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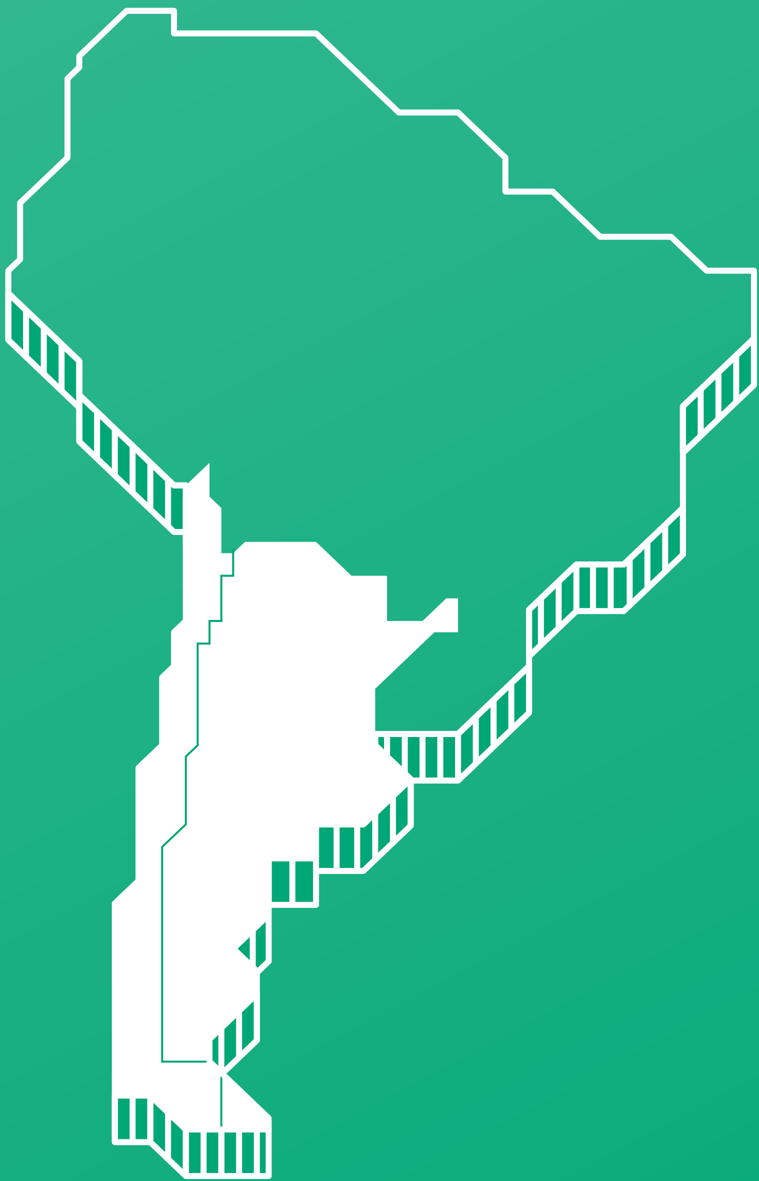

Variable Renewable Energy Sources (VRES) deployment and role of interconnection lines for their optimal exploitation: the **Chile-Argentina** case study

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Edited By
Fondazione Centro Studi Enel
00198 Rome,
Viale Regina Margherita 137
Tax I.D. 97693340586

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LIST OF ACRONYMS

BAT	Best Available Technology
BESS	Battery Energy Storage System
CCGT	Combined Cycle Gas Turbine
CEN	Coordinador Eléctrico Nacional
EENS	Expected Energy Not Supplied
EHV	Extra High Voltage
EOH	Equivalent Operating Hours
GBA	Grand Buenos Aires
GHG	Greenhouse gas
GT	Gas Turbine
HVDC	High Voltage Direct Current
LACE	Levelized Avoided Cost of Energy
LATAM	Latin America
LCOE	Levelized Cost of Energy
LCOT	Levelized Cost of Transmission
MC	Monte Carlo
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine
PV	PhotoVoltaic
RES	Renewable Energy Sources
SEN	Sistema Eléctrico Nacional
SIC	Sistema Interconectado Central
SING	Sistema Interconectado del Norte Grande
ST	Steam Turbine
T&D	Transmission & Distribution
VRES	Variable Renewable Energy Sources

1 FOREWORD

1.1 Introduction

Latin America is endowed with outstanding Renewable Energy Sources (RES), namely wind and solar energy, but some areas offer also a good potential for hydro, biomass and geothermal power production. The current decrease of upfront investment costs in RES power plants make power production from green resources more and more competitive with conventional generation from fossil fuels, especially considering that the ongoing trend in investment cost reduction is expected to continue in the coming years. In addition, the achievement of the COP21 targets, widely shared by the Latin American countries[1], further enhances the superiority of RES power plants against conventional generation, when accounting the externality costs associated to the power generation (see costs associated to the various GHG emissions and particulate). The two above driving factors (lower investment costs and progressive decarbonisation of the power sector) are prompting an accelerated deployment of RES power plants in Latin America.

Unfortunately, the location of new power plants exploiting RES is strictly constrained to the geographical availability of the resources (wind, sun, geothermal, biomasses, hydro). Hence, the connection of a large quantity of RES generation shall be carefully examined in advance to avoid operating conditions calling for RES generation curtailment for security reasons (e.g.: overloads due to insufficient power transfer capability; impossibility to balance the system due to the inflexibility of the conventional generation, poor voltage profiles, risk of cascading effects following an outage on a grid component / generating unit, etc.).

The limitation in the development of RES generation, particularly the variable generation such as wind and PV, can be overcome exploiting the existing interregional or cross-border interconnections, reinforcing the existing ones and building new cross-border corridors.

As a matter of fact, Latin America is still fragmented in national or regional power pools: SIEPAC (interconnected pool from Guatemala to Panama), the Andean interconnected system (from Colombia to Peru) and the Brazilian system (SIN) interconnected basically with Uruguay and Argentina. Other countries are still fully isolated, like Guyana, Suriname, French Guyana and Bolivia or very weakly interconnected, like Chile where just one cross-border line is in operation between SING (Chile) and SADI (Argentina): the Salta-Andes line with a power transfer capacity of about 200 MW owing to network constraints, despite this line is designed for a capacity of about 600 MW.

Thus, dedicated studies shall be carried out specifically to identify the feasible penetration limits of Variable RES (VRES) generation accounting also for the possible power interchange across interconnection lines so to cope with conditions of power surplus or shortfall. Considering the wide geographical extension of Latin America, the analyses shall be applied at a regional level.

[1] Almost all Latin American countries signed the Paris Agreement and a large majority of them already ratified the Agreement. See the updated status of Paris Agreement ratification and entry into force on: http://unfccc.int/paris_agreement/items/9444.php

Within the context recalled above, this study aims at examining the optimal economic penetration of VRES generation (namely wind and solar) in some Latin American (LATAM) countries and regions within the countries accounting for the possible cross border power exchanges.
The analysis is performed for the target year 2030 and starts from a given set of thermal/hydro generation, defined based on the already existing plants, the ones under construction and the planned ones which will be built before the target year.

This first report is focused on Chile and Argentina (Cluster 1), the second one is focused on Argentina, Brazil and Uruguay (Cluster 2) and the third one is focused on Colombia, Peru and Ecuador (Cluster 3). Finally, there will be a continental report featuring the main findings across the three geographical clusters including all the above-mentioned countries.

Argentina is present in the first two clusters of countries, connected in the first case only to the Chilean system, and in the second one to Uruguay and Brazil. Whereas the first report is based on data and projections collected in 2017, the second one is based on more updated data and projections (collected in 2018).

Furthermore, it should be highlighted that the results of the optimisations carried out during the activities are affected by the characteristics of the interconnected system under examination, notably the load patterns of each country, the conventional generation fleet and the potential of VRES generation deployment in the various regions. These factors have a direct impact on the benefits arising from new VRES plants and the limitations they face. For instance, the presence of big hydropower plants with reduced storage capacity (and for this reason not able to reduce significantly their production without wasting free energy) might represent an operational constraint preventing a higher penetration of VRES technologies, which require high flexibility in the system.

In interconnected systems, the complementarity between the resources and between their availability in different countries is a key driver towards the development of VRES plants, especially when there is enough transmission capacity close to the areas characterised by the higher potential of renewable energy sources. In this context, the interconnection between Chile and Argentina allows a more effective exchange of renewable production surplus whenever necessary with respect to the interconnection on the Eastern border towards Uruguay and Brazil. This is due to the fact that interconnections between Argentina and Chile are located closer to the Argentinean regions with best wind regimes (southern Argentinean region) and also favourable PV regimes (northern Chilean and Argentinean regions).

Therefore, the differences in data used as basis for the optimization (2017 vs 2018) and the overall characteristics of the analysed power systems in the Cluster 1 and 2 cause obviously a slight variation of the optimal amount of wind and PV installable in Argentina: however, as it will be shown, the results remain quite aligned, being the gap between the two final values lower than 10%.

1.2 Contents of the report

This report describes the activities performed and the results of the analysis on the Argentinean and Chilean systems aimed at assessing the optimal economic penetration of VRES generation (wind and PV)

taking into account the operational constraints, and evaluating the impact of such VRES generation on the operational costs and the power flows in the power systems.
The information collected and the Reference Scenario described in the “Inception Report” [1], which represents in the best way the basic situation expected at the target year in terms of demand, generation and transmission lines, are the basis for the performed assessments.
Chapter 2 to Chapter 5 presents the evaluation of the optimal VRES penetration carried out assuming that the new PV and wind plants are operating in the system according to the best available technology today (and for this reason it is called “BAT” scenario). Under this hypothesis, quantitative evaluations are performed to assess:

- the limit of VRES generation penetration within a country due to system operation constraints;
- the possible benefits which might be generated by additional VRES, which are the basis for the definition of the optimal amount and mix of new power plants.

