals in the historic data, then such intervals will not be considered in the calculation.
- Whenever no data is present for individual units, or cannot be derived from the data by the before mentioned criteria, an estimated availability index will be used.

- For combined cycle plants availabilities, an approximation of the availability will be obtained based on the available data as follows: when the capacity of the individual generators composing the combined cycle and an individual or plant average availability is indicated in the data, then the individual generators will be treated independently according to the previously defined criteria. If no individual capacity for the generators is given, then the combined cycle will be treated as a single unit (i.e, units will not operate independently).
- The availability indexes for the future units will be based on the average availability indexes for the Mexican system used for planning studies for the period 2010-2018 as reported in [22], p. 3-15. The estimated availability will be of 88% for all units, exception made for hydro units, for which the availability considered will be 87%.

For each probabilistic event, the on-off status of the machine will be drawn according to the obtained availability index of the unit.

4.1.2.2 Variable Generation

The following types of variable generation technologies have been considered in the studies presented in this report:

- Wind Generation
- Cogeneration
- Mini and Micro Hydro
- PV
- Solar-thermal power plants (CSPs, with and without storage)

The modelling of wind generation, co-generation, mini hydro and solar power plants will be described in the following sections.

4.1.2.2.1 Wind Generation

The wind generation considered for the present study consists of various wind farms located in two different regions:

- La Ventosa (Area Oriental system)
- Baja California (Area Baja California Norte system).

The model of the wind generation will consider site –specific homogenized historical wind speed hourly time series for each wind farm in La Ventosa region from historical data from 1999 to 2009 [17].

The model for the Baja California wind farms will be based on 5 synthesized yearly site-specific time series (no official wind data for the Baja California sites is available) [18].

In the presented studies, wind generation is directly derived from time series, which were available over a period of 10 years.

Correlation between load and generation and seasonal correlation is considered by only considering those samples that fall within the considered peak load period and peak load season.

Samples of the different years are drawn arbitrarily, adding a probabilistic component to the wind generation modelling.

The generic power curve (see also [19]), which is depicted in Figure 8, transforms wind speed time series into power infeeds for each individual wind farm.

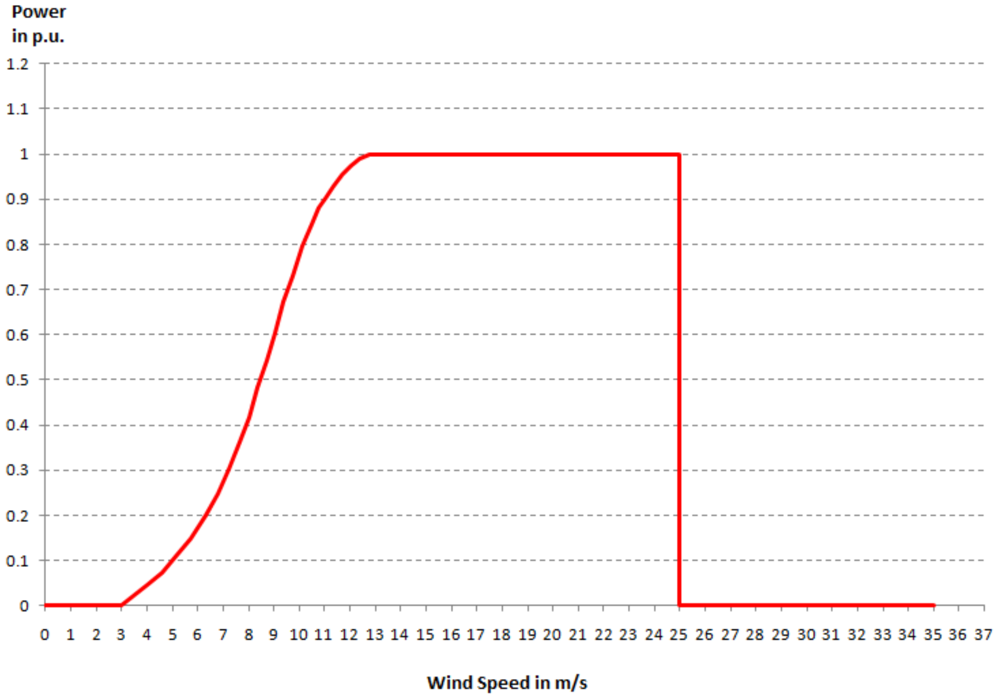

Figure 8: Generic power curve for transforming wind speeds into power injections

4.1.2.2.2 Cogeneration

The cogeneration model is based on power delivered to the system (not the installed cogeneration capacity) after having supplied its own process load. For each region an equivalent lumped model represents co-generation outputs of that particular region. This has been done in this way, because no individual plant information was available.

The probabilistic model used for the lumped generator is multi-state Marcov-Model, i.e., the probability distribution function for the generation output will be given in discrete (tabular) format. Data for this probability distribution function is given in [20].

4.1.2.2.3 Mini Hydro Generation

The probabilistic model for mini and micro hydro generation is analogue to the model for cogeneration plants (see previous section). The mini and micro Hydro generation model is based on the probability distribution function of the per-area mini and micro Hydro generation, according to [24]. Each area lumped equivalent generator will deliver power to the system according to the probability distribution function. Data for this probability distribution function for different possible scenarios is given in [24].

4.1.2.2.4 Photovoltaic Generation

Generally, as explained in the report [15], the correlation between solar power and load is very poor in the SIN (full load hours during evening hours in the SIN) and therefore, it is recommended not to assign a capacity credit to these sources in the SIN.

In the Baja de California system, full load hours are during day time and therefore, PV can have a considerable contribution to the ELCC. It is therefore recommended to assign a capacity credit in the Baja de California system that is based on the average generation during full load hours.

4.1.2.2.5 Solar-Thermal Generation

The contribution of CSPs to capacity credit will highly depend on their storage capability and will therefore be highly project-specific.

When assuming that there is sufficient storage capability available that allows shifting the energy production into the full load hour period, a capacity credit that is equal to the capacity of the storage system can be assigned to a CSP. Besides the size of the storage system, the actual concept for managing the storage system will also have an influence on the capacity credit that one can assign to a CSP plant in Mexico.

When assuming that there is only very low or even no storage capability available, the capacity credit of CSPs in the SIN would be close to zero, as in case of PV.

At present, only a small CSP plant for research purposes is under detailed planning. For this reason, besides the above mentioned considerations with regard to storage, a general methodology for assigning capacity credit to CSPs cannot be recommended at this stage. However, it is recommended to work out capacity credit of CSPs specifically for every project.

In the actual capacity credit studies related to the SIN, no CSP has been considered.

4.1.3 System Load Model

The capacity credit studies will be purely based on an assessment of the capacity of the system that can be provided at a given confidence level. This firm capacity shall obviously be greater or equal to the system peak load.

An assessment of the 2010 load has led to the conclusion, that the installed capacity is so high that any actual loss of load probability is so low that any other approach cannot be applied.

However, daily load variations are considered by only using variable generation data during peak load hours. With this approach, the correlation between load and variable generation is considered with a sufficient degree of accuracy.

4.1.4 Transmission Grid and System Boundaries

4.1.4.1 SIN

Until 2013, the SIN represents an independent system, without any links to any neighbouring network. Therefore, a generation-load balance must be established within the SIN at every moment of time until 2013.

In 2013, a connection to the Baja de California system will probably be commissioned. This link will initially have a rating of 300MW and will connect the SIN to the Baja California system and hence to the American WSCC power system.

Because of the relatively low capacity of the link to Baja de California, also in Scenario 3 (2019), capacity credit for the SIN is still calculated by considering the SIN only. The interconnection to the Baja de California system has been modelled by an equivalent generation with an assumed forced outage rate (FOR) of around 7%/year.

Transmission constraints within the SIN or within Baja de California are generally not considered. The impact of transmission constraints within the SIN has been assessed separately. Corresponding results are presented in section 4.3.4.

4.1.4.2 Baja de California

Most wind farms installed in the Baja de California system will be directly connected to the American WSCC-system and therefore don’t contribute to the Mexican Baja de California system.

The amount of wind farms that are truly integrated into the Baja de California system is very small and therefore the BC system represents a system with very low penetration of renewable generation.

For these reasons, no actual capacity credit studies have been carried out for the Baja de California system.

4.2 Study Scenarios

The study will be performed on three different scenarios, or configurations, each one corresponding to a stage of development of the Mexican system. These scenarios are described as follows:

Scenario 1: This scenario will consider the current system condition. Load will be considered to be the maximum expected for year 2010 as given in [21]. The Wind Generation model will include all currently operational wind farms. The Cogeneration scenario corresponds to the "base scenario" according to [20]. The Mini Hidro scenario corresponds to the "base scenario" according to [23].

Scenario 2: This Scenario will consider the system according to the year 2013 but assuming that the interconnection to the area Baja California Norte has not yet been commissioned (Area Baja California Norte not interconnected). The load scenario of this scenario corresponds to the year 2013. Wind generation will include the currently operational wind farms plus the CFE wind farms required for year 2013 as from [22]. Cogeneration and Mini Hidro scenarios correspond to the "minimum growth scenarios" (scenario "Bajo" in [20] and Base II in [23]). The conventional generation park will be modified according to the generation expansion plans until 2013 described in [22].

Scenario 3: This scenario represents the system conditions for the horizon year of the considered time span of the study. This scenario will consider the area of Baja California Norte interconnected to the system. Wind Generation will consist of all the wind farms in operation and under construction as stated in [17], [18] and [19]. Cogeneration and Mini Hydro scenarios will consider the medium expected growth (scenario "Medio" in [20] and "Alta I" in [23]). The conventional generation park will be modified according to the generation expansion plans until end of 2018 as described in [22].

4.2.1 Scenario 1

4.2.1.1 Overview

Scenario 1 represents the actual configuration of the SIN of the year 2010.

The main parameters of Scenario 1 are the following:

- Total conventional generation (with IPPs but without Self-supply power plants): **48 152 MW**
- Total wind generation: **416 MW** Wind penetration level CP_{wind}=0,86%
- Total cogeneration: Installed: 2502 MW, max. delivery to the SIN: **659 MW** CP_{cg} =1,37%
- Total Min-hydro: Installed 382 MW, max. delivery to the SIN: **328 MW** CP_{mh} =0,68%
- Yearly peak load: **36 042 MW**

4.2.1.2 Conventional Generation

All conventional generation units as considered by Scenario 1 are listed in Table 11 in Annex 1. The total conventional generation considered for the SIN will amount to 48151.733 MW. This total includes units of CFE, LYFC and independent producers (PIE), and does not include self-supply power plants other than those considered as "variable generation" (co-generation and mini-hydro).

4.2.1.3 Wind Generation

Wind generation considered for this scenario will include the currently operational wind farms in the La Ventosa region. All such plants will be considered as connected to the system (PEMEX and CEM projects are listed in [22] as self-supplied systems). The details for such wind generation will be given in Table 1. The wind speed time series associated to each wind farm, and the wind farm's installed capacities are according to [17]. An index as been added to Table 1 referencing the actual time series listed in [17] with the corresponding wind farm.

Table 1: Wind Farms of Scenario 1

Wind Farms considered for the SIN, Scenario 1					
Wind Farm	**Area**	**Mw x unit**	**No of units**	**Total Plant MW**	**Wind Speed Series**
Proyecto Eolico Eurus, CEMEX	Oriental	1.50	167	350.5	1
La Venta II	Oriental	0.85	98	83.3	2
Parques Ecologicod de Mexico PEM	Oriental	0.85	95	80.8	3
La Venta	Oriental	0.23	7	1.6	4
TOTAL MW				416.1	

4.2.1.4 Cogeneration

The cogeneration in the SIN will be represented as per area lumped generation. The detail of such generation, and its generation probability functions, are given in [20] as "Base" scenario. A summary of the lumped generators is given in table 3.

Table 2: Cogeneration of Scenario 1

Cogeneration considered for the SIN LOLP Calculations, Scenario 1				
Cogeneration in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	283.2	3.4	0.9	9.5
Oriental	1299.7	195.4	76.7	322.6
Occidental	464.6	40.9	1.4	89.2
NorOeste	49.5	4.5	0.0	22.9
Norte	35,0	0.04	0.0	0.2
NorEste	353.8	167.2	1.8	206.5
Peninsular	16.2	6.2	0.0	8.2
TOTAL MW	2502.1	417.7	80.9	659.0

According to this table, the cogeneration plants output available to the system is in average 16.7 % of the installed capacity, with a maximum of 26.3 %.

4.2.1.5 Mini Hydro

The Mini Hydro generation in the SIN is represented as per area lumped generation. The detail of such generation, and its generation probability functions, are given in [24] as "Base I" scenario. A summary of the lumped generators is given in table 4.