More in detail, Chapter 2 illustrates the activities aimed at defining an upper bound limit of VRES installed capacity in the power system under investigation. In particular, the highest amount of VRES (wind farms, PV solar) that can operate in the system without jeopardizing the security of the grid is defined. In fact, the new VRES plants typically replace production provided by the thermal generating units which are responsible to ensure, thanks to their dispatchability, the balance between load and generation in every moment.
This first analysis takes into account the system wide operating constraints such as the needs for upward and downwards secondary and tertiary reserves and the “must run” units, hence ensuring among others a suitable capability for ramp up/ramp down to face the load pattern and the variability of wind and PV. Most critical conditions will be analysed with a deterministic approach.
At the end of this task, an upper bound of the feasible VRES penetration in a whole country or in the various regions of a country is defined.

Chapter 3 presents a detailed investigation performed on the power systems based on the BAT scenario and considering the boundaries resulting from the previous assessment.
One year of operation at the target year is simulated with a probabilistic approach based on Monte Carlo method for increasing levels of VRES in compliance with the technical limits due to operation constraints of the system found in Chapter 2.
For every simulation, which summarizes the results of thousands of different system configuration weighted by their likelihood to happen, main outcomes are provided, such as:

- solar and wind production and curtailments due to overgeneration and line overloads;
- overall generation costs for each area;
- average annual value of Expected Energy Not Supplied (EENS);
- a list of transmission lines which would be overloaded if only the cheapest thermal generation is used to supply the load: their limited transmission capacity represents a cost for the system because it requires the usage of more expensive thermal generators to avoid the violation of the constraint;
- a summary of Net Transfer Capacity (NTC), energy exchanges and saturation hours for each interconnection.

Benefits for the system are evaluated in terms of generation costs, considering where necessary also investment costs, and adequacy of the generation (measured through the possible variation of the

Expected Energy Not Supplied index). The comparison of these benefits calculated with different amount of VRES production provides the information necessary to define the optimal configuration.
A similar approach allows to assess also investments in Transmission system, which bring benefits to the system which have to be compared with the costs of the improvement of the network.
At the end of Chapter 3, the optimal amount of VRES power plants is estimated for the Argentinean and Chilean power system considering the countries as isolated systems and then considering them as interconnected.
Evaluations of possible benefits for the systems coming from the improvement of the network are presented in case there are significant congestions which limit the VRES generation and increase the overall production costs.
Moreover, the expected operation of the systems with the resulting generation fleet is also evaluated for different hydrological conditions, in order to verify that security of supply does not become critical during adverse years.

Chapter 4 introduce two Variants, aimed at evaluating the behaviour of the system in case of some major changes, such as different demand and generation fleet. In these conditions, new optimal VRES penetration is estimated, in order to investigate how the results in the BAT scenario are affected by the variation of main assumptions.

Chapter 5 reports the outcomes of some Load Flow calculations performed on deterministic snapshots representative of particular situations, such has high or low load and different levels of renewable generation (PV, wind and hydro). This allows to highlight how the power flows between the areas selecting some specific cases among the thousands analysed with the probabilistic approach.

Finally, Chapter 6 describes the analysis of a different scenario, called “Breakthrough”, in which system operational constraints are loosened, for instance considering a reduced reserve need or without taking into account the required inertia. This evaluation is based on the assumption that VRES power plants in future will be able to actively support the system operation with services that currently are not possible due to technological limitations or to regulatory restrictions. New features and technological developments, including a wider diffusion of energy storage systems, will allow the PV and wind plants to increase their penetration without jeopardizing the security of supply.

BEST AVAILABLE TECHNOLOGY TODAY FOR VRES GENERATION

2 ASSESSMENT OF THE TECHNICAL LIMITS OF VARIABLE RENEWABLE GENERATION PENETRATION WITHIN A COUNTRY DUE TO SYSTEM OPERATION CONSTRAINTS

2.1 Introduction

The purpose of this task is to assess the upper bound limit of VRES installed capacity in Chilean and Argentinian power systems in 2030 scenario, focusing on the frequency control requirements (secondary and tertiary regulations).

The analysis takes into account the characteristics of the existing and future generation fleet together with the most restrictive load conditions for RES operation, coherently with the data collected in the Inception Report [1]. The ability of conventional generation to provide the upward and downward reserve needed to face the increasing penetration of VRES production is checked, and it is estimated the maximum VRES installable capacity ensuring that the reserve requirement is fulfilled by the conventional plants in service. According to the assumptions of the BAT scenario, PV and wind power plants do not support actively the system operation providing regulation capacity, reserve or other ancillary services.
The VRES taken into account are wind farms and solar PV. There are several combinations of installed power of these sources that can be integrated in the power system still ensuring that the conventional power plants are able to provide the needed reserve. One of the main outcomes of the analysis is then a description of the allowable combinations of wind and PV installed power.

At this stage network constraints are not considered, but a system wide analysis is carried out considering the demand and generation mix. This means that a single bus-bar model is used to model the whole power system of each nation (Chile and Argentina).
A more detailed model with a single bus-bar for each system area is then used to provide some further considerations about how the VRES geographical distribution could be limited due to cross-area interconnection limits internal to each power system.

2.2 Methodology

This section reports details about methodology and analysis process for a preliminary evaluation of the admissible VRES penetration in each country for the 2030 scenario. The analysis has been carried out firstly assuming the condition of isolated system (without power exchanges with the neighbouring countries) and then when the power exchange between Argentina and Chile is introduced.

The first analysis is performed by means of a simplified model where every Country is represented as a single bus-bar system, where load and generation are connected and must be balanced. In the following analysis, the countries are divided in two or three areas, modelled as bus-bar systems and connected through lines which allow the power to flow from one area to another up to defined limits, calculated as net transfer capacities. In this case, the balance in every area must take into account also the net value of import-export through the interconnection lines. Load level and constraints on generation are defined according to the assumptions described in the following paragraphs. The balance in each area must be ensured considering also the secondary and tertiary reserves requirements which are necessary to allow the electric system to manage both the uncertainty of the load and the variability of RES generation, without jeopardizing the security of the system.
The limited net transfer capacity between the different areas inside each country has been investigated in order to evaluate how it can influence the maximum amount of VRES that can be installed in each area.

This procedure is based on a deterministic approach taking into account the critical operating conditions for the power system in presence of VRES generation, generally represented by off-peak load and peak solar radiation conditions. In particular, in off-peak operating hours, a high value of wind generation forces the conventional power plants to generate energy at a very low level. Even in this condition it should be guaranteed a proper amount of reserve in order to cope with the normal fluctuations of load and VRES.
The same problem could occur during the hours with high level of solar radiation and low load.

2.2.1 Description of the computational approach

In this activity only two variable energy sources are taken into account: wind farms and solar PV.
These sources typically have different hourly patterns of production and their forecasts are uncertain. The PV solar has a more predictable hourly pattern of production – since it depends on the solar radiation – and peaks during the central hours of the day. The wind farms production in general is more variable due to the strongly non-linear correlation between the wind intensity and the produced power and to the usual changes of wind conditions in the areas where the plants are located. The uncertainty of the wind production forecasts is for this reason typically greater than the uncertainty of solar PV.

Because of the differences in the uncertainty of the productions by PV or wind, different shares of PV/wind installed capacity cause different effects on the reserve management of the system. It is then not possible to calculate the maximum acceptable amount of generic VRES, but it is necessary to define pairs of admissible values: the more PV plants are installed, the less wind farms are suitable to be installed and vice versa.

Due to these reasons, the study has calculated some admissible pairs of values which belong to the border of the allowable area on the Wind / PV plane. At each amount of installed PV corresponds a maximum amount of installed wind farms and vice versa. An example of the resulting pairs of PV-wind admissible capacity is shown in Figure 1.

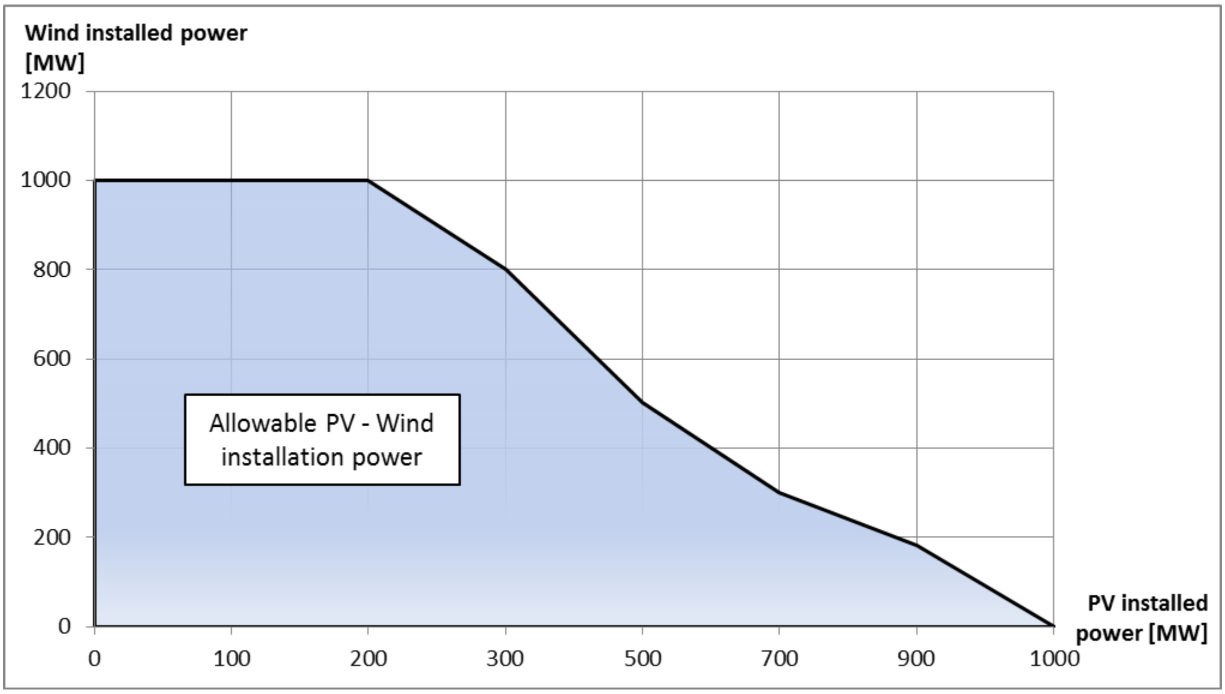


Figure 1 - Example of the allowable area on the PV/Wind installed power chart

To determine the maximum amount of VRES which can be installed in the system without affecting its security, the analysis focuses on the most critical conditions, which are characterized by low load and high VRES production. It is assumed that also in these conditions the VRES production should not be curtailed due to reserve constraints.

In this low load condition the sum of PV and wind production covers a large amount of the load. The residual load is supplied by traditional hydroelectric and thermal plants. These traditional plants operate therefore near their minimum output, although they have to provide the system with all the downward secondary and tertiary reserve required in order to cope with the uncertainty of load and VRES production, guaranteeing the stability and security of the whole system.

A further element that must be taken into account is that the unit commitment of the traditional power plants in the low load condition is not completely free. In fact it must be suitable to provide services to the system such as voltage regulation, inertia, etc. In other words, there is a minimum number of traditional power generation that must be in service.

Also the production of plants such as run of the river and biomass cannot be neglected even in low load condition.

The need to guarantee a suitable amount of downward reserve on the traditional plants is then the factor that limits the amount of VRES installed.

The calculation is performed in two steps for wind and for PV power plants.

The maximum wind power production is assessed considering the 10th percentile of the load and no PV production, condition which can happen during the night. The selection of the 10th percentile of the load instead of the absolute minimum is proposed because the acceptance of a risk margin is a common practice during the planning process. With a deterministic approach, like in this task, 10% of probability of VRES curtailment is considered acceptable.

The calculation is performed evaluating the maximum wind power production admissible in the system which does not affect the fulfilment of the reserve constraint. Since the reserve requirements depend also on the amount of wind power production, this maximization is calculated with an iterative method. The corresponding maximum admissible installation of VRES is then calculated assuming a contemporaneity factor which is also commonly adopted as the probability that the wind power plants run at full power all together is pretty low.

The procedure is depicted in the Figure 2.

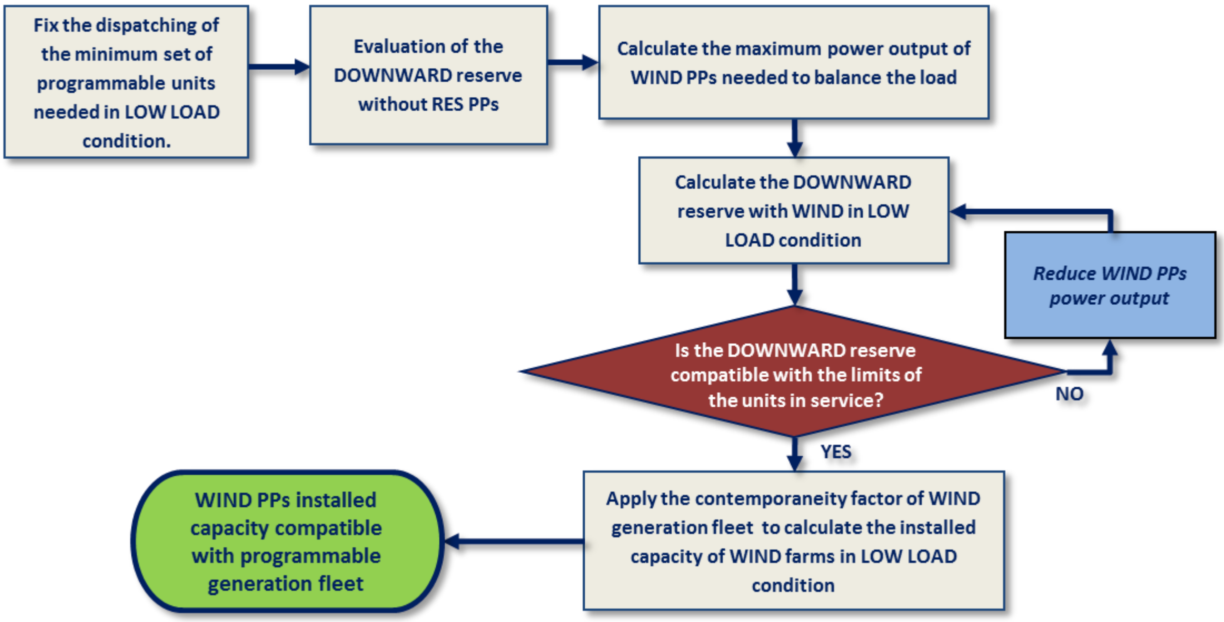


Figure 2 - iterative calculation of max installation of wind power plants

Once the maximum installed wind power is defined, a similar approach is followed to evaluate the maximum allowable PV production which does not require any curtailment due to reserve requirements. Also in this case a low load condition is analysed, selected among the hours in which the PV production is high. In particular, the 10th percentile of the loads that occur during the hours of maximum solar radiation is considered. The calculation of the maximum PV production is performed for different levels of wind production, from the maximum value calculated in the previous step to 0 MW, in order to define the allowable PV/Wind installed power area as depicted in Figure 1.

The points of the upper bound of the area are calculated assuming an installed value for one technology (i.e. Wind) and calculating the corresponding maximum amount of admissible installed power for the other technology (i.e. PV). Four conditions are analysed:

- Calculation of maximum PV installable power in presence of the maximum wind installable power defined in the first step

- Calculation of maximum wind installable power in presence of an amount of PV installed power equal to the target defined at 2025
- Calculation of maximum PV installable power in presence of an amount of wind installed power equal to the target defined at 2025
- Calculation of maximum PV installable power in presence of no wind installed power

To maximize the installed power of a VRES source means to find the maximum amount of production that can assure the presence of the reserve requirements on the traditional unit. Since the reserve requirements depend also on the amount of solar PV and wind farms, this maximization is calculated with an iterative method (Figure 3 and Figure 4)

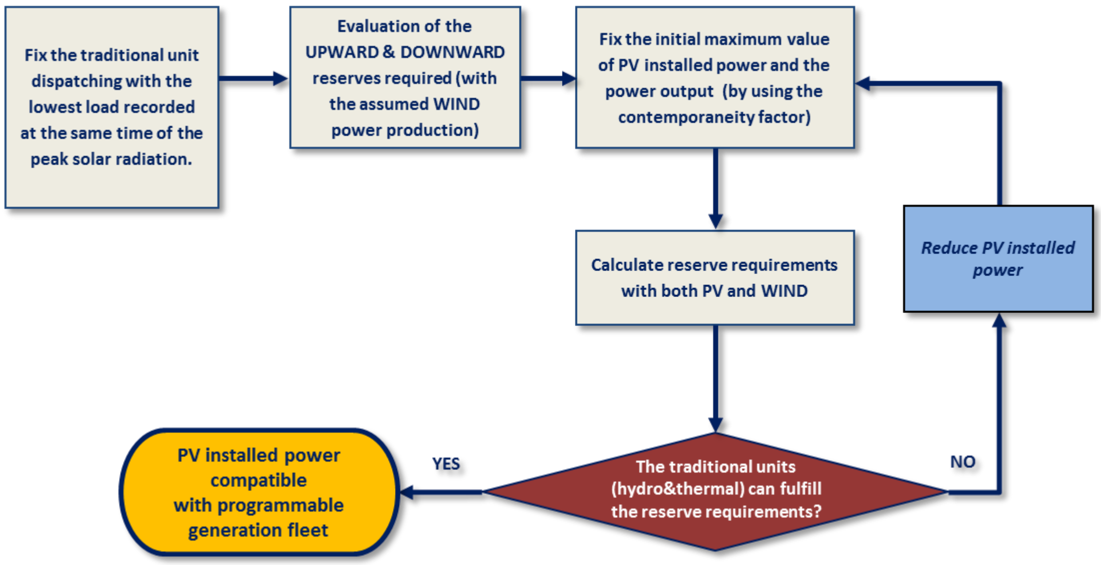


Figure 3 - iterative calculation of max installation of PV once assumed a fixed value of Wind

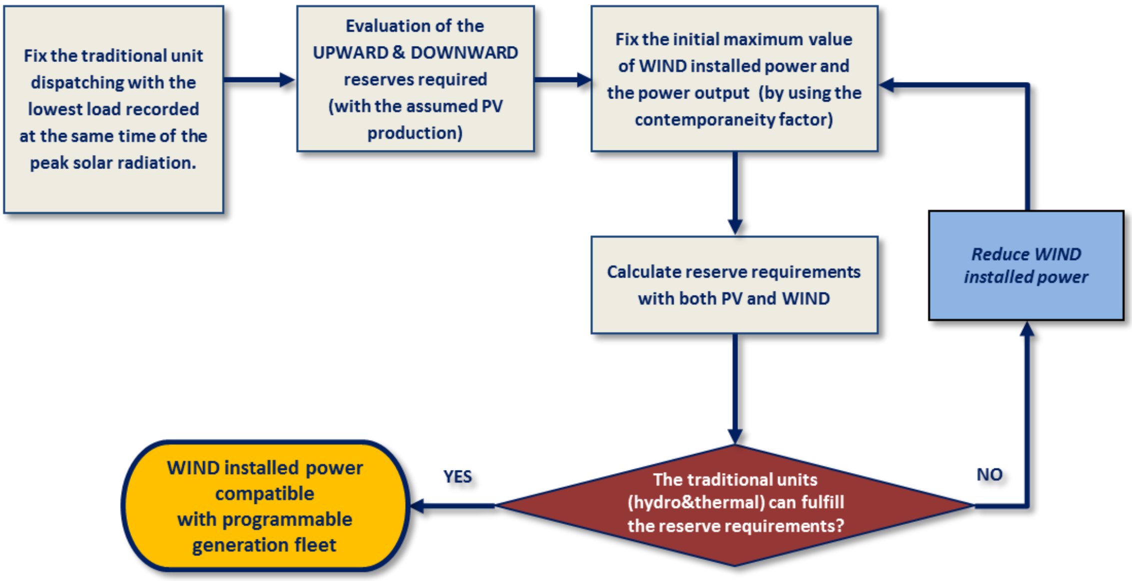


Figure 4 - iterative calculation of max installation of WIND once assumed a fixed value of PV

The results section will report a snapshot of the power system in low load condition considered in the above described methodology, including the main data about type of generation and reserve for each combination of maximum VRES calculated in the form showed in Figure 5.