Table 3: Mini Hydro Generation for Scenario 1

Mini Hydro considered for the SIN LOLP Calculations, Scenario 1				
MiniHydro in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	20.8	6.2	1.4	13.1
Oriental	174.4	105.9	35.4	148.5
Occidental	83.0	45.7	16.8	74.5
NorOeste	42.8	16.2	10.8	38.9
Norte	41.9	14.7	4.5	33.7
NorEste	19.4	10.7	0.5	19.6
Peninsular	0.0	0.0	0.0	0.0
TOTAL MW	382.3	199.4	69.2	328.4

According to this table, the mini Hidro plants output to the system is in average 52.1 % of the installed capacity, with a maximum of 85.9 %.

4.2.2 Scenario 2

4.2.2.1 Overview

Scenario 1 represents the actual configuration of the SIN of the year 2010.

The main parameters of Scenario 1 are the following:

- Total conventional generation (with IPPs but without Self-supply power plants): **49 967 MW**
- Total wind generation: **927 MW** Wind penetration level CP_{wind}=1,85%
- Total cogeneration: Installed: **3 009 MW**, max. delivery to the SIN: **724 MW** CP_{cg} ,=1,45%
- Total Min-hydro: Installed **479 MW**, max. delivery to the SIN: **403 MW** CP_{mh} =0,81%
- Yearly peak load: **39 929 MW**

4.2.2.2 Conventional Generation

The conventional generation modelled for this scenario considers all modifications with regard to commissioned and decommissioned power plants described in [22] , as per tables "Programa de retiros de unidades generadoras, Escenario Base" and Programa de requerimientos de capacidad para servicio público, Escenario base", pp 3-11 and 3-29. Additions and decommission programs up to year 2012 are included in this scenario. Table 12 and Table 13 of Annex-1 list the variations to the conventional generation park of Scenario 1.

4.2.2.3 Wind Generation

For this scenario, only the required wind generation additions for the period up to 2013 according to [22] will be considered. This will result in 5 new wind farms of approximately 100 MW each. The details for such new wind farms, according to [17], [18] and [19] are given in Table 4.

Table 4: Wind farms considered for Scenario 2

Wind Farms considered for Scenario 2					
Wind Farm	**Area**	**Mw x unit**	**No of units**	**Total Plant MW**	**Wind Speed Series**
Proyecto Eolico Eurus, CEMEX	**Oriental**	**1.50**	**167**	**250.5**	**1**
La Venta II	**Oriental**	**0.85**	**98**	**83.3**	**2**
Parques Ecologicod de Mexico PEM	**Oriental**	**0.85**	**95**	**80.8**	**3**
La Venta	**Oriental**	**0.23**	**7**	**1.6**	**4**
La Venta III	**Oriental**	**0.85**	**121**	**102.9**	**7**
Oaxaca I	**Oriental**	**2.00**	**51**	**102.0**	**14**
Oaxaca II	**Oriental**	**1.50**	**68**	**102.0**	**19**
Oaxaca III	**Oriental**	**1.50**	**68**	**102.0**	**20**
Oaxaca IV	**Oriental**	**1.50**	**68**	**102.0**	**21**
TOTAL MW				**927.0**	

4.2.2.4 Cogeneration

The cogeneration model for Scenario 2 corresponds to the scenario "Bajo" according to [20]. A summary of all lumped area cogeneration models is given in Table 5.

Table 5: Cogeneration of Scenario 2

Cogeneration considered for the SIN LOLP Calculations, Scenario 2				
Cogeneration in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	**283.2**	**3.4**	**0.9**	**9.5**
Oriental	**1599.7**	**251.5**	**76.7**	**382.3**
Occidental	**671.9**	**44.4**	**2.1**	**94.6**
NorOeste	**49.51**	**4.5**	**0.0**	**22.9**
Norte	**35.0**	**0.0**	**0.0**	**0.2**
NorEste	**353.9**	**167.2**	**1.8**	**206.5**
Peninsular	**16.3**	**6.2**	**0.0**	**8.2**
TOTAL MW	**3009.7**	**477.4**	**81.5**	**724.2**

For this scenario, the cogeneration plants output available to the system is in average 15.9 % of the installed capacity, with a maximum of 24 %.

4.2.2.5 Mini Hydro

The Mini-Hydro Generation of Scenario 2 corresponds to the scenario "Base II" according to [24]. A summary of the lumped generators is given in Table 6.

Table 6: Mini Hydro Generation for Scenario 2

Mini Hydro considered for the SIN LOLP Calculations, Scenario 2				
MiniHydro in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	**20.8**	**6.2**	**1.4**	**13.1**
Oriental	**224.4**	**129.6**	**54.6**	**181.7**
Occidental	**130.0**	**69.6**	**18.5**	**116.2**
NorOeste	**42.8**	**16.2**	**10.8**	**38.9**
Norte	**41.0**	**14.7**	**4.5**	**33.7**
NorEste	**19.4**	**10.7**	**0.5**	**19.6**
Peninsular	**0.0**	**0.0**	**0.0**	**0.0**
TOTAL MW	**479.3**	**247.0**	**90.2**	**403.3**

According to this table, the mini Hydro plants delivery to the system is in average 51.5 % of the installed capacity, with a maximum of 84.1 %.

4.2.3 Scenario 3

4.2.3.1 Overview

Scenario 3 represents the final study year of the studied time frame and represents the planned SIN system of the year 2019.

The main parameters of Scenario 3 are the following:

- Total conventional generation (with IPPs but without Self-supply power plants): **56 954 MW**
- Interconnection capacity with Baja California Norte: **300 MW**
- Total wind generation: **3 428 MW** Wind penetration level: CP_{wind}=6,05%
- Total cogeneration: Installed: **4 851**, max. delivery to the SIN: **1 288 MW** CP_{cg} =2,26%
- Total Mini-hydro: Installed **585 MW**, max. delivery to the SIN: **496 MW** CP_{mh} =0,87%
- Yearly peak load: **47 861 MW**

4.2.3.2 Conventional Generation

The conventional generation for Scenario 3 considers all commissioned and decommissioned power plants until end of 2018 according to [22] , as per tables "Programa de retiros de unidades generadoras, Escenario Base" and Programa de requerimientos de capacidad para servicio público, Escenario base", pp 3-11 and 3-29, listing the system requirements. Additions and decommissions up to year 2018 will be included in this scenario, to account for generation expansion delays. An overview over all added and removed conventional power plants (compared to Scenario 2) is depicted in Table 14 and Table 15 of Annex-1.

It is to be noted that the two units Manzanillo II currently in service will be upgraded.

4.2.3.3 Wind Generation

For this scenario, all the La Ventosa wind farms in operation or under construction as stated in [24] will be considered to be connected to the system, and along with them the in operation and under construction wind farms in NorEste (Nuevo Leon and Tamaulipas). This will result in a total of 22 wind farms in the area Oriental , and 2 wind farms in NorEste. The details for the new wind farms according to [17], [18] and [19] are given in table 12, in the same format as the wind generation table 2. It is to be noted that the wind speeds for NorEste wind farms are given in synthesized form, for 5 wind correlation factors, in [19].

Table 7: Wind Farms considered for Scenario 3

Wind Farms considered for the SIN LOLP Calculations, Scenario 3					
Wind Farm	**Area**	**Mw x unit**	**No of units**	**Total Plant MW**	**Wind Speed Series**
Proyecto Eolico Eurus, CEMEX	**Oriental**	**1.50**	**167**	**250.5**	**1**
La Venta II	**Oriental**	**0.85**	**98**	**83.3**	**2**
Parques Ecologicod de Mexico PEM	**Oriental**	**0.85**	**95**	**80.8**	**3**
La Venta	**Oriental**	**0.23**	**7**	**1.6**	**4**
La Venta III	**Oriental**	**0.85**	**121**	**102.9**	**7**
Oaxaca I	**Oriental**	**2.00**	**51**	**102.0**	**14**
Oaxaca II	**Oriental**	**1.50**	**68**	**102.0**	**19**
Oaxaca III	**Oriental**	**1.50**	**68**	**102.0**	**20**
Oaxaca IV	**Oriental**	**1.50**	**68**	**102.0**	**21**
Bii Nee Stipa – La Ventosa	**Oriental**	**0.85**	**31**	**26.4**	**La Ventosa 5**
Bii Stinu - Eoliatec del Istmo, SAP de CV	**Oriental**	**1.32**	**124**	**163.7**	**La Ventosa 6**
Desarrollos Eólicos Mexicanos	**Oriental**	**2.00**	**114**	**228.0**	**La Ventosa 8**
Electrica del Valle de Mexico	**Oriental**	**2.50**	**27**	**67.5**	**La Ventosa 9**
Fuerza Eolica del Istmo (1era etapa)	**Oriental**	**1.50**	**20**	**30.0**	**La Ventosa 10**
Fuerza Eolica del Istmo (2da etapa)	**Oriental**	**1.50**	**34**	**51.0**	**La Ventosa 11**
Energía a Alterna Istmeña (Prensa)	**Oriental**	**2.27**	**95**	**215.7**	**La Ventosa 12**
Instituto de Investigaciones Eléctricas	**Oriental**	**5.00**	**1**	**5.0**	**La Ventosa 13**
Parque Eólico de Santo Domingo	**Oriental**	**2.00**	**80**	**160.0**	**La Ventosa 15**
Fuerza y Energía BII Hioxo (Unión Fenosa)	**Oriental**	**0.90**	**252**	**226.8**	**La Ventosa 16**
Vientos del Istmo (Preneal)	**Oriental**	**3.00**	**40**	**120.0**	**La Ventosa 17**
Bii Nee Stipa – Gamesa Energia	**Oriental**	**2.00**	**144**	**288.0**	**La Ventosa 18**
Fuerza Eolica del Istmo (3era etapa)	**Oriental**	**1.50**	**13**	**19.5**	**La Ventosa 22**
Nuevo Leon	**NorEste**			**100.0**	**S. Catarina**
Tamaulipas	**NorEste**			**800.0**	**S. Fernando**
TOTAL MW				**3 428,4**	

4.2.3.4 Cogeneration

The cogeneration model for this scenario is set according to the information given in [20] as "Alto" scenario. A summary of the lumped generators is given in Table 8.

Table 8: Cogeneration for Scenario 3

Cogeneration considered for the SIN, Scenario 3				
Cogeneration in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	**499.5**	**6.6**	**1.9**	**21.8**
Oriental	**2280.0**	**525.5**	**327.5**	**704.9**
Occidental	**966.9**	**125.2**	**68.0**	**192.6**
NorOeste	**78.5**	**28.7**	**17.0**	**52.5**
Norte	**35.0**	**0.0**	**0.0**	**0.2**
NorEste	**863.9**	**196.3**	**16.2**	**276.0**
Peninsular	**127.3**	**31.4**	**6.8**	**40.3**
TOTAL MW	**4850,9**	**913,7**	**437.3**	**1288.2**

For this scenario, the cogeneration plants output available to the system is in average 18.8 % of the installed capacity, with a maximum of 26.5 %.

4.2.3.5 Mini Hydro

The detail of mini hydro generation and its generation probability functions are given in [24] as "Alta I" scenario. A summary of the lumped generators is given in Table 9.

Table 9: Mini Hydro Generation for Scenario 3

Mini Hydro considered for the SIN, Scenario 3				
MiniHydro in Area	**Installed MW**	**Average MW**	**Minimum MW**	**Maximum MW**
Central	**20.80**	**6.17**	**1.38**	**13.13**
Oriental	**330.44**	**202.61**	**71.24**	**274.22**
Occidental	**130.00**	**69.57**	**18.49**	**116.21**
NorOeste	**42.80**	**16.15**	**10.79**	**38.92**
Norte	**41.90**	**14.74**	**4.45**	**33.74**
NorEste	**19.40**	**10.73**	**0.46**	**19.61**
Peninsular	**0.0**	**0.0**	**0.0**	**0.0**
TOTAL MW	**585.34**	**319.96**	**106.81**	**495.83**

According to this table, the mini Hydro output to the system is in average 54.7 % of the installed capacity, with a maximum of 84.7 %.

4.3 Results of Simulation Studies

Based on the modelling assumptions described in section 3 and the scenarios described in section 4.2, Monte Carlo simulation studies have been carried out for assessing the contribution of variable generation to the firm capacity of the SIN.

The results of all studies are presented in the next sections in Figure 9 to Figure 13. Numerical results are available in Annex-2, Table 16 to Table 19.