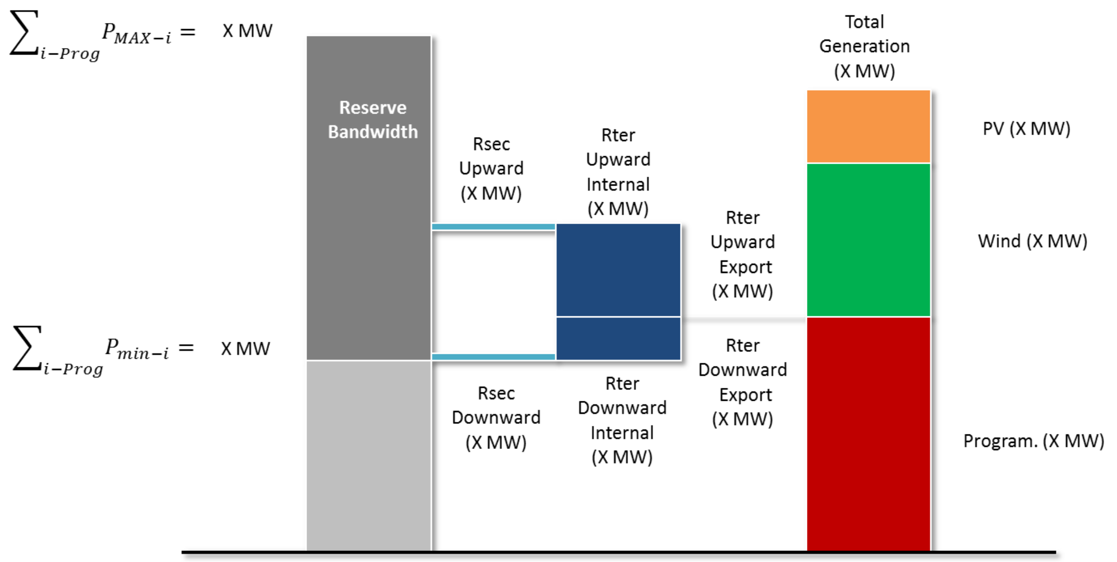


Figure 5 - Example of presentation of the upper bound limit definition for VRES installed capacity

In this graph, the different parts have the following meaning:

- $\sum_{i-Prog} P_{min-i}$: is the minimum amount of generation which must be in service and produce for operational constraints (voltage control, cogeneration, etc.) or for imposed generation (Run of River, Biomass, etc.). It is an input for the calculation of maximum VRES installed capacity.
- $\sum_{i-Prog} P_{MAX-i}$: is the maximum power that can be generated by the spinning thermal and hydro generation. The dark grey column is the range of generation that can be covered by the spinning programmable production unit.
- Total generation: is the total amount of generation in the specific load condition under assessment. For instance, in case of isolated country the total generation is equal to the load to be covered (10^{th} percentile of load curve). It is an input for the calculation of maximum VRES installation.
- PV: it is the energy generated by PV plants considering the maximum installed capacity as a result of the methodology described above in the present paragraph.
- Wind: it is the energy generated by PV plants considering the maximum installed capacity as a result of the methodology described above in the present paragraph.
- Program.: it is the programmable generation calculated as a result of the methodology described above in the present paragraph. The value is the sum of the minimum generation plus the downwards tertiary reserve, which depends on load and VRES generation.
- Rter (upward and downward): tertiary reserve, calculated considering the load and the VRES generation
- Rsec (upward and downward): secondary reserve, calculated considering the load.

For each pair of values calculated for the whole system on the single bus-bar model, the presence of possible constraints due to the inter-area limited net transfer capacity is checked. The amount of load and VRES additional generation defined for the whole system is divided in the different areas assuming at first a distribution which respect in percentage the distribution assumed for the VRES generation present in the Reference Scenario, as defined in [1]. This distribution reflects in a good way the allocation of the new VRES power plants in the areas according to their relevant potential.
With this new generation scenario the reserve requirements for each area and the power flows between them are calculated. Each area must fulfil its reserve requirements using its own generation or using the interconnection with other areas. In this case, the sum of the actual power flow plus the needed reserve should not exceed the net transfer capacity of the section.

2.2.2 Assumptions

2.2.2.1 Load

The low load conditions are calculated using for both the countries the data presented in [1]. The available hourly profiles (referred to 2016) have been rescaled in order to have the 2030 foreseen peak value and annual energy demand.

Low load during night

The load used to analyse the most binding condition during the night hours (useful to calculate the absolute maximum wind installation, regardless the PV) is calculated as the 10^{th} percentile of loads of all the year.

Low load condition during solar radiation peak

The load used to analyse the most binding condition during the solar radiation peak hours (useful to calculate the maximum combined installable power of PV and wind) is calculated as the 10^{th} percentile of loads that occurs during these hours in the rescaled trends.

For both the analysed situations the most binding condition for wind and PV exploitation is the absolute minimum load, nevertheless, the absolute minimum load is a too strict condition since it occurs only once a year and the probability of having very high production of VRES power plants during the absolute minimum load is very low. The acceptance of a risk margin is a common practice during the planning process; in fact, with a deterministic approach, 10% of probability of RES curtailment is acceptable. Therefore in both the analysed extreme scenario the 10^{th} percentile of load can be used for this preliminary analysis. In this way the VRES curtailment could occur only when the load will be lower than the 10th percentile;

In the following table are depicted the load values used for both the countries.

Table 1 - Low load value in most binding condition [MW]

[MW]	Chile			Argentina				Chile – Argentina Interconnected system[2]
	SIC	SING	Total	PAT	NEC	NWE	Total	
Low load during night	7,909	2,776	11,685	677	15,683	4,976	21,336	32,707
Low load condition during solar radiation peak	8,438	2,714	11,152	699	16,179	5,133	22,011	35,189

2.2.2.2 PV and WIND contemporaneity factor and uncertainty

As a general definition, the contemporaneity factor is the ratio between the maximum actual power production of a given set of power plants and the sum of their nominal power. It summarizes the fact that not all the power plants are producing at full power at the same time, so the sum of the maximum actual production of the plants is lower than the sum of the installed power; or vice versa it can be seen as the factor to be considered to evaluate which installed power is necessary to obtain a maximum power production.

The contemporaneity factor is used in this activity in this last way, to estimate the amount of MW which can be installed for the PV or the wind technology which can inject in the system the maximum power production which does not affect the fulfilment of the reserve requirements. Given a specific power production, the relevant installed power can be obtained dividing it by the estimated contemporaneity factor.

The contemporaneity factors used in this study are shown in Table 2.

Table 2 - Contemporaneity factor for solar PV and Wind farms [%]

[%]	Chile			Argentina				Chile – Argentina Interconnected system
	SIC	SING	Total	PAT	NEC	NWE	Total	
Wind farms	70	70	70	80	70	65	73.9	70
Solar PV	70	70	70	70	70	70	70	70

[2] The 10th percentile of interconnected system is calculated on a load trend that sum hour by hour the Argentinian and Chilean load trends. The time shift due to the different time zones is taken into account.

The secondary and tertiary reserve requirements with PV and wind farms are calculated in accordance to the description provided in [1] §2.6.
As described there, one of the main factors for the assessment of upward and downward reserve is the standard deviation of load and VRES production. This standard deviation represents how the actual load and VRES production are statistically distributed around the foreseen values. In other words, it provides an indication about the possible discrepancy between the forecasted values of load or generation (which determine how the operation of the power system is planned), and their actual values. This difference must be compensated by available dispatchable generation with higher or lower production, to keep the balance of the whole system.
The standard deviations used in the analysis, defined based on CESI experience, are shown in Table 3.

Table 3 - Standard deviation of load, PV and wind production [%]

[%]	Chile			Argentina				Chile – Argentina Interconnected system
	SIC	SING	Total	PAT	NEC	NWE	Total	
Load	2.92	2.92	2.92	2.92	2.92	2.92	2.92	2.92
Solar PV	10	10	10	10	10	10	10	10
Wind farms	20	20	20	20	20	20	20	20

2.2.2.3 Net transfer capacity between countries and between areas inside each country

As described in [1], both for Chile and Argentina the interconnection with neighbouring countries have not been considered. Only the possibility to exchange energy between the two countries is taken into account, after the analysis of the isolated countries is completed.
The net transfer capacity depends on the expected network reinforcements in the 2030 scenario (as described in [1]):

- existing line Salta-Andes (operated with limit at 600 MW). It connects NWE Argentinian area and SING Chilean area.
- future interconnection in the area of Gran Mendoza-Santiago (max 1,000 MW). It connects NWE Argentinian area and SIC Chilean area.

Moreover, when the countries are analysed divided in different areas, the maximum power exchanges between them have been taken into account as depicted in Figure 6.

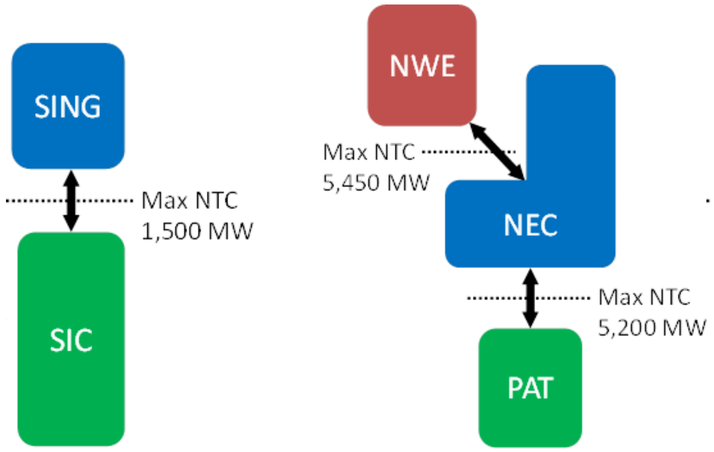


Figure 6 - Net transfer capacity between Argentinian and Chilean areas

2.2.2.4 *"Must run" and traditional units needed in low load condition*

In the most binding low load scenarios used to determine the maximum amount of VRES installable capacity, an important hypothesis is related to the "must run" units and to the minimum set of hydraulic and thermal units that must be kept in service (even in very low load conditions) in the system. These power plants are usually required in order to provide services such as voltage regulation or rotating inertia as well as a proper margin of primary reserve and cannot be shut down even when the load is low to ensure the system is operating in a secure way.