4.3.1 ELCC and Capacity Credit

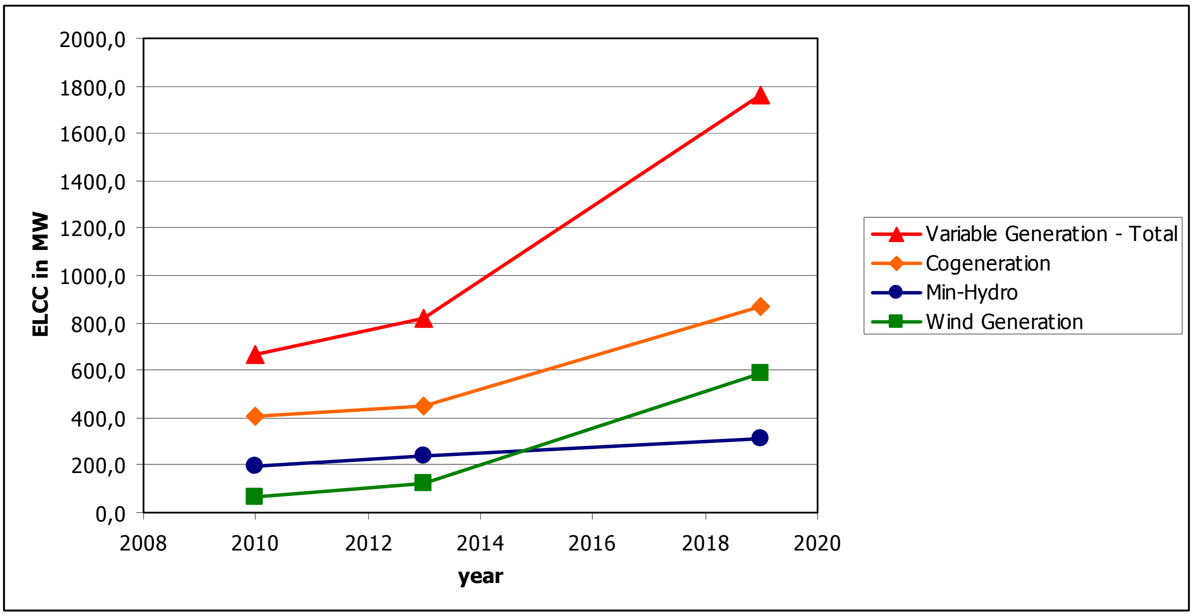

Figure 9: Equivalent Load Carrying Capability (ELCC) of variable generation in the SIN

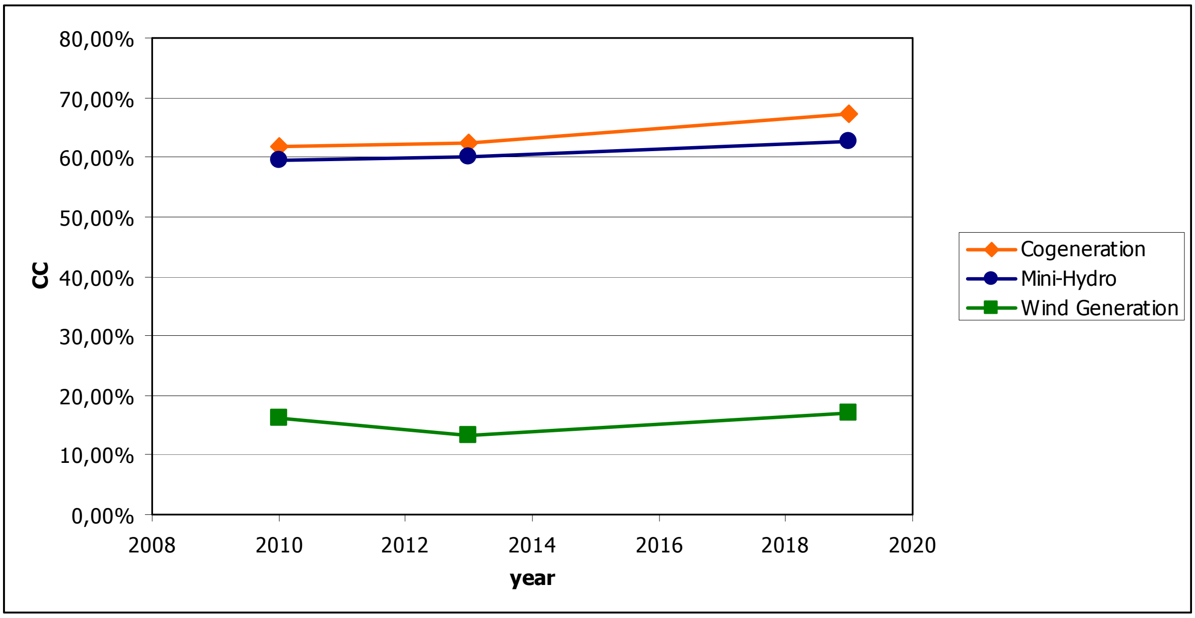

Figure 10: Capacity Credit (CC) of Variable Generation in the SIN

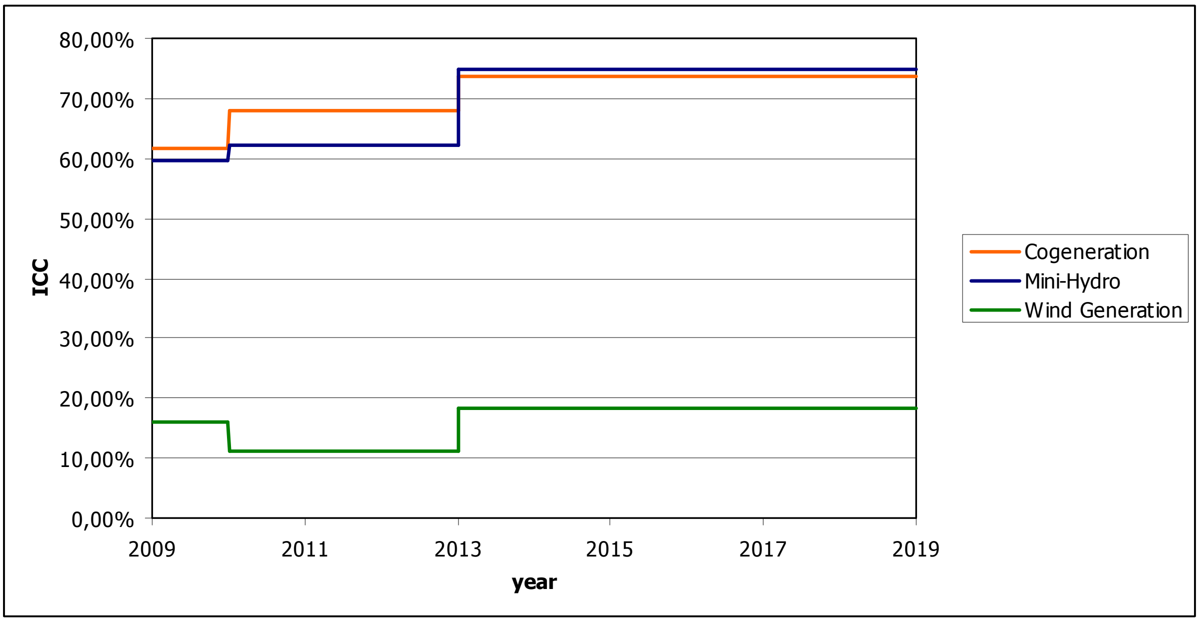

Figure 11: Incremental Capacity Credit (ICC) of Variable Generation in the SIN

The Equivalent Load Carrying Capability of variable generation in the SIN, which is equivalent to the contribution to the firm capacity of the SIN is depicted in Figure 9.

It varies between 600MW in 2010 and 1800MW in 2019 (Scenario 3). The main contribution comes in all scenarios from co-generation.

The capacity credit of the individual power sources rates the ELCC to the installed capacity (wind generation) or maximum delivered power (co-generation and mini-hydro), see also section 4.3.2.

As shown in Figure 10, capacity credit of co-generation plants slightly increases over the years but remains in a range between 60% and 70% in all studied scenarios. The capacity credit of mini-hydro power plants is similar to the capacity credit of co-generation plants.

Capacity credit of wind generation is equal to around 16% in 2010, decreases to a level of around 13% in 2013 and increases again until 2019 up to a level of 17%. This increase between 2013 and 2019 is noticeable because the penetration level of wind generation increases during the same period, which has a reducing effect on capacity credit. However, wind speed properties of wind farms added to the system between 2013 and 2019 and much more favourable with regard to its contribution to the ELCC because of a much better correlation of wind speeds in the NorEste area with full load hours leading to considerable higher capacity credits.

The incremental capacity credit, as depicted in Figure 11 evaluates the contribution of added variable generation to ELCC. Here different properties of variable generation plants are much better visible.

In the case of wind generation, the incremental capacity credit drops to a level of 11% in 2013, which is mainly due to higher wind penetration levels and rises up to around 18% in 2019 because of more favourable wind speed properties of wind farms installed during this time period as explained before.

4.3.2 Allocation to Individual Power Plants

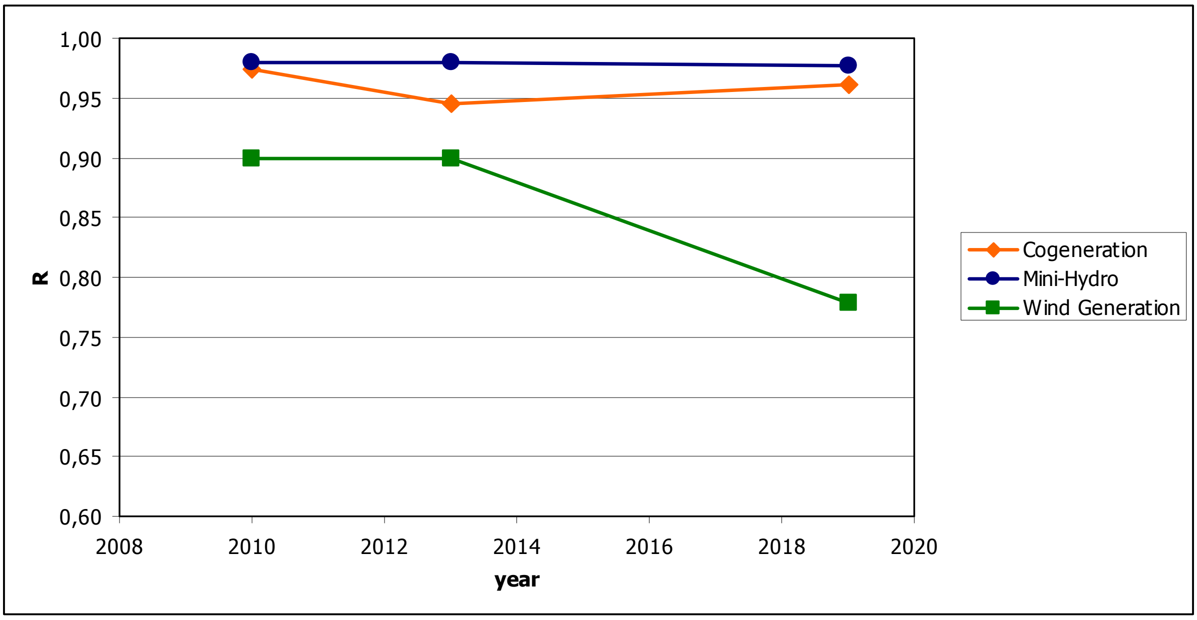

Figure 12: Reduction Factor R of Variable Generation in the SIN

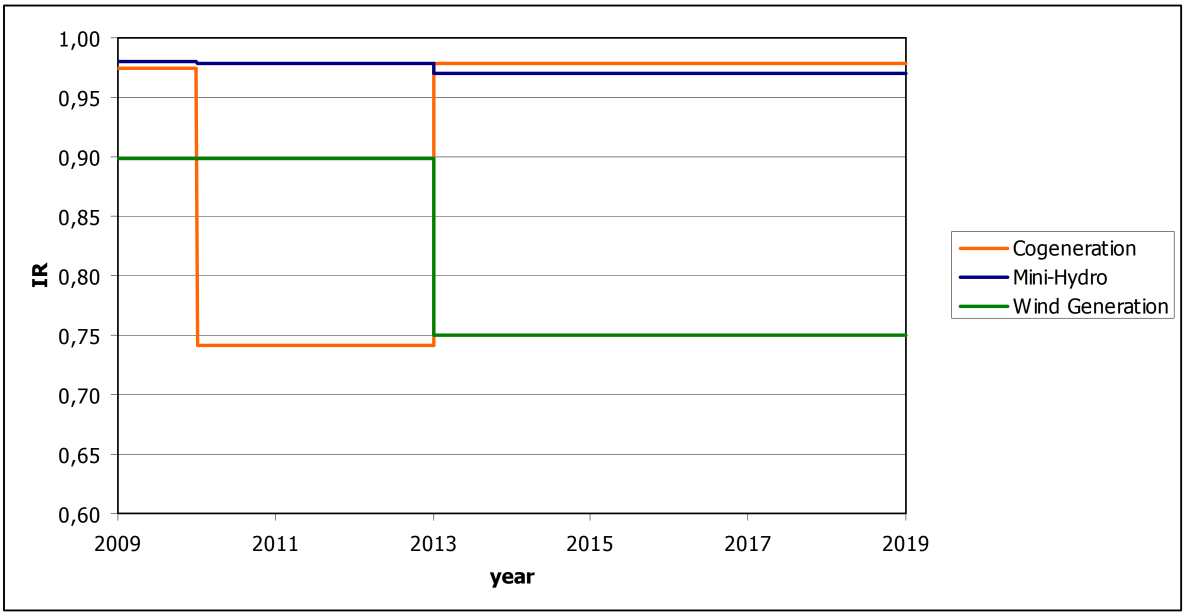

Figure 13: Incremental Reduction Factor IR of Variable Generation in the SIN

For calculating the contribution of individual wind farms to ELCC and for assigning a capacity credit to individual wind-farms, the technology-specific reduction factors R_{cogen}, R_{mh} and R_{wind} have been proposed in section 2.2.5.3.