This set of generators introduces a constraint of minimum power output which must remain in service, reducing the space for other VRES generation.

<u>Chile</u>

The information regarding "must run" units and the minimum set of traditional plants in 2030 scenario has been extracted from the DIgSilent database provided by "Coordinador Eléctrico Nacional" on the official website as "Bases de datos en formato Power Factory DigSilent para estudios estáticos y de cortocircuitos para el largo plazo"[3].

In 2030 scenario it is foreseen a peak load of 15,745 MW. The ratio between peak load and minimum load in 2016 hourly trend is about 42% - this means that, if this ratio remain the same in 2030, the expected minimum load is about 6,600 MW.

In DIgSilent scenario the load SIC-SING is about 9,480 MW, higher than the minimum load to be considered in the analysis at 2030. The use of a scenario with a load greater than what could be expected as a minimum in 2030 is a conservative hypothesis since it implies a larger amount of "must run" and needed traditional plants in service.

The "must run" production taken into account for each area of Chilean power system is specified in the Table 4.

[3]https://sic.coordinadorelectrico.cl/informes-y-documentos/fichas/estudios-de-planificacion/attachment/bd-sic-dpd-2016-ett-15-sept/

Table 4 - "Must run" in low load condition (Chile)

[MW]	SIC	SING	Total
Biomass / Process	442	20	462
Run of the River	1,454	12	1,467
Total	1,896	32	1,928

As can be seen in the previous table, the “must run” are run of the river hydroelectric plants or thermal units such as biomass or other thermal plants connected to industrial process.

The minimum set of traditional plants that must be in service as defined in the database provided by “Coordinador Eléctrico Nacional” entails a minimum and a maximum output (respectively the sum of the minimal/maximal output of all the units in service).
The minimum output is particularly important in the assessment of the maximum amount of VRES allowable plants. The values for each area are shown in Table 5.

Table 5 - Minimum and maximum output on traditional plants that must be in service (Chile)

[MW]	SIC		SING		Total	
	min	max	min	max	min	max
Thermal	1,258	2,462	1,110	2,144	2,368	4,606
Hydro	0	5,362	0	0	0	5,362
Total	1,258	7,824	1,110	2,144	2,368	9,968

Argentina
The minimum set of thermal power plants considered in service in 2025 is defined taking into account the information included in the “Guia de Referencia 2017-2024” by Transener, minimum load scenario 2024.
Thermal programmable generators are assumed in service at least with their technical minimum power due to stability reasons (e.g. Atucha, Rio Turbio), while run of the river power plants operating at maximum power due to their limited regulation capacity (conservative assumption. E.g. Yacireta). In the two analyzed conditions (low load and peak solar radiation), hydro reservoir power plants are assumed out of service due to their regulation capacity.
In the following Table 6 and Table 7 information about “must run” (hydro and traditional plants) is provided.

Table 6 - "Must run" in low load condition (Argentina)

[MW]	PAT	NEC	NWE	Total
Run of the river	0	3,300	600	3,900

Table 7 - Minimum and maximum output on traditional plants that must be in service (Argentina)

[MW]	PAT		NEC		NWE		Total	
	min	max	min	max	min	max	min	max
Thermal	145	489	4251	16,839	814	3,370	5,210	20,698

2.3 Results of performed analysis

This section describes the results of the assessment of the limit of VRES due to system operation constraints considering a single bus-bar modelling of Argentina and Chile, i.e. neglecting the possible internal network constraints. After the analysis of the whole country power system, also the results considering the internal macro-areas are presented in order to evaluate potential limitations due to the internal cross-area NTC foreseen in the reference scenario.

2.3.1 Argentina

Figure 7 shows the maximum VRES installed capacity considering different combination of Wind and PV generation. The blue line represents the values obtained considering Argentina as isolated system (i.e.: "*Analysis considering the Transmission System in the Reference Scenario*"). The grey line is calculated assuming the usage of the two interconnections between Argentina and Chile (600 MW through the Salta-Andes and 1,000 MW through the Gran Mendoza-Santiago) for a full export towards Chile (i.e.: "*Analysis considering the Transmission System with the possible reinforcements defined in the Inception Report*"). It probably does not represent a possible operational condition, but provides a clear indication about a maximum value beyond which a significant part of new VRES should be curtailed for operational constraints. In the figure the actual VRES installed capacity is also indicated as well as the installed capacity target set for 2025.

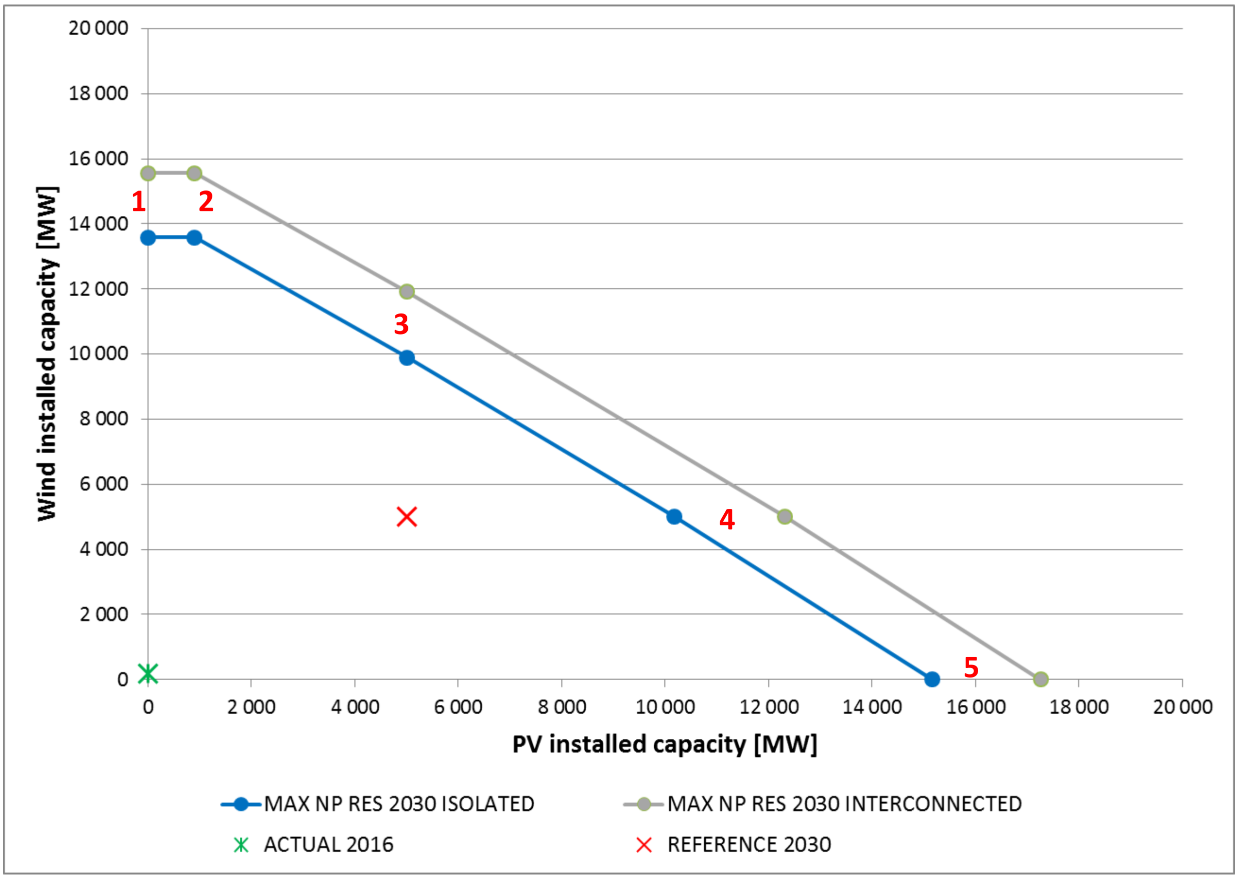


Figure 7 - VRES installed capacity limits due to system operation constraints in Argentina – 2030

As described in paragraph 2.2.1, the boundary lines are obtained by the interpolation of the following PV-wind combination:

- maximum wind installed capacity in low load scenario (point 1 in the previous picture)
- maximum PV installed capacity corresponding to the maximum installed wind generation calculated during solar radiation peak (point 2)
- maximum wind installed capacity meeting PV target at 2025 in low load and high VRES scenario (point 3)
- maximum PV installed capacity meeting wind target at 2025 in low load and high VRES scenario (point 4)
- maximum PV installed capacity in low load and high VRES scenario with no wind installed power (point 5)

Points 1, 2 and 5 do not represent situations which are likely to happen, because the planned development of VRES generation in Argentina foresees a growth of both PV and wind power installed plants, so at 2030 it is expected that there will be a balanced mix of PV and wind installed capacity and not the predominance of only one technology, as indicated by these points. Even if it is not probable that the system will operate in these conditions, they have been anyway evaluated in order to provide a general overview of the boundaries due to the system constraints.

The most interesting results are related to the maximum penetration of wind and PV in Argentina when the other two technologies are set to the value considered in 2025 target (point 3 and point 4):

- when the PV target is 5,016 MW, the analysis shows a potential wind installed capacity limit of 9,800 MW in case of isolated system (blue point 3 in Figure 7) and 11,900 MW if 1,600 MW interconnection with Chile is fully available for export (grey point 3 in Figure 7). Further installation of wind over these limits should determine an unacceptable curtailment of VRES in low load conditions.
- when the wind target is 5,000 MW, the analysis shows a potential PV installed capacity limit of 10,200 MW in case of isolated system (blue point 4 in Figure 7) and 12,300 MW if 1,600 MW interconnection with Chile is fully available for export (grey point 4 in Figure 7). Further installation of PV over these limits should determine an unacceptable curtailment of VRES in low load conditions.

All the acceptable limits of PV-wind are defined by interpolating the points obtained applying the methodology shown in Figure 2, Figure 3 and Figure 4 and described in paragraph 2.2.