The absolute reduction factors R, which relate the ELCC to the average production during peak load hours, are depicted in Figure 12.

The "incremental reduction factors" IR, which relate the incremental effect of added variable generator sources to the increment of average production of these power plants are depicted in Figure 13.

Reduction factors of co-generation plants and mini-hydro power plants are very close to 1: They vary in a range between 0,95 and 0,98. It should be considered that there are only very few added co-generation plants in the studies scenarios between 2010 and 2010 and hence, the drop of IR to 0,74 in 2013 is due to the high sensitivity of this coefficient in the case that the average production only increases slightly.

From Figure 12 and Figure 13 it can be concluded that for co-generation and mini-hydro their contribution to ELCC is almost equal to their average production during full load hours.

For wind generation, a considerable decrement of R and IR from around 0,9 to around 0,75 can be observed, which is mainly due to the increased penetration level of wind generation during this period. It must be noted that these incremental factor represent the complete time span between 2019 and 2013. When calculating incremental factors e.g. on a yearly basis, they would be close to to 0,9 in 2013 and subsequently drop to a value below 0,75 because of the slope of the corresponding ELCC-curve.

The shape of the reduction factors for wind (both, R and IR) also demonstrate the validity of the proposed approach: The reduction factors become lower because of increased wind penetration levels whereas the corresponding capacity credits increase because of higher average wind speeds during full load hours. The correlation between load and generation is mainly reflected by the average production during full load hours whereas the influence of wind penetration level is mainly reflected by the reduction factor R.

4.3.3 Sensitivity Studies

The sensitivity studies presented in this section allow analyzing the dependence of capacity credit and reduction actor on penetration level and specific distribution of variable generation (wind, mini-hydro and co-generation).

For each scenario, representing a specific distribution of wind generation, min-hydro, co-generation and conventional generation, the sensitivity of capacity credit and reduction factor of wind generation in function of total penetration level of variable generation (wind+mini-hydro+cogeneration) has been analyzed.

For this purpose, the rating of each modelled variable generation power plant has been scaled up subsequently and the influence of this scaling on the most relevant parameters has been calculated:

- Capacity credit of wind generation CCwind
- Reduction factor of wind generation Rwind
- Incremental capacity credit of wind generation ICCwind
- Incremental reduction factor of wind generation IRwind

By this scaling approach, the so-called "specific distribution of variable generation", meaning the proportion between wind generation, cogeneration and mini-hydro generation as well as specific wind speed properties, remain constant whereas the penetration level of variable generation varies.

The results according to Figure 14 to Figure 17 lead to the following conclusions:

- There is a strong dependence of capacity credit on the specific distribution of variable generation (represented by the three scenarios) and the penetration level of variable generation (see Figure 14 and Figure 15).
- The reduction factor R, which relates capacity credit (CC) to the average production during full load hours however depends much less on the specific distribution of wind generation.

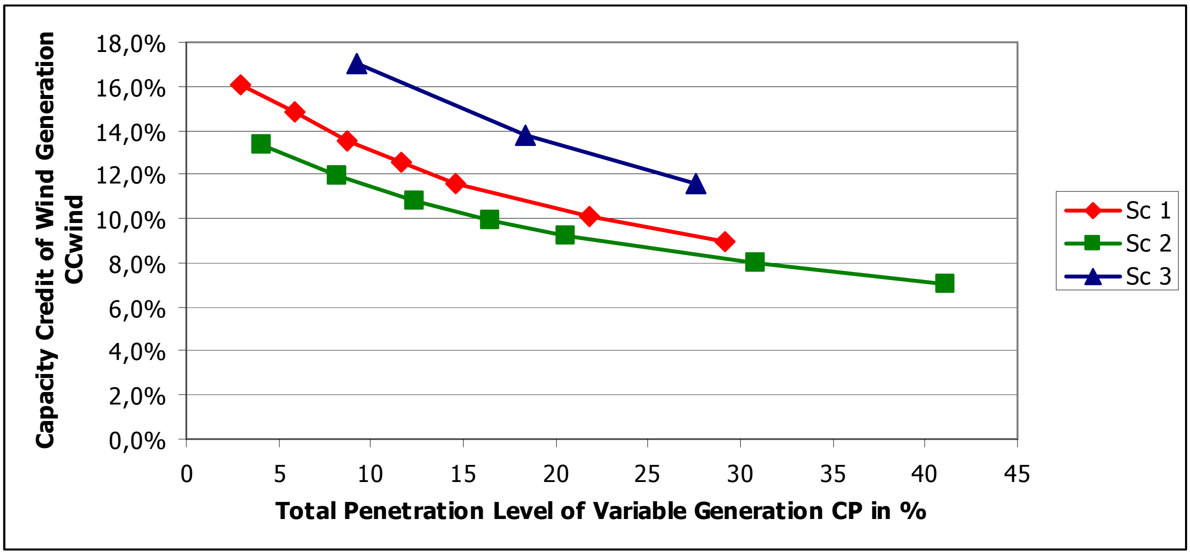

Figure 14: Capacity Credit of Wind Generation (CCwind) in function of the penetration level of variable generation (wind, min-hydro and cogeneration)

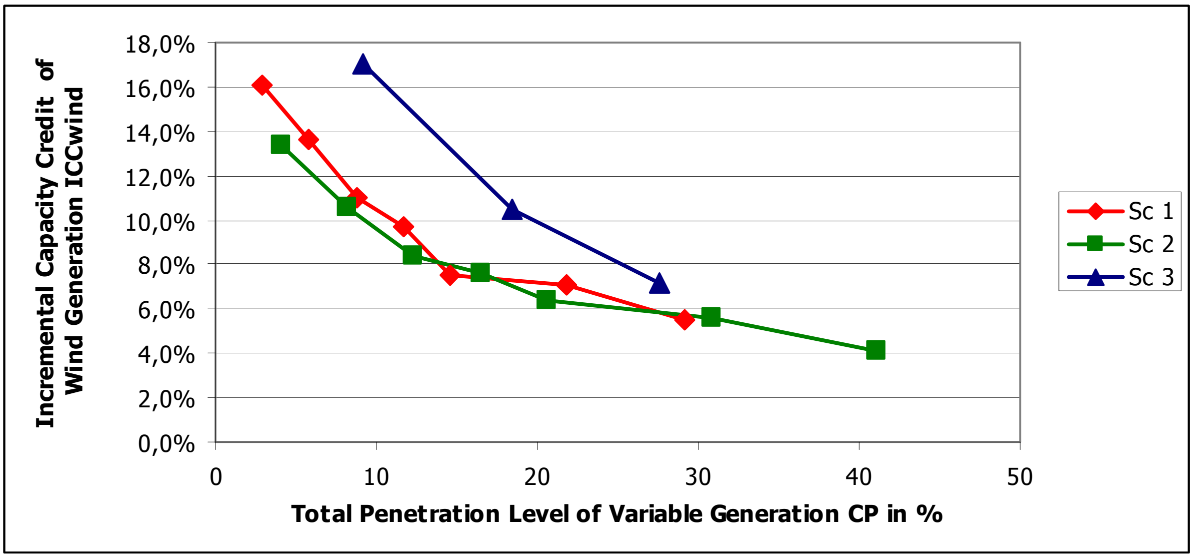

Figure 15: Incremental Capacity Credit of Wind Generation (ICCwind) in function of the penetration level of variable generation (wind, min-hydro and cogeneration)

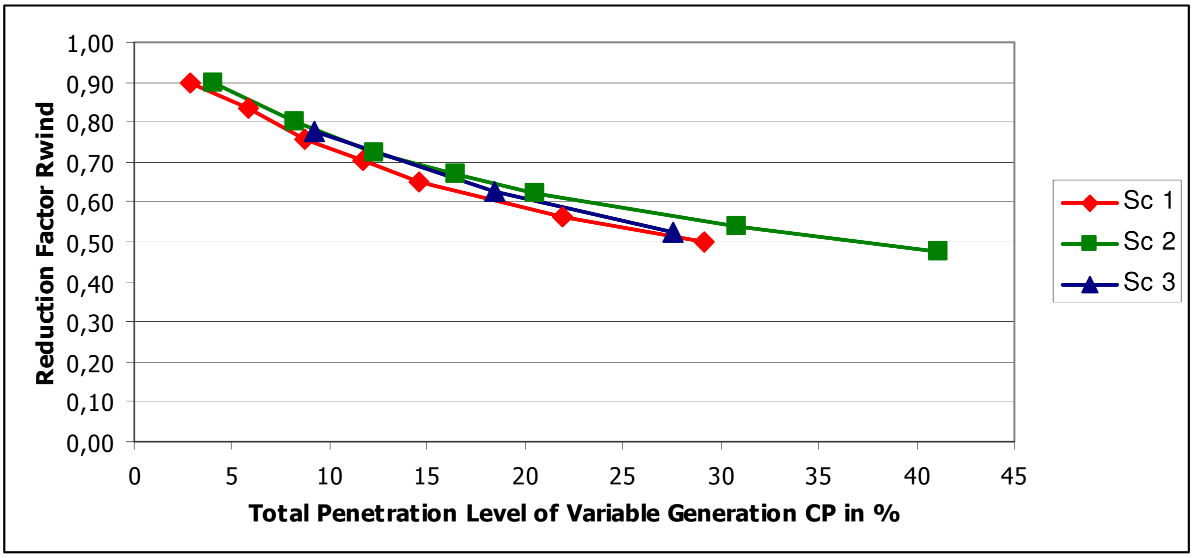

Figure 16: Reduction Factor of Wind Generation (Rwind) in function of the penetration level of variable generation (wind, min-hydro and cogeneration)

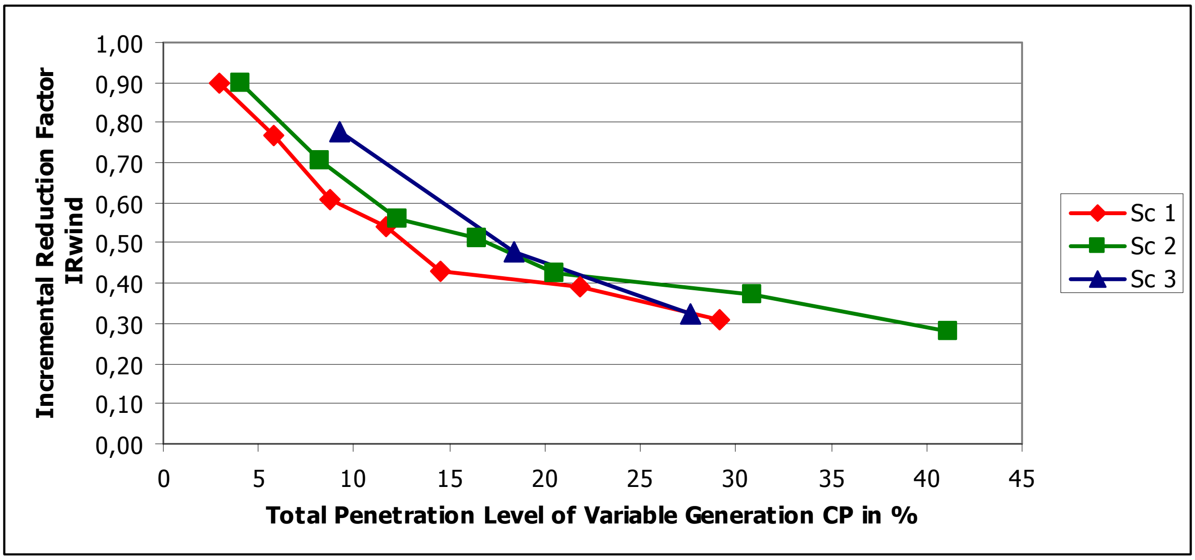

Figure 17: Incremental Reduction Factor of Wind Generation (IRwind) in function of the penetration level of variable generation (wind, min-hydro and cogeneration)

4.3.4 Consideration of Transmission Constraints

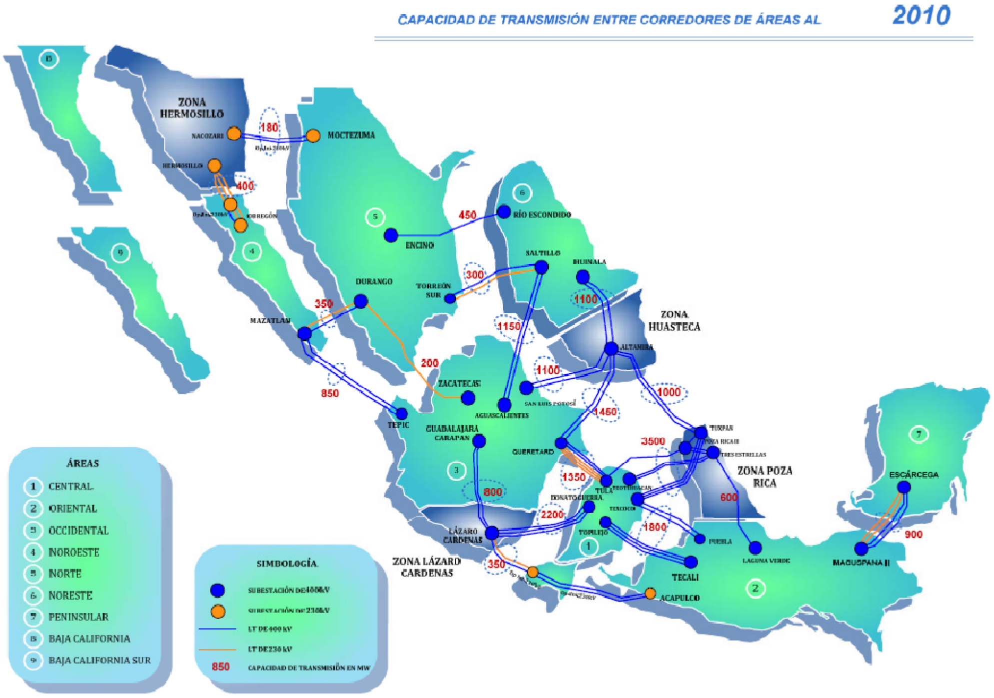

Figure 18: Inter-Area Limits, 7-region model

Table 10: LOLP with and without transmission constraints

	LOLP unconstraint in %	LOLP constraint in %
Sc1	10,09	10,41
Sc2	10,06	10,20
Sc3	10,00	10,19

For assessing whether transmission constraints can have an influence on capacity credit in the SIN, all three scenarios (Sc1, Sc2 and Sc3) have been reassessed using a 7-region model, which considers constraints on transmission lines linking these 7 regions and the regional peak load for the 3 study scenarios (Figure 18 shows an example for such a model).

The results of capacity credit studies with and without transmission constraints show that transmission limits only have an extremely low impact on generation adequacy and hence capacity credit. Table 18 shows results of generation adequacy simulations with and without the consideration of transmission constraints for load levels that lead to a LOLP of around 10% in the unconstraint situation.

As the results according to Table 18 show, the considered transmission constraints have no considerable impact on generation adequacy

For this reason, it is recommended not to consider transmission constraints for the calculation of capacity credit in Mexico but to assess grid reinforcements required for a safe network operation separately from capacity credit considerations.

5 Proposed Methodology for Capacity Credit Evaluation of Variable Energy Sources in Mexico

Based on the fundamental concepts described in the report [15], the definitions introduced in section 3 of this report and the calculation results presented in section 4.3 of this report, a concept for considering the contribution of variable energy sources to the firm capacity of the Mexican power systems is proposed. The concept shall be used for working out a remuneration scheme for the contribution of variable energy sources to the firm capacity of the Mexican system.

The objectives of such a concept are the following:

- It should reflect the actual contribution of variable energy sources to capacity credit as good as possible.
- It should be relatively easy to evaluate and to understand.
- It should be based on data that are available.
- It should be predictable over time in order to ensure a reasonably predictable return of investment.

The contribution of variable energy sources to the firm capacity of a system depends according to section 4.1.1 mainly on the following aspects:

- Average power production (or capacity factor).
- Penetration level of variable power sources (e.g. expressed in terms of the ratio between the installed capacity of variable energy sources and peak load).
- Correlation between power generation of variable sources and load.

Considering the above three aspects, the contribution of each variable power source to the firm capacity of a system can be described by the following approximate formula (see section 2.2.5.2):

$$P_{firm_i} = R(c_p) \times Pav_{FLi}$$

with:

P_{firm_i} : Contribution to the firm capacity of power plant "i"

Pav_{FLi} : Average power production of power plant "i" during full load hours

$R(c_p)$: Reduction factor, which is mainly a function of the penetration level c_p of variable power sources (see also Figure 16).

The correlation between variable generation and load is considered by considering only the power production during full load hours.

5.1 Determination of Pav_{FL}

Pav_{FL} represents the long-term average value of the power production during full load hours of any power plant based on a variable generation source.

For estimating Pav_{FL} the long-term average of the power production during full load hours has to be calculated over time, since the beginning of operation of the power plant. In the beginning, the value of Pav_{FL} will show substantial variations which will become smaller and smaller the longer the power plant is in operation because the measured value of Pav_{Fl} will more and more approximate its long term average.

In the case that the average power production during full load hours P_{avFl} is evaluated on a monthly basis, the evaluation can be carried out based on the following two-step approach:

1.) Evaluation of the monthly average:

$$Pav_{FLmonth} = \frac{1}{n}\sum_{j=1}^{n} P(t_j)$$

With:

- n: Number of time samples during full load hours during the month of consideration.
- $P(t_j)$: Power production at time sample t_j. Only samples during full load hours are considered.

2.) Evaluation of the long term average Pav_{Fl} for the month k:

$$Pav_{FL}(k) = \frac{1}{k}\sum_{i=1}^{k} Pav_{FLmonth}(i)$$

With:

- k: number of months since the commissioning of the power plant.
- $Pav_{Flmonth}(i)$: Average of power production during full load hours of the month "i".

If seasonal effects shall be considered (as it has been done in this study) only the average of months which fall within the peak load season shall be considered by the long-term average.

5.2 Evaluation of R(cp)

The reduction factors R(cp) reflects system-wide aspects and mainly depends on the penetration level of variable power sources.

Reduction factors should be calculated for:

- Different regions (SIN, Baja California)
- Different generation technologies (wind, solar, hydro, cogeneration)

5.2.1 Wind Generation in the SIN

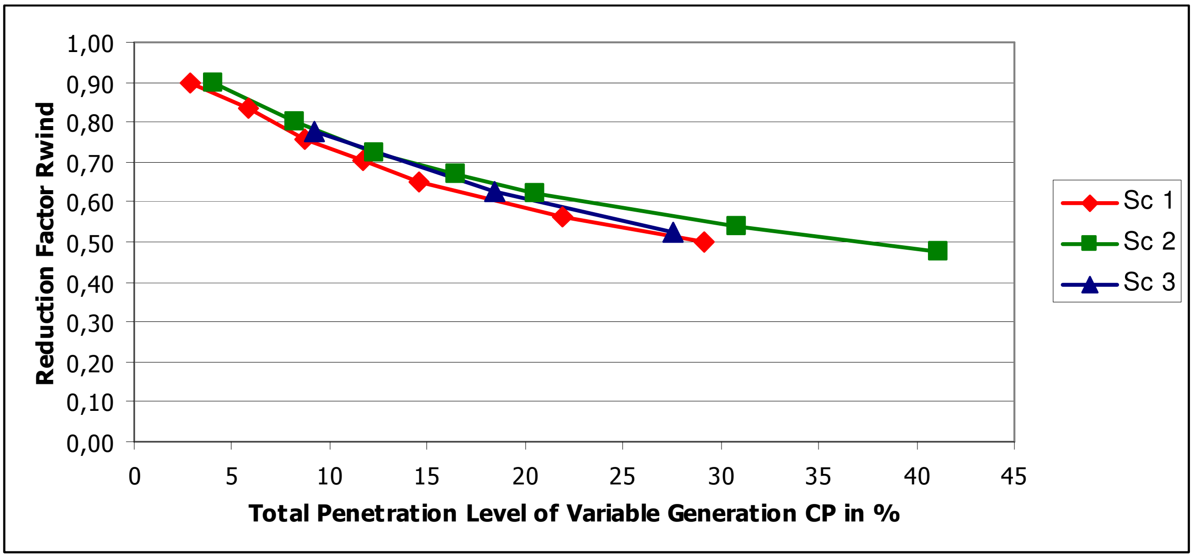

Figure 19: Reduction Factor of Wind Generation (Rwind) in function of the penetration level of variable generation (wind, min-hydro and cogeneration)

An example for the calculation of R(cp) for different technologies based on Monte Carlo simulations of the complete SIN-model is described in section 2.2.7.

The calculation of Rwind(cp) for the SIN requires a complete system simulation considering data of all conventional and variable power plants (see also section 5.3).

For simplifying the process, the penetration level of renewable in the SIN can be calculated and the wind-specific reduction factors can be taken from Figure 19. For a correct interpretation, the following aspects have to be considered:

- The penetration level shown on the x-axis refers to the penetration level of all variable generation sources in the SIN (wind, solar, mini-hydro, cogeneration)
- The reduction factor shown on the y-axis is the reduction factor R for wind generation in the SIN.

The values of R(cp) according to Figure 19 have been obtained with the following considerations:

- In each scenario, the penetration level cp has been varied while keeping the specific distribution of variable energy sources constant. With this approach, the reduction factor R(cp) can also be estimated for the coming years, just by evaluating the actual penetration level of variable energy sources.
- The curves according to Figure 19 further show that the reduction factor R(cp) is very insensitive of the specific distribution of variable generation but mainly depends on the penetration level of variable generation in system.

Only if the structure of the SIN starts deviating considerably from the scenarios analysed in these studies, all reliability studies will have to be re-executed.

For simplicity, it is further recommended to fix and publish the region-wide reduction factors R at the beginning of each year and to leave it constant during the year. For calculating a yearly value of R, the penetration level cp of variable energy sources has to be estimated for every year.

5.2.2 Wind Generation in Baja California

Most wind farms in the Baja California region are directly connected to the American WSCC system and therefore, don’t contribute to the capacity credit within the Baja California system.

Because there are only very few wind farms connected to the Mexican Baja California system, the penetration level of wind generation in BC is very low and consequently, the following assumption is valid for all those wind farms:

- Rwind=1

5.2.3 Mini-hydro and Cogeneration

The results of all studies indicate that reduction factors calculated for Mini-hydro and Cogeneration plants are very close to unity. Therefore it is recommended to consider a reduction factor of:

- Rhyro=1 and
- Rcogen=1

5.2.4 Solar Generation

PV in the SIN will not contribute to capacity credit because their average production during full-load hours tends towards 0. Therefore, their contribution to the equivalent firm capacity of the SIN can be neglected.

In Baja California however, full-load hours are during daytime and PV-plants can have a contribution to capacity credit. Because the penetration levels of solar power plants (PV and soler-thermal/CSP) are very low at present, it is recommended to consider

- Rsolar=1

for the time being.

In case of CSP-plants the available thermal storage capacity will finally determine the contribution to the firm capacity of the system of such a power plant. In the case that there will sufficient thermal storage, CSP-plants can even be considered as dispatchable power plants. In the case that storage is only very small, it will have to be treated more like PV.

5.3 Data Requirements

5.3.1 Mexican Power System

For calculating the reduction factors R, generation reliability studies have to be carried out taking the complete Mexican power system into consideration, as it has been demonstrated in chapter 0 of this report.

For the power system, the following data are required:

- Installed capacity of all Mexican power plants
- Forced and planned outage rates of all Mexican power plants

- Yearly peak load (for the year(s) of consideration)
- Date about variable generation plants as detailed in section 5.3.

Based on this information, the technology-specific reduction factors in function of the penetration level can be calculated for one or several years, as described in chapter 2 and demonstrated in chapter 0.