The following paragraphs show in detail the results of each PV-wind combination corresponding to point 2, point 3, point 4 and point 5 in terms of generation and reserve in Argentina and power and reserve exchanges between the Argentinian areas. The results are reported both considering Argentina as isolated system and considering the possibility to export 1,600 MW toward Chile.
In particular it can be seen that in extreme binding operating conditions, in presence of maximum installation of only one technology (i.e. wind generation in the range of 13,600 MW mainly located in PAT and NEC, PV with more than 15,000 MW concentrated in NWE), the transmission grid gets saturated, thus causing the need of one of the following solutions:

- Curtailment of installed VRES;
- Different distribution among areas of the VRES installed capacity;
- Further transmission system reinforcements compared to the development plan.

The first solution can be implemented during the operation of the power system while the last two alternatives are related to the planning phase and they have to be properly evaluated in advance.
Anyhow, this risk of having the interconnection from PAT saturated by wind production or the interconnection from NWE saturated by PV appears only if there is a strong predominance of only one VRES generation technology in the overall system concentrated in these areas.
This suggests a balanced development of wind and PV power plants.

2.3.1.1 Max. PV wind installable capacity in presence of max. installed wind power (point 2)

Figure 8 shows that with the maximum wind generation of 10,000 MW (which corresponds to 13,600 MW of installed capacity because of the considered contemporaneity factor) the Argentinian system can accept additional 630 MW of PV production fulfilling the conventional generation reserve requirements.
Figure 9 highlights that the high amount of wind capacity defined looking at the whole system would cause the NTC limit between PAT and NEC to be exceeded (considering the distribution of the new installed wind power equal to the distribution of wind power plants in the Reference Scenario). The situation is even more evident in case of full export toward Chile, because the possibility to export power towards a neighbour Country determines a higher allowable wind generation and installed capacity (respectively up to 11500 MW and 15600 MW), with a consequent increase of power transfer from PAT to NEC (Figure 11).

Power and reserve exchanges among the Argentinian areas, represented in Figure 9, highlight that the high amount of wind capacity defined looking at the whole system would cause the NTC limit between PAT and NEC to be exceeded (considering the distribution of the new installed wind power equal to the distribution of wind power plants in the Reference Scenario). The situation is even more evident in case of full export toward Chile, because the possibility to export power towards a neighbour Country determines a higher allowable wind generation and installed capacity (respectively up to 11,500 MW and 15,600 MW), with a consequent increase of power transfer from PAT to NEC (Figure 11).

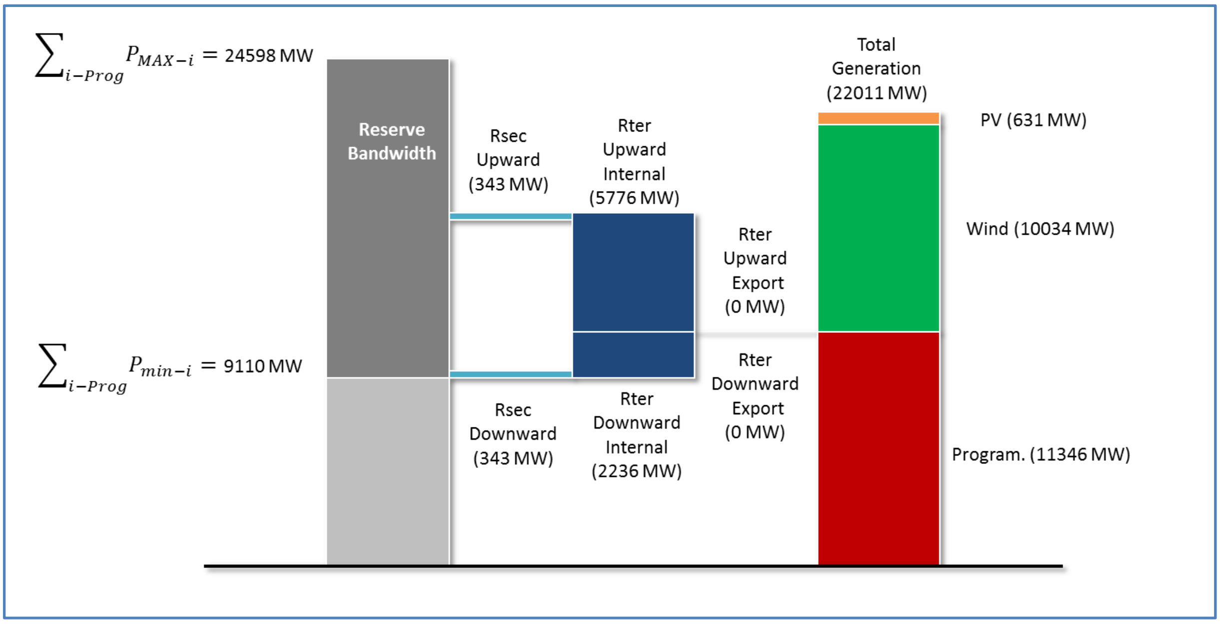


Figure 8 - Generation and reserve in Argentina- Low load and high VRES scenario, maximum wind installed capacity, no cross-border exchanges

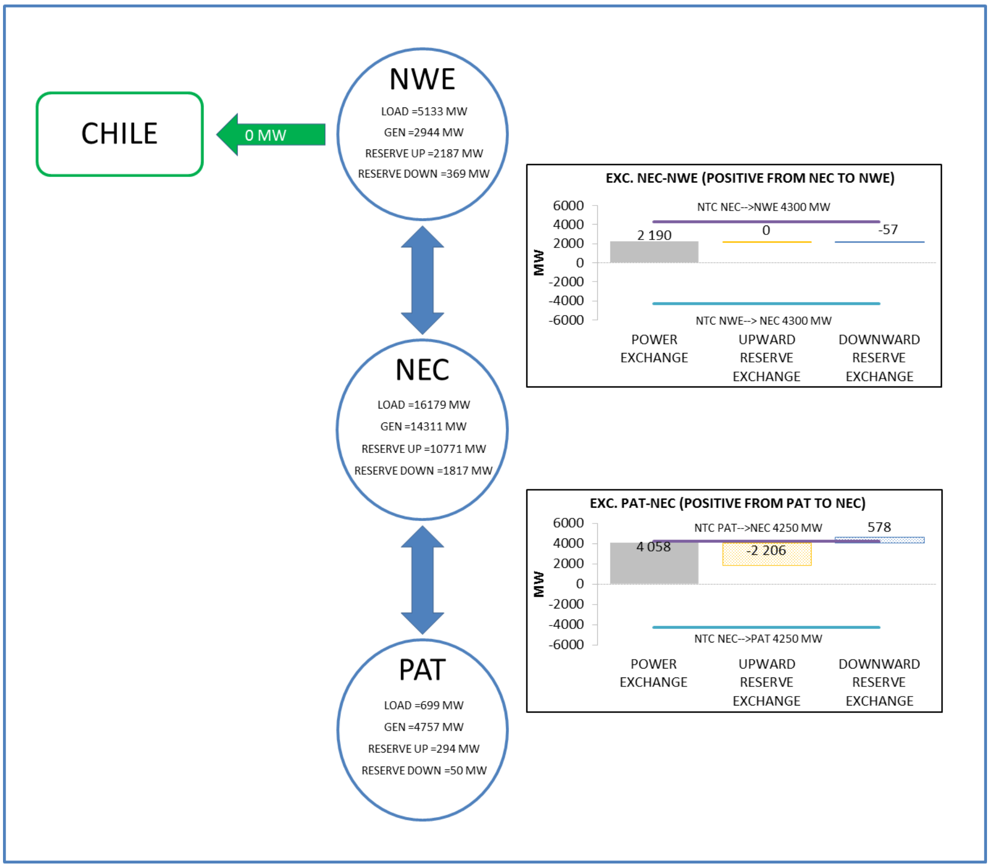


Figure 9 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum wind installed capacity, no cross-border exchanges

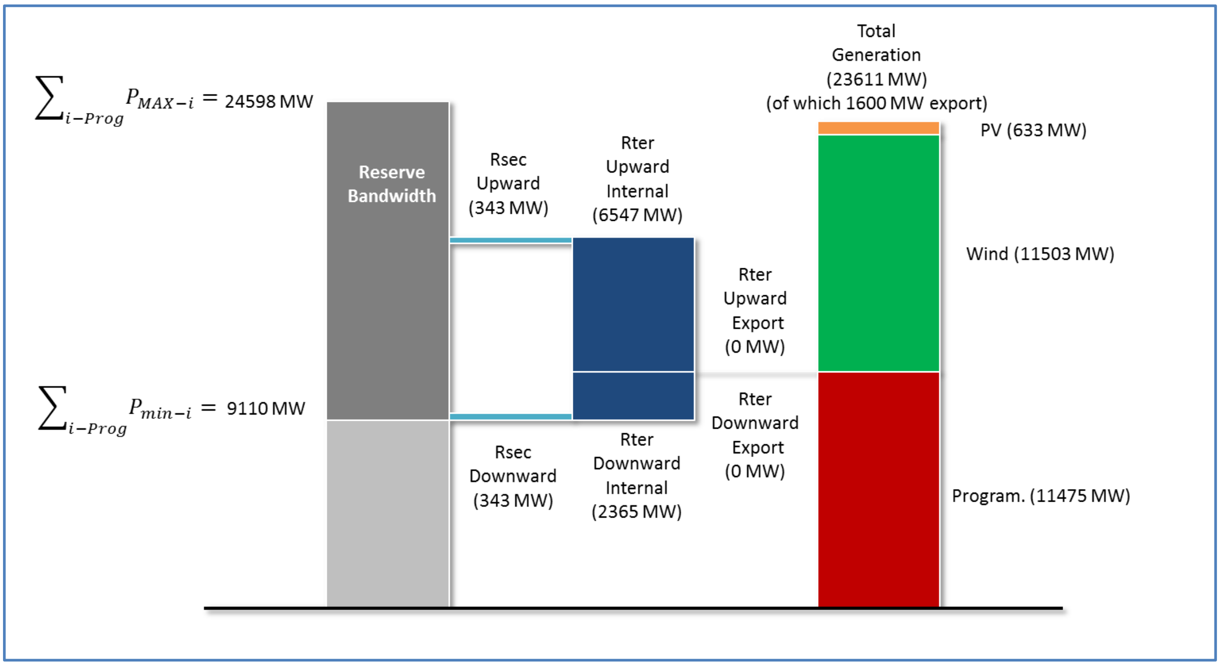


Figure 10 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum wind installed capacity, maximum export