5.3.2 Variable Generation Power Plants

For every wind farm and for every cogeneration plant the following data are required for carrying out the necessary assessment:

- Time series (e.g. one sample per hour) of the power production.
- Installed capacity (for wind farms)
- Maximum power delivery to the system (cogeneration, hydro)

Based on this information, the average power production Pav during peak load hours of each variable power plant can be calculated according to the method described in section 5.1.

6 Conclusions and Recommendations

This report presents a theoretical overview about the capacity credit concept for assigning to variable generation sources a contribution to the firm capacity of a system (see chapter 2), presents results of corresponding studies for Mexico (see chapter 0) and gives a recommendation for assessing capacity credit of renewable generation (especially wind generation) in Mexico (see chapter 5).

The results of the simulation studies presented in this report show that variable generation sources such as cogeneration, mini-hydro and wind can have a considerable contribution to the firm capacity of the Mexican SIN system (around 670MW in 2010, 820MW in 2013 and around 1760MW in 2019).

Further, the studies have shown that the capacity credit of co-generation plants and mini-hydro power plants is approximately equal to their average production during full load hours.

In case of wind generation, the average production during full load hours has to be multiplied by a reduction factor, which is a system-wide parameter that depends predominantly on the penetration level of variable generation in the SIN (see also Figure 16). This reduction factor varies between R=0,9 in 2010 and R=0,78 in 2019).

For the area Baja California, which is interconnected to the western American power system (WSCC), a reduction factor of R=1 can be assigned to all variable generation sources (including wind and PV) because the penetration level of variable generation can be assumed to be very low.

Power plants based on CSP technologies must be treated differently from other variable generation plants, depending on their thermal storage capacity and their storage management. In the case that sufficiently large storage will be installed, these power plants will actually become dispatchable power plants and should also be treated as such.

From 2013 on, when an interconnection between Baja California and the SIN will be in place, it is recommended to leave system boundaries as they are and to model the impact of the interconnection on generation adequacy in the SIN by an additional generator having a capacity that is equal to the interconnection capacity.

With regard to the actual determination of the average production during full load hours, it is recommended to calculate a long-term average of the generation of each variable generation plant during full load hours, so that over the lifetime of a variable generation plant, this measured average approximates the theoretical mean value during full load hours of the power plant (see also chapter 5).

The reduction factor R of wind generation should be assessed on a yearly basis, based on the existing penetration level of variable generation and Figure 19 or alternatively by carrying out a detailed capacity credit study for every year.

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ANNEX 1: Conventional Generation of the SIN

Table 11: Conventional Generation SIN considered for Senario 1 – Grey: Small hydro power plants (considered as variable generation)

			Conventional Generation SIN						
Unit	**Area**	**Comp**	**MW**	**AVL. %**	**Unit**	**Area**	**Comp**	**MW**	**AVL. %**
Infiernillo 01	CEL	CFE	200.000	77.6334	Cuautitlan	CEL	LYFC	32.000	90.2526
Infiernillo 02	CEL	CFE	200.000	84.7155	Coyotepec	CEL	LYFC	64.000	90.2526
Infiernillo 03	CEL	CFE	160.000	85.0454	Escatepec	CEL	LYFC	32.000	90.2526
Infiernillo 04	CEL	CFE	160.000	90.7468	Iztalapa	CEL	LYFC	32.000	90.2526
Infiernillo 05	CEL	CFE	180.000	88.8021	Lecheria 01	CEL	LYFC	32.000	90.2526
Infiernillo 06	CEL	CFE	180.000	86.4305	Lecheria 02	CEL	LYFC	32.000	90.2526
Villita 01	CEL	CFE	70.000	93.2423	Lecheria 03	CEL	LYFC	32.000	90.2526
Villita 02	CEL	CFE	80.000	82.3219	Lecheria 04	CEL	LYFC	42.000	90.2526
Villita 03	CEL	CFE	80.000	85.5499	Magdalena	CEL	LYFC	42.000	90.2526
Villita 04	CEL	CFE	70.000	94.1186	Nonoalco 01	CEL	LYFC	32.000	90.2526
Portezuelo I 01	CEL	CFE	0.600	74.6664	Nonoalco 02	CEL	LYFC	32.000	90.2526
Portezuelo I 02	CEL	CFE	0.800	74.7097	Nonoalco 03	CEL	LYFC	42.000	90.2526
Portezuelo I 03	CEL	CFE	0.600	74.7269	Nonoalco 04	CEL	LYFC	42.000	90.2526
Portezuelo II 02	CEL	CFE	1.060	65.7515	Vallejo	CEL	LYFC	32.000	90.2526
Tula (F. P. Rios) 01	CEL	CFE	330.000	65.5145	Villa de las Flores	CEL	LYFC	32.000	90.2526
Tula (F. P. Rios) 02	CEL	CFE	330.000	68.2544	Valle de Mexico	CEL	LYFC	88.000	90.2526
Tula (F. P. Rios) 03	CEL	CFE	322.800	62.6672	Victoria	CEL	LYFC	32.000	90.2526
Tula (F. P. Rios) 04	CEL	CFE	322.800	75.2160	Remedios	CEL	LYFC	32.000	90.2526
Tula (F. P. Rios) 05	CEL	CFE	300.000	76.8353	Caracol 01	ORI	CFE	200.000	92.5401
V. Valle de México 01	CEL	CFE	150.000	77.7848	Caracol 02	ORI	CFE	200.000	88.3559
V. Valle de México 02	CEL	CFE	150.000	83.4979	Caracol 03	ORI	CFE	200.000	91.5587
V. Valle de México 03	CEL	CFE	150.000	89.9746	La Venta 01	ORI	CFE	6.000	87.0270
CC Valle de México 04	CEL	CFE	300.000	**82.3312**	La Venta 02	ORI	CFE	6.000	92.2632
CC Valle de México 05	CEL	CFE	83.100	**91.9925**	La Venta 03	ORI	CFE	6.000	87.9431
CC Valle de México 06	CEL	CFE	83.100	**91.9109**	La Venta 04	ORI	CFE	6.000	91.3505
CC Valle de México 07	CEL	CFE	83.100	**93.9015**	La Venta 05	ORI	CFE	6.000	88.2269
Tula 01	CEL	CFE	69.000	91.3246	Colotlipa 01	ORI	CFE	2.000	90.1367
Tula 02	CEL	CFE	69.000	72.3159	Colotlipa 02	ORI	CFE	2.000	93.1879
Tula 03	CEL	CFE	100.000	79.3441	Colotlipa 03	ORI	CFE	2.000	93.5821
Tula 04	CEL	CFE	72.000	84.3758	Colotlipa 04	ORI	CFE	2.000	91.2876
Tula 05	CEL	CFE	72.000	82.4564	Las Cruces 01	ORI	CFE	14.000	96.2922
Tula 06	CEL	CFE	107.000	83.5678	Las Cruces 02	ORI	CFE	14.000	92.7535
El Gallo 01	CEL	CFE	19.000	89.1529	Las Cruces 03	ORI	CFE	15.000	94.4944
El Gallo 02	CEL	CFE	19.000	89.1529	San Lorenzo 01	ORI	CFE	133.000	83.550
Tepuxtepec	CEL	LYFC	60.000	89.1529	San Lorenzo 02	ORI	CFE	133.000	79.182
Necaxa	CEL	LYFC	109.000	89.1529	San Lorenzo 03	ORI	CFE	116.120	99.348
Patla	CEL	LYFC	**37.000**	89.1529	Micos 02	ORI	CFE	0.288	92.5530
Jorge Luque 01	CEL	LYFC	32.000	84.2500	Micos 03	ORI	CFE	0.400	94.9920
Jorge Luque 02	CEL	LYFC	32.000	84.2500	Tuxpan 01	ORI	CFE	350.000	81.8116
Jorge Luque 03	CEL	LYFC	80.000	84.2500	Tuxpan 02	ORI	CFE	350.000	83.1041
Jorge Luque 04	CEL	LYFC	80.000	84.2500	Tuxpan 03	ORI	CFE	350.000	76.0538
Aragon	CEL	LYFC	32.000	90.2526	Tuxpan 04	ORI	CFE	350.000	84.8019
Atencio	CEL	LYFC	32.000	90.2526	Tuxpan 05	ORI	CFE	350.000	85.7249
Coapa	CEL	LYFC	32.000	90.2526	Tuxpan 06	ORI	CFE	350.000	87.7542
Santa Cruz	CEL	LYFC	32.000	90.2526	Tuxpan 07	ORI	CFE	163.000	73.3950

Conventional Generation SIN									
Unit	**Area**	**Comp**	**MW**	**AVL. %**	**Unit**	**Area**	**Comp**	**MW**	**AVL. %**
Poza Rica 01	ORI	CFE	39.000	87.0210	Chicoasen 01	ORI	CFE	300.000	89.7812
Poza Rica 02	ORI	CFE	39.000	83.9981	Chicoasen02	ORI	CFE	300.000	91.9887
Poza Rica 03	ORI	CFE	39.000	89.8451	Chicoasen 03	ORI	CFE	300.000	90.1604
Dos Bocas 01	ORI	CFE	63.000	74.3774	Chicoasen 04	ORI	CFE	300.000	86.9231
Dos Bocas 02	ORI	CFE	63.000	74.7948	Chicoasen 05	ORI	CFE	300.000	87.5497
Dos Bocas 05	ORI	CFE	100.000	70.8716	Chicoasen 06	ORI	CFE	300.000	87.9400
Dos Bocas 03	ORI	CFE	63.000	83.4197	Chicoasen 07	ORI	CFE	300.000	93.8295
Dos Bocas 04	ORI	CFE	63.000	81.6292	Chicoasen 08	ORI	CFE	300.000	84.7226
Dos Bocas 06	ORI	CFE	100.000	75.9215	Malpaso 01	ORI	CFE	180.000	91.6854
Humeros 01	ORI	CFE	5.000	89.8190	Malpaso 02	ORI	CFE	180.000	88.4569
Humeros 02	ORI	CFE	5.000	86.2599	Malpaso 03	ORI	CFE	180.000	78.0053
Humeros 03	ORI	CFE	5.000	91.9036	Malpaso 04	ORI	CFE	180.000	85.9878
Humeros 04	ORI	CFE	5.000	93.1776	Malpaso 05	ORI	CFE	180.000	95.5570
Humeros 05	ORI	CFE	5.000	94.6007	Malpaso 06	ORI	CFE	180.000	93.4162
Humeros 06	ORI	CFE	5.000	94.8858	Angostura 01	ORI	CFE	180.000	89.5432
Humeros 07	ORI	CFE	5.000	93.9707	Angostura 02	ORI	CFE	180.000	90.4539
Humeros 08	ORI	CFE	5.000	95.665	Angostura 03	ORI	CFE	180.000	91.4579
Electroquímica 01	ORI	CFE	1.440	92.8919	Angostura 04	ORI	CFE	180.000	91.8883
Mazatepec 01	ORI	CFE	55.000	90.0278	Angostura 05	ORI	CFE	180.000	89.3649
Mazatepec 02	ORI	CFE	55.000	92.8687	Peñitas 01	ORI	CFE	105.000	94.8243
Mazatepec 03	ORI	CFE	55.000	92.6721	Peñitas 02	ORI	CFE	105.000	95.4884
Mazatepec 04	ORI	CFE	55.000	90.0758	Peñitas 03	ORI	CFE	105.000	95.0405
Temascal 01	ORI	CFE	38.500	93.1213	Peñitas 04	ORI	CFE	105.000	78.8066
Temascal 02	ORI	CFE	38.500	94.2521	J. Cecilio del Valle 02	ORI	CFE	7.000	90.6119
Temascal 03	ORI	CFE	38.500	88.2616	J. Cecilio del Valle 03	ORI	CFE	7.000	93.7308
Temascal 04	ORI	CFE	38.500	92.7760	J. Cecilio del Valle 04	ORI	CFE	7.000	92.0746
Temascal 05	ORI	CFE	100.000	92.5767	Bombaná 01	ORI	CFE	1.320	84.6961
Temascal 06	ORI	CFE	100.000	95.4907	Bombaná 02	ORI	CFE	1.320	85.0967
Tuxpango 01	ORI	CFE	6.000	91.7643	Bombaná 03	ORI	CFE	1.300	88.1509
Tuxpango 02	ORI	CFE	6.000	92.1669	Bombaná 04	ORI	CFE	1.300	89.4929
Tuxpango 03	ORI	CFE	9.000	92.6584	Tamazulapan 01	ORI	CFE	1.240	95.6434
Tuxpango 04	ORI	CFE	15.000	87.7097	Tamazulapan 02	ORI	CFE	1.240	95.3613
Chilapan 01	ORI	CFE	4.000	87.8539	Schpoina 01	ORI	CFE	0.600	94.0329
Chilapan 02	ORI	CFE	4.000	92.3640	Schpoina 02	ORI	CFE	0.600	94.0074
Chilapan 03	ORI	CFE	9.000	93.8631	Schpoina 03	ORI	CFE	1.040	93.4527
Chilapan 04	ORI	CFE	9.000	95.0960	Laguna Verde 01	ORI	CFE	682.400	90.0000
Camilo Arriaga 01	ORI	CFE	9.000	93.5481	Laguna Verde 02	ORI	CFE	682.400	90.0000
Camilo Arriaga 02	ORI	CFE	9.000	89.5201	Tuxpan II - EAT_U1	ORI	PIE	155.000	95.0716
Encanto 01	ORI	CFE	5.000	94.5425	Tuxpan II - EAT_U2	ORI	PIE	155.000	95.0716
Encanto 02	ORI	CFE	5.000	93.2683	Tuxpan II - EAT_U3	ORI	PIE	185.000	95.0716
Minas 01	ORI	CFE	5.000	95.6938	Tuxpan III-IV FET_U1	ORI	PIE	171.500	94.4497
Minas 02	ORI	CFE	5.000	95.3544	Tuxpan III-IV FET_U2	ORI	PIE	160.000	94.4497
Minas 03	ORI	CFE	5.000	95.8000	Tuxpan III-IV FET_U3	ORI	PIE	160.000	94.4497
Texolo 01	ORI	CFE	0.800	88.7493	Tuxpan III-IV FET_U4	ORI	PIE	171.500	94.4497
Texolo 02	ORI	CFE	0.800	89.8958	Tuxpan III-IV FET_U5	ORI	PIE	160.000	94.4497
Ixtacoquitlan 01	ORI	CFE	1.600	81.4198	Tuxpan Iii-IV FET_U6	ORI	PIE	160.000	94.4497

Conventional Generation SIN									
Unit	**Area**	**Comp**	**MW**	**AVL. %**	**Unit**	**Area**	**Comp**	**MW**	**AVL. %**
Tuxpan V - ETS_U1	ORI	PIE	155.000	97.7965	Huicot 01	OCC	CFE	1.180	95.000
Tuxpan V - ETS_U2	ORI	PIE	155.000	97.7965	Petacalco 01	OCC	CFE	350.000	72.350
Tuxpan V - ETS_U3	ORI	PIE	185.000	97.7965	Petacalco 02	OCC	CFE	350.000	74.538
Cupatitzio 01	OCC	CFE	36.225	95.389	Petacalco 03	OCC	CFE	350.000	84.386
Cupatitzio 02	OCC	CFE	36.225	95.374	Petacalco 04	OCC	CFE	350.000	80.963
Cobano 01	OCC	CFE	26.010	87.524	Petacalco 05	OCC	CFE	350.000	89.318
Cobano 02	OCC	CFE	26.010	89.775	Petacalco 06	OCC	CFE	350.000	85.087
Platanal 01	OCC	CFE	5.600	95.311	Azufres 02	OCC	CFE	5.000	95.708
Platanal 02	OCC	CFE	3.600	91.580	Azufres 03	OCC	CFE	5.000	89.843
Botello 01	OCC	CFE	4.050	81.742	Azufres 04	OCC	CFE	5.000	95.799
Botello 02	OCC	CFE	9.000	91.231	Azufres 05	OCC	CFE	5.000	93.741
Tirio 02	OCC	CFE	0.216	95.412	Azufres 06	OCC	CFE	5.000	91.909
Tirio 03	OCC	CFE	0.240	96.156	Azufres 07	OCC	CFE	50.000	86.479
Tirio 04	OCC	CFE	0.640	88.813	Azufres 09	OCC	CFE	5.000	89.843
Bartolinas 01	OCC	CFE	0.400	80.139	Azufres 10	OCC	CFE	5.000	92.650
Bartolinas 02	OCC	CFE	0.350	87.269	Azufres 11	OCC	CFE	1.450	21.614
Itzicuaro 01	OCC	CFE	0.312	91.146	Azufres 12	OCC	CFE	1.450	27.311
Itzicuaro 02	OCC	CFE	0.312	93.374	Azufres 13	OCC	CFE	26.800	79.678
Zumpimito 01	OCC	CFE	0.800	85.188	Azufres 14	OCC	CFE	26.600	90.338
Zumpimito 02	OCC	CFE	0.800	90.845	Azufres 15	OCC	CFE	26.600	88.084
Zumpimito 03	OCC	CFE	2.400	88.725	Azufres 16	OCC	CFE	26.600	83.222
Zumpimito 04	OCC	CFE	2.400	90.387	El Verde 01	OCC	CFE	24.000	97.970
San Pedro Poruas 01	OCC	CFE	1.600	94.577	Villa de Reyes 01	OCC	CFE	350.000	87.311
San Pedro Poruas 03	OCC	CFE	0.960	95.007	Villa de Reyes 02	OCC	CFE	350.000	71.177
Puente Grande 03	OCC	CFE	2.800	83.510	Zimapán 01	OCC	CFE	146.000	90.832
Puente Grande 05	OCC	CFE	9.000	93.095	Zimapán 02	OCC	CFE	146.000	91.624
Intermedia 01	OCC	CFE	5.320	88.299	Salamanca 01	OCC	CFE	158.000	78.860
Santa Rosa 01	OCC	CFE	30.600	88.349	Salamanca 02	OCC	CFE	158.000	87.878
Santa Rosa 02	OCC	CFE	30.600	86.124	Salamanca 03	OCC	CFE	300.000	65.679
Jumatán 01	OCC	CFE	0.220	85.990	Salamanca 04	OCC	CFE	250.000	45.230
Jumatán 02	OCC	CFE	0.220	85.338	El Sauz 01	OCC	CFE	52.000	95.828
Jumatán 03	OCC	CFE	0.500	86.878	El Sauz 02	OCC	CFE	52.000	95.657
Jumatán 04	OCC	CFE	1.240	85.949	El Sauz 03	OCC	CFE	52.000	93.421
Agua Prieta 01	OCC	CFE	120.000	88.239	El Sauz 04	OCC	CFE	68.000	95.428
Agua Prieta 02	OCC	CFE	120.000	87.256	El Sauz 05	OCC	CFE	122.000	60.473
Aguamilpa 01	OCC	CFE	320.000	92.876	El Sauz 06	OCC	CFE	129.000	85.170
Aguamilpa 02	OCC	CFE	320.000	80.932	El Sauz 07	OCC	CFE	128.000	70.855
Aguamilpa 03	OCC	CFE	320.000	78.546	Chilatan 01	OCC	CFE	14.500	89.153
El Cajón 01	OCC	CFE	375.000	76.606	Bajio - BAJ_U1	OCC	PIE	150.000	95.437
El Cajón 02	OCC	CFE	375.000	63.033	Bajio - BAJ_U2	OCC	PIE	115.000	95.437
Manzanillo 01	OCC	CFE	300.000	82.522	Bajio - BAJ_U3	OCC	PIE	115.000	95.437
Manzanillo 02	OCC	CFE	300.000	80.720	Bajio - BAJ_U4	OCC	PIE	115.000	95.437
Manzanillo 03	OCC	CFE	300.000	81.007	Sanalona 01	NOR	CFE	7.000	95.460
Manzanillo 04	OCC	CFE	300.000	82.861	Sanalona 02	NOR	CFE	7.000	95.802
Manzanillo II 01	OCC	CFE	350.000	83.282	Humaya 01	NOR	CFE	45.000	91.503
Manzanillo II 02	OCC	CFE	350.000	84.386	Humaya 02	NOR	CFE	45.000	93.948

Conventional Generation SIN									
Unit	**Area**	**Comp**	**MW**	**AVL. %**	**Unit**	**Area**	**Comp**	**MW**	**AVL. %**
Novillo 01	NOR	CFE	45.000	94.068	Chávez 01	NTE	CFE	14.000	98.740
Novillo 02	NOR	CFE	45.000	93.209	Chávez 02	NTE	CFE	14.000	97.397
Novillo 03	NOR	CFE	45.000	95.236	Samalayuca 01	NTE	CFE	158.000	93.458
Oviachic 01	NOR	CFE	9.600	90.364	Samalayuca 02	NTE	CFE	158.000	86.238
Oviachic 02	NOR	CFE	9.600	88.636	Samalayuca 03	NTE	CFE	114.400	86.629
Mocuzari 01	NOR	CFE	9.600	89.078	Samalayuca 04	NTE	CFE	59.520	86.510
El Fuerte 01	NOR	CFE	19.800	93.413	Samalayuca 05	NTE	CFE	114.400	91.523
El Fuerte 02	NOR	CFE	19.800	95.432	Samalayuca 06	NTE	CFE	59.520	91.370
El Fuerte 03	NOR	CFE	19.800	94.344	Samalayuca 07	NTE	CFE	114.400	93.824
Bacurato 01	NOR	CFE	46.000	93.517	Samalayuca 08	NTE	CFE	59.520	93.733
Bacurato 02	NOR	CFE	46.000	90.497	Francisco Villa 04	NTE	CFE	150.000	86.879
Comedero 01	NOR	CFE	50.000	96.511	Francisco Villa 05	NTE	CFE	150.000	87.241
Comedero 02	NOR	CFE	50.000	96.443	Gómez Palacio 01	NTE	CFE	73.400	55.989
Huites 01	NOR	CFE	211.000	97.912	Gómez Palacio 02	NTE	CFE	73.400	74.803
Huites 02	NOR	CFE	211.000	95.390	Gómez Palacio 03	NTE	CFE	93.000	72.859
Puerto Libertad 01	NOR	CFE	158.000	83.906	Lerdo 01	NTE	CFE	160.000	89.459
Puerto Libertad 02	NOR	CFE	158.000	72.366	Lerdo 02	NTE	CFE	160.000	88.064
Puerto Libertad 03	NOR	CFE	158.000	79.917	El Encino 01	NTE	CFE	138.150	90.968
Puerto Libertad 04	NOR	CFE	158.000	82.092	El Encino 02	NTE	CFE	138.150	90.682
Guaymas II 01	NOR	CFE	84.000	79.538	El Encino 03	NTE	CFE	147.000	89.492
Guaymas II 02	NOR	CFE	84.000	86.050	El Encino 04.	NTE	CFE	130.800	83.531
Guaymas II 03	NOR	CFE	158.000	79.441	El Encino 05.	NTE	CFE	65.300	91.183
Guaymas II 04	NOR	CFE	158.000	67.941	Chihuahua III -PTC_P1	NTE	PIE	271.000	92.2916
Topolobampo 01	NOR	CFE	160.000	85.483	La Laguna II - IEL_U1	NTE	PIE	165.000	90.2016
Topolobampo 02	NOR	CFE	160.000	88.713	La Laguna II - IEL_U2	NTE	PIE	165.000	90.2016
Mazatlán 01	NOR	CFE	158.000	77.304	La Laguna II _ IEL_U3	NTE	PIE	168.000	90.2016
Mazatlán 02	NOR	CFE	158.000	86.604	Huinalá 01	NES	CFE	62.340	92.175
Mazatlán 03	NOR	CFE	300.000	76.863	Huinalá 02	NES	CFE	62.340	90.390
Caborca 01	NOR	CFE	12.000	97.000	Huinalá 03	NES	CFE	62.340	90.368
Caborca 02	NOR	CFE	30.000	97.478	Huinalá 04	NES	CFE	62.340	95.144
Ciudad Obregón 01	NOR	CFE	14.000	96.755	Huinalá 05	NES	CFE	128.300	88.591
Ciudad Obregón 02	NOR	CFE	14.000	96.859	Huinalá 06	NES	CFE	150.000	93.121
Culiacán 01	NOR	CFE	30.000	95.990	Huinalá II 07	NES	CFE	225.099	87.941
CC. Hermosillo 01	NOR	CFE	133.770	73.832	Huinalá II 08	NES	CFE	225.099	84.835
CC. Hermosillo 02	NOR	CFE	93.252	86.193	Universidad 01	NES	CFE	12.000	96.052
Hermosillo - FEH_P1	NOR	PIE	250.000	96.362	Universidad 02	NES	CFE	12.000	94.270
Naco Nogales-FEN_U1	NOR	PIE	158.000	89.338	Leona 01	NES	CFE	12.000	99.845
Naco Nogales-FEN_U2	NOR	PIE	100.000	89.338	Leona 02	NES	CFE	12.000	99.708
Parque 02	NTE	CFE	18.000	98.951	Río Escondido 01	NES	CFE	300.000	93.023
Parque 03	NTE	CFE	13.000	96.056	Río Escondido 02	NES	CFE	300.000	89.281
Parque 04	NTE	CFE	28.000	96.618	Río Escondido 03	NES	CFE	300.000	95.057
Industrial 01	NTE	CFE	18.000	98.957	Río Escondido 04	NES	CFE	300.000	93.981
La Laguna 05	NTE	CFE	14.000	96.976	Carbón II 01	NES	CFE	350.000	78.992
La Laguna 06	NTE	CFE	14.000	98.127	Carbón II 02	NES	CFE	350.000	76.316
La Laguna 07	NTE	CFE	14.000	96.560	Carbón II 03	NES	CFE	350.000	73.471
La Laguna 08	NTE	CFE	14.000	97.745	Carbón II 04	NES	CFE	350.000	76.442