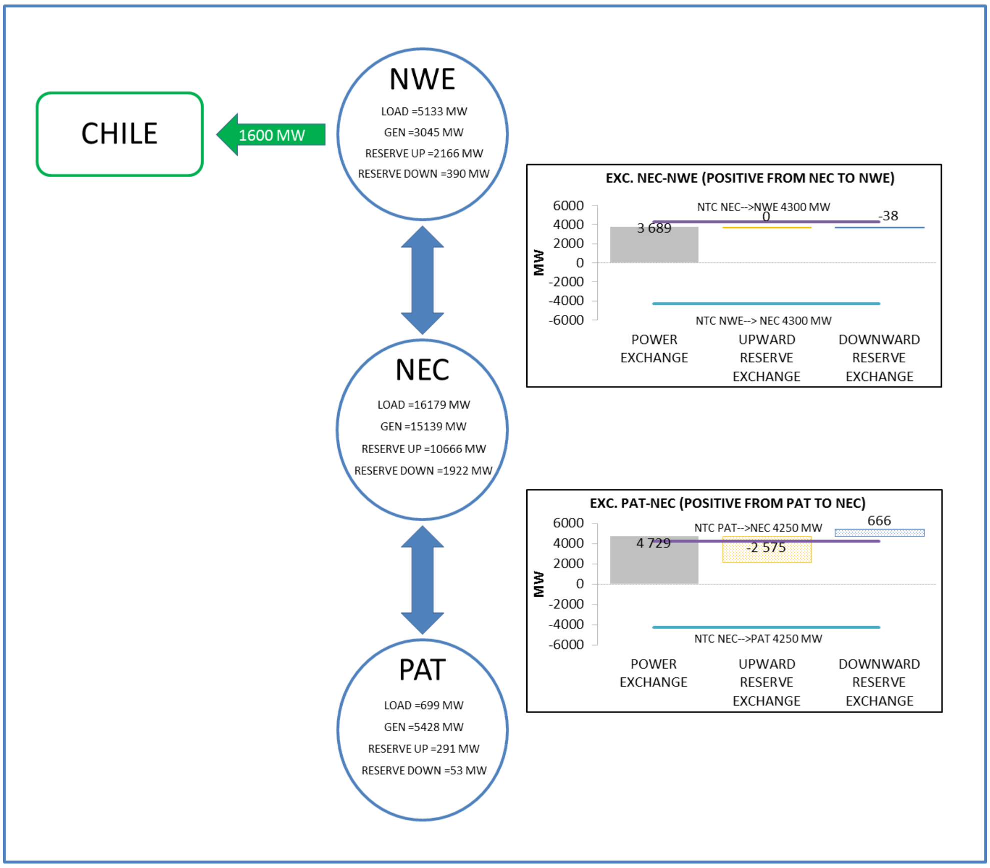


Figure 11 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum wind installed capacity, maximum export

2.3.1.2 Maximum wind installable capacity meeting PV target (point 3)

The maximum acceptable wind installed capacity in the Argentinian system considering 5,000 MW of installed PV power plants, which corresponds to the 2025 PV target, is 9,900 MW, with an actual maximum generation of 7,300 MW. The programmable generation can provide the needed reserves (4,500 MW upwards, 2,100 MW downwards) as can be seen in Figure 12.

Analyzing the flows between areas, it can be noted that NTCs are not exceeded (Figure 13).

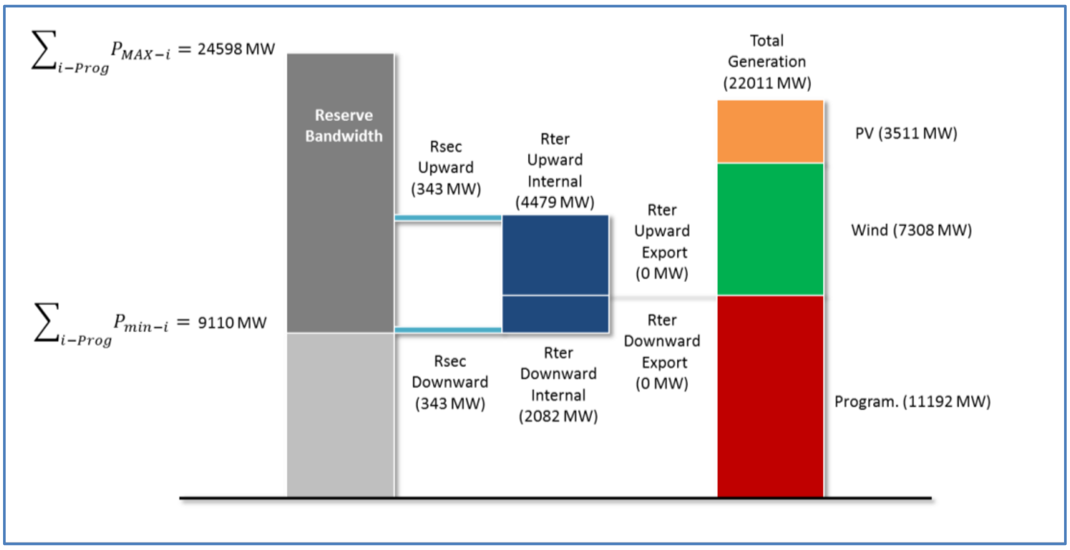


Figure 12 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, no cross-border exchanges

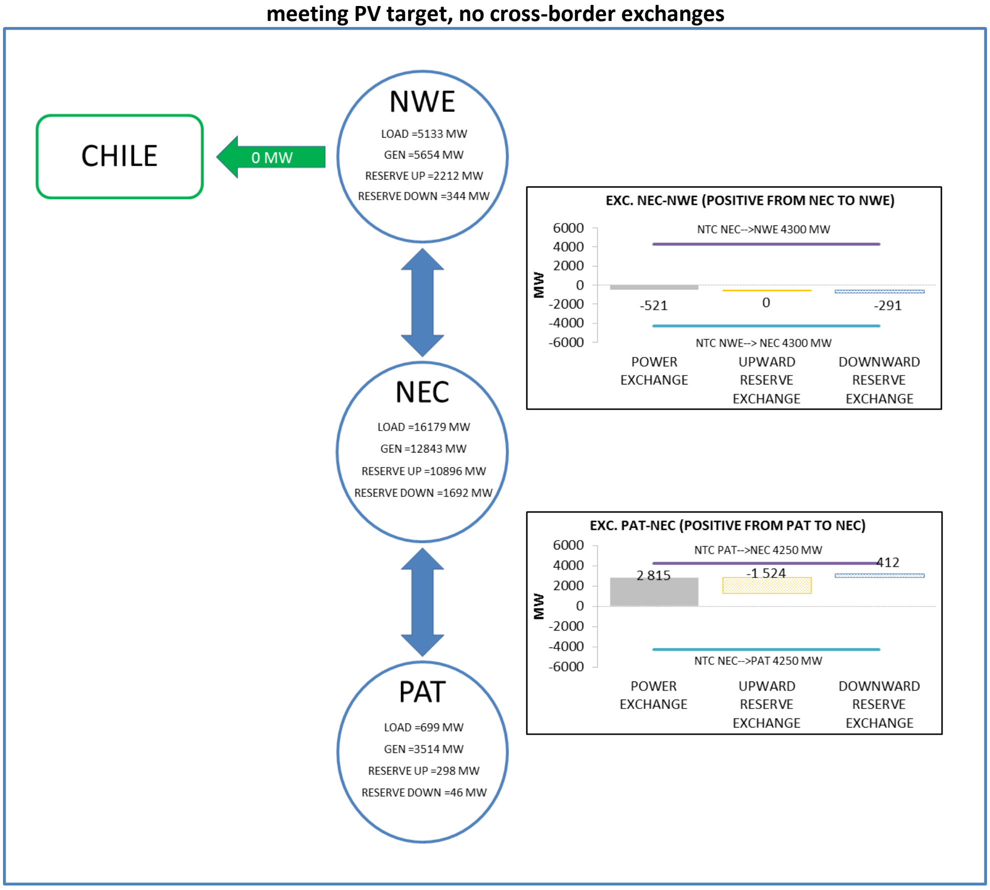


Figure 13 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, no cross-border exchanges

In case the additional 1,600 MW of possible power export are considered, the maximum wind installed capacity in presence of the PV target amount increases up to 11,900 MW, with an actual maximum generation of 8,800 MW. Also in this case the NTCs are not exceeded.