Conventional Generation SIN									
Unit	Area	Comp	MW	AVL. %	Unit	Area	Comp	MW	AVL. %
Fundidora 01	NES	CFE	12.000	99.986	Anahuac - CAH_U1	NES	PIE	170.000	84.8924
Tecnologico 01	NES	CFE	26.000	99.968	Anahuac - CAH_U2	NES	PIE	170.000	84.8924
Río Bravo 03	NES	CFE	33.000	63.971	Anahuac - CAH_U3	NES	PIE	155.000	84.8924
Río Bravo 01	NES	CFE	33.000	65.793	TamazunchaleTMH_U1	NES	PIE	180.000	97.7081
Río Bravo 02	NES	CFE	145.123	79.834	TamazunchaleTMH_U2	NES	PIE	180.000	97.7081
Río Bravo 04.	NES	CFE	18.000	96.866	TamazunchaleTMH_U3	NES	PIE	180.000	97.7081
Monclova 01	NES	CFE	30.000	99.011	TamazunchaleTMH_U4	NES	PIE	180.000	97.7081
Monclova 02	NES	CFE	6.250	92.939	TamazunchaleTMH_U5	NES	PIE	205.000	97.7081
Boquilla 01	NES	CFE	6.250	93.824	TamazunchaleTMH_U6	NES	PIE	210.000	97.7081
Boquilla 02	NES	CFE	6.250	94.733	Mérida II 01	PEN	CFE	84.000	84.728
Boquilla 03	NES	CFE	6.250	93.493	Mérida II 02	PEN	CFE	84.000	81.420
Boquilla 04	NES	CFE	6.250	98.003	Mérida II 03	PEN	CFE	30.000	77.743
Colina 01	NES	CFE	3.000	90.352	Cancún 01	PEN	CFE	14.000	83.891
Amistad 01	NES	CFE	33.000	91.152	Cancún 02	PEN	CFE	14.000	84.780
Amistad 02	NES	CFE	10.500	95.355	Cancún 03	PEN	CFE	30.000	77.497
Falcón 01	NES	CFE	10.500	94.942	Cancún 05	PEN	CFE	44.000	60.459
Falcón 02	NES	CFE	10.500	95.757	Nizuc 01	PEN	CFE	44.000	78.322
Falcón 03	NES	CFE	150.000	87.4565	Nizuc 02	PEN	CFE	44.000	53.744
Altamira 01	NES	CFE	150.000	72.2794	F. Carrillo Puerto 01	PEN	CFE	37.500	88.254
Altamira 02	NES	CFE	250.000	38.9635	F. Carrillo Puerto 02	PEN	CFE	37.500	86.454
Altamira 03	NES	CFE	250.000	56.5538	F. Carrillo Puerto 03	PEN	CFE	80.000	78.059
Altamira 04	NES	CFE	33.000	63.971	F. Carrillo Puerto 04	PEN	CFE	70.000	83.117
Altamira II - EAA_U1	NES	PIE	155.000	84.2559	F. Carrillo Puerto 05	PEN	CFE	70.000	90.281
Altamira II - EAA_U2	NES	PIE	155.000	84.2559	Lerma 01	PEN	CFE	37.500	85.786
Altamira II - EAA_U3	NES	PIE	185.000	84.2559	Lerma 02	PEN	CFE	37.500	74.346
Altamira III-IVATC_U1	NES	PIE	170.000	90.7524	Lerma 03	PEN	CFE	37.500	86.695
Altamira III-IVATC_U2	NES	PIE	170.000	90.7524	Lerma 04	PEN	CFE	37.500	73.398
Altamira III-IVATC_U3	NES	PIE	170.000	90.7524	Nachicocom 03	PEN	CFE	30.000	60.109
Altamira III-IVATC_U4	NES	PIE	170.000	90.7524	Xul-Ha 01	PEN	CFE	14.000	33.176
Altamira III-IVATC_U5	NES	PIE	178.000	90.7524	C. Del Carmen 01	PEN	CFE	14.000	89.608
Altamira III-IVATC_U6	NES	PIE	178.000	90.7524	C. Del Carmen 02	PEN	CFE	16.000	89.204
Altamira V - ATV_U1	NES	PIE	180.000	96.9118	C. Del Carmen 03	PEN	CFE	17.000	89.204
Altamira V - ATV_U2	NES	PIE	180.000	96.9118	Hol-Box 06	PEN	CFE	0.800	96.037
Altamira V - ATV_U3	NES	PIE	180.000	96.9118	Hol-Box 07	PEN	CFE	0.800	89.615
Altamira V - ATV_U4	NES	PIE	180.000	96.9118	Hol-Box 08	PEN	CFE	0.800	71.112
Altamira V - ATV_U5	NES	PIE	200.000	96.9118	Hol-Box 09	PEN	CFE	0.800	91.708
Altamira V - ATV_U6	NES	PIE	201.000	96.9118	Chankanaab 01	PEN	CFE	14.000	83.141
Rio Bravo III - RBT_U1	NES	PIE	160.000	90.4407	Chankanaab 02	PEN	CFE	14.000	75.779
Rio Bravo III - RBT_U2	NES	PIE	165.000	90.4407	Chankanaab 04	PEN	CFE	25.000	86.031
Rio Bravo III - RBT_U3	NES	PIE	170.000	90.4407	Campeche - CPC_P1	PEN	PIE	252.000	86.8642
Rio Bravo IV - RBC_U1	NES	PIE	165.000	95.7885	Merida III - MDP_U1	PEN	PIE	160.000	89.7260
Rio Bravo IV - RBC_U2	NES	PIE	165.000	95.7885	Merida III - MDP_U2	PEN	PIE	160.000	89.7260
Rio Bravo IV - RBC_U3	NES	PIE	170.000	95.7885	Merida III - MDP_U3	PEN	PIE	164.000	89.7260
Monterrey III -CDU_U1	NES	PIE	244.500	96.5821	Valladolid III - VLT_U1	PEN	PIE	170.000	94.2637
Monterrey III -CDU_U2	NES	PIE	244.000	96.5821	Valladolid III - VLT_U2	PEN	PIE	170.000	94.2637
Saltillo - CSO_P1	NES	PIE	247.500	92.6722	Valladolid III - VLT_U3	PEN	PIE	185.000	94.2637

Table 12: Scenario 2- Newly installed conventional generation in the SIN

Additional Generation considered for Scenario 2			
Project	**Type**	**Capacity units x MW**	**Area**
CC Norte (La Trinidad)	**Combined cycle**	**3 x 155.33**	**Norte**
Carboelectrica del Pacifico	**Thermal**	**2 x 339**	**Occidental**
Humeros fase B	**Thermal**	**7x 3.3**	**Oriental**
Humeros fase A	**Thermal**	**1 x 28**	**Oriental**
Manzanillo U1 (upgrade)[1] (1)	**Combined cycle**	**1x 460**	**Occidental**
Manzanillo U2 (upgrade) (1)	**Combined cycle**	**1 x 460**	**Occidental**
La Yesca	**Hidro**	**2 x 375**	**Occidental**
Norte II (Chihuahua)	**Combined cycle**	**3 x 153**	**Norte**
Agua Prieta II	**Combined cycle**	**3 x 159**	**NorOeste**
TOTAL MW		**3801,1**	

Table 13: Scenario 2- Decommissioned conventional generation

Decommissioned Generation considered for Scenario 2			
Plant	**Units**	**Capacity MW**	**Area**
Salamanca	**1, 2**	**316**	**Occidental**
Nonoalco	**1 - 4**	**148**	**Central**
Lerma	**2 - 4**	**112.5**	**Peninsular**
Felipe Carrillo Puerto	**1,2**	**75**	**Peninsular**
Dos Bocas	**1 - 6**	**452**	**Oriental**
Jorge Luque	**1 -3**	**144**	**Central**
Lecheria	**1 - 4**	**138**	**Central**
TOTAL MW		**1385.5**	

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[1] *these units will substitute the current units 1 and 2 at Manzanillo I plant (300 MW each)*

Table 14: Scenario 3- Newly installed conventional generation in the SIN

Additional Generation considered for the SIN, Scenario 3			
Project	**Type**	**Capacity units x MW**	**Area**
Rio Moctezuma	Hydro	2 x 40, 1 x 12	Occidental
Salamanca fase I	-	1 x 314	Occidental
Valle de Mexico II	Combined Cycle	2 x 300.5	Central
Norte III	Combined Cycle	6 x 115	Norte
Ampliacion Villita	Hydro	2 x 75	Central
Noreste (Escobedo)	Combined Cycle	3 x 172.3	Noreste
Guadalajara I	Combined Cycle	3 x 151	Occidental
Valle de Mexico III	Combined Cycle	2 x 300.5	Central
Azufres III	GeoThermal	1 x 50, 1 x 25	Occidental
Noreste II (Monterrey)	Combined Cycle	3 x 172.3	Noreste
Occidental	Combined Cycle	3 x 151	Occidental
Salamanca fase II	-	1 x 314	Occidental
Noroeste 4	-	2 x 320.5	Noroeste
Manzanillo II (1)	Combined Cycle	2 x 230	Occidental
Norte IV	Combined Cycle	2 x 334	Norte
Copainala	Hydro	1 x 232	Oriental
Carboelectrica del Pacifico II	Thermal	2 x 350	Occidental
Jorge Luque	Combined Cycle	2 x 300.5	Central
Azufres IV	GeoThermal	1 x 50, 1 x 25	Occidental
Noreste III (Salinas)	Combined Cycle	3 x 233.33	Noreste
La Parota	Hydro	3 x 300	Oriental
Manzanillo II (1)	Combined Cycle	2 x 230	Occidental
Carboelectrica del Pacifico III	Thermal	2 x 350	Occidental
TOTAL MW		10680,46	

Table 15: Scenario 3- Decommissioned conventional generation

Generation decommissions considered for the SIN LOLP Calculations, Scenario 3			
Plant	**Units**	**Capacity MW**	**Area**
Salamanca	3	300	Occidental
Valle de Mexico	1 – 3	450	Central
Francisco Villa	4 – 5	300	Norte
Altamira	3 – 4	500	NorEste
Guaymas II	1 y 3	242	NorOeste
Salamanca	4	250	Occidental
Azufres	2 - 6, 9	30.0	Occidental
Tula	1 - 3	238	Central
Samalayuca	1 - 2	316	Norte
Gomez Palacio	1 - 3	239.8	Norte
Tula	4-6	251	Central
Guaymas II	2 y 4	242	NorOeste
Merida II	1-2	168	Peninsular
TOTAL MW		3526,8	

ANNEX 2: Study Results

Table 16: Simulation Results for Variable Generation in the SIN-total variable generation

Scenario	Year	CP	ELCC in MW	CC	R	ICC	IR
1	2010	2,91%	669,2	47,68%	0,97	47,68%	0,97
2	2013	4,11%	817,2	39,78%	0,95	22,74%	0,87
3	2019	9,20%	1763,5	33,83%	0,89	29,96%	0,85

Table 17: Simulation Results for Wind Generation in the SIN

Scenario	Year	CP	ELCC in MW	CC	R	ICC	IR
1	2010	0,86%	66,7	16,04%	0,90	16,04%	0,90
2	2013	1,86%	124,0	13,37%	0,90	11,20%	0,90
3	2019	6,05%	584,4	17,05%	0,78	18,41%	0,75

Table 18: Simulation Results for Cogeneration in the SIN

Scenario	Year	CP	ELCC in MW	CC	R	ICC	IR
1	2010	1,37%	407,0	61,76%	0,97	61,76%	0,97
2	2013	1,45%	451,3	62,32%	0,95	67,91%	0,74
3	2019	2,27%	867,6	67,36%	0,96	73,83%	0,98

Table 19: Simulation Results for Mini-Hydro Generation in the SIN

Scenario	Year	CP	ELCC in MW	CC	R	ICC	IR
1	2010	0,68%	195,4	59,50%	0,98	59,50%	0,98
2	2013	0,81%	242,0	60,00%	0,98	62,19%	0,98
3	2019	0,88%	311,5	62,80%	0,98	74,97%	0,97