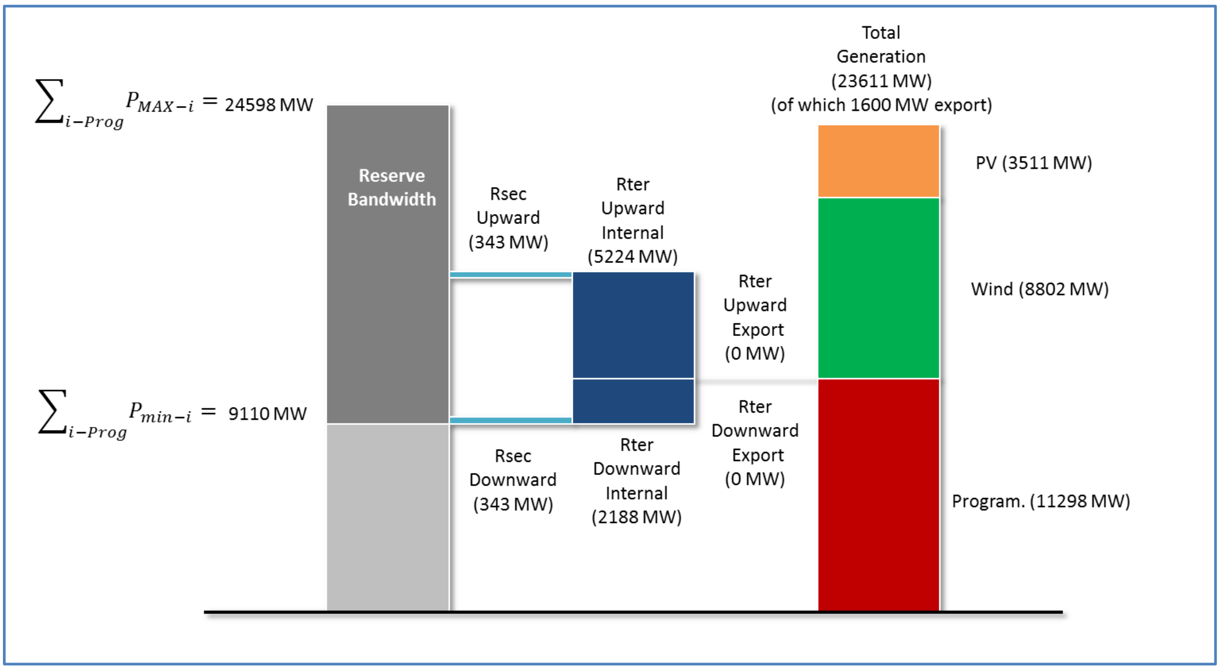


Figure 14 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, maximum export

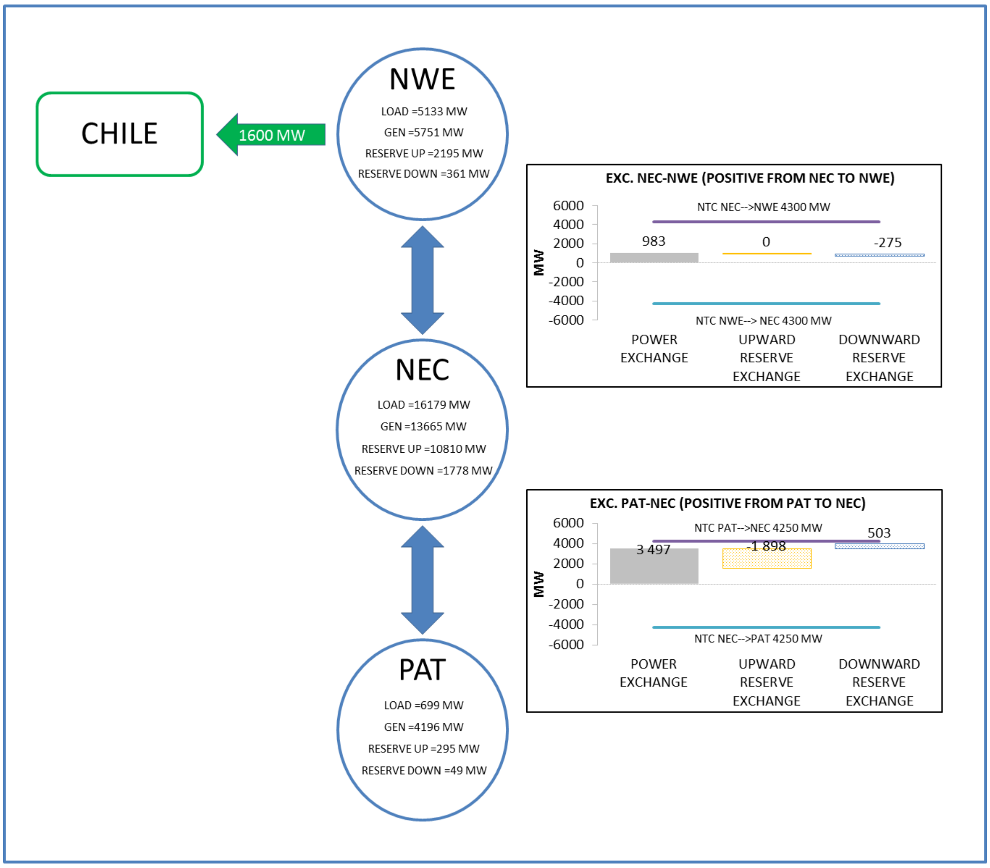


Figure 15 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, maximum export

2.3.1.3 Maximum PV installable capacity meeting wind target (point 4)

When the target amount of wind installed power is considered (5,000 MW), the calculation of the maximum installable PV power indicates that the Argentinian system may accept 10,170 MW.

The power flows between the areas resulting when the VRES plants are assigned to the different areas shows that the NTC between NWE and NEC is slightly exceeded, by less than 400 MW, corresponding to a 9% overload. In order to avoid this limitation, the PV plants might be installed partially in the NEC area, for instance close to the main load center, or the NTC on the section might be improved. These options will be evaluated during the following activities, where the optimal economic generation mix is defined, in case the result will suggest an optimal operating condition which activates the same constraint and a solution must be investigated.

It is worth underlining that the real expected power flow is lower than the NTC, but the need of more downward reserve in the NWE area needs the possibility to evacuate more power in case for instance of overproduction by PV or lower load than forecasted, thus requiring that a share of the transfer capacity is left available.

In case the export towards Chile is considered, the amount of maximum installable PV power plants increases up to 12,300 MW, because the additional production can flow to the neighbour country. The requirement of downward reserve in NWE increases due to the higher amount of VRES, and for this reason the section towards NEC shows a higher overload, even if the real expected power flow is lower.

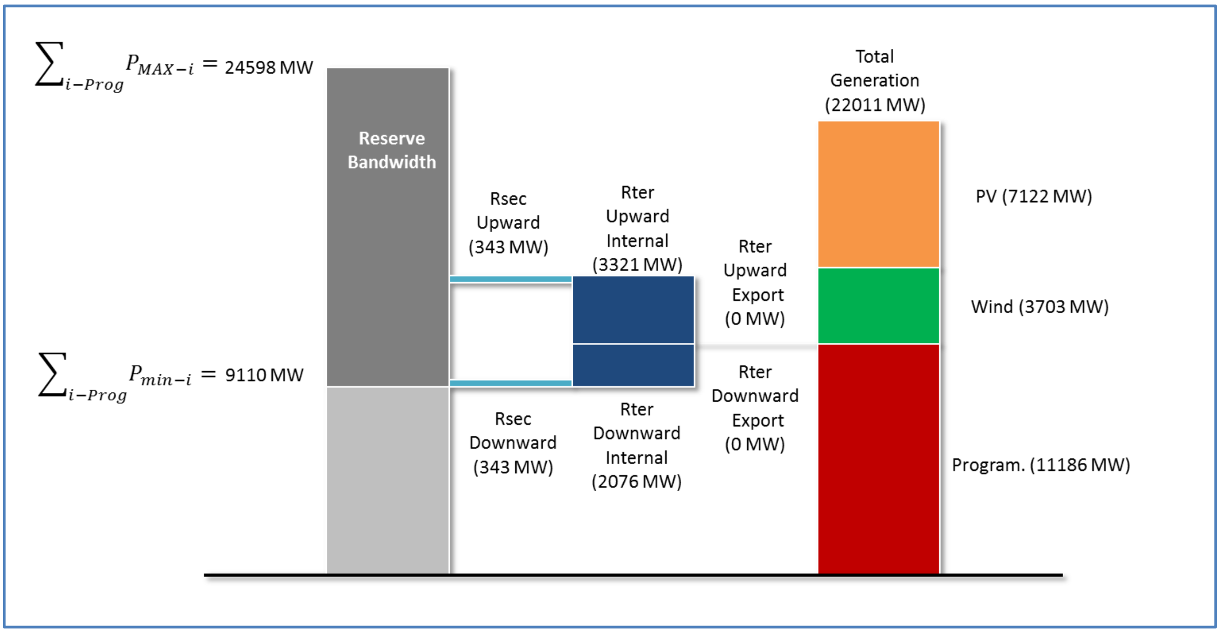


Figure 16 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, no cross-border exchanges

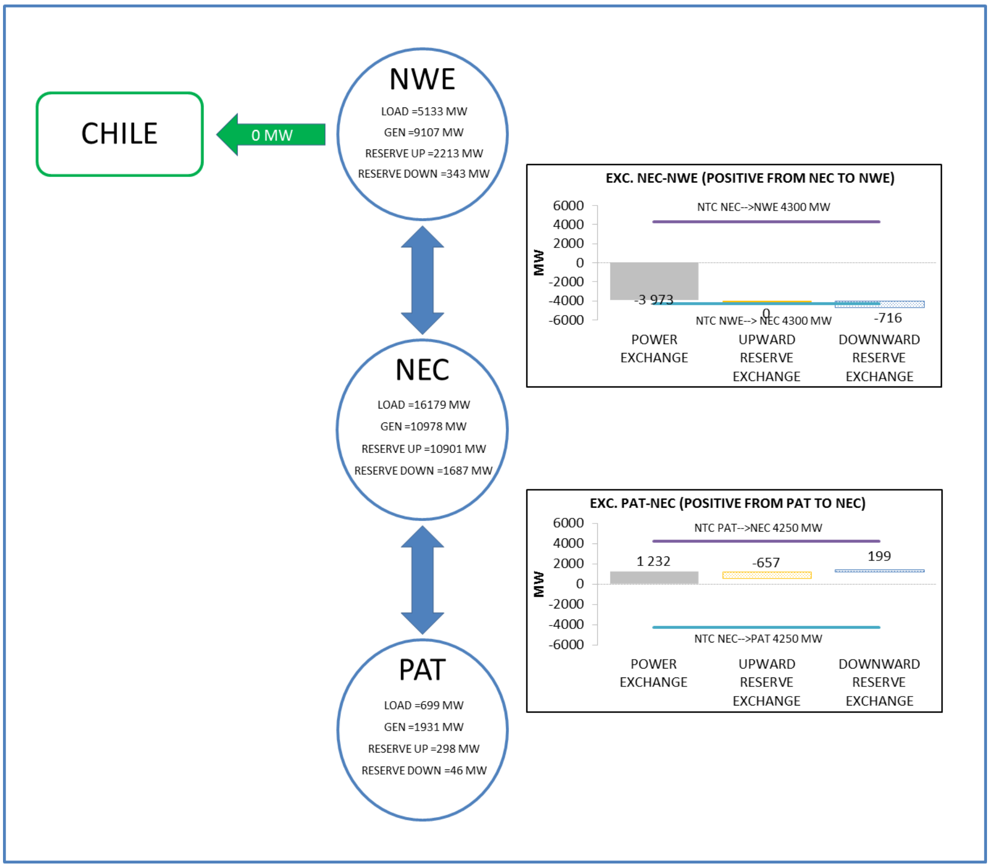


Figure 17 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, no cross-border exchanges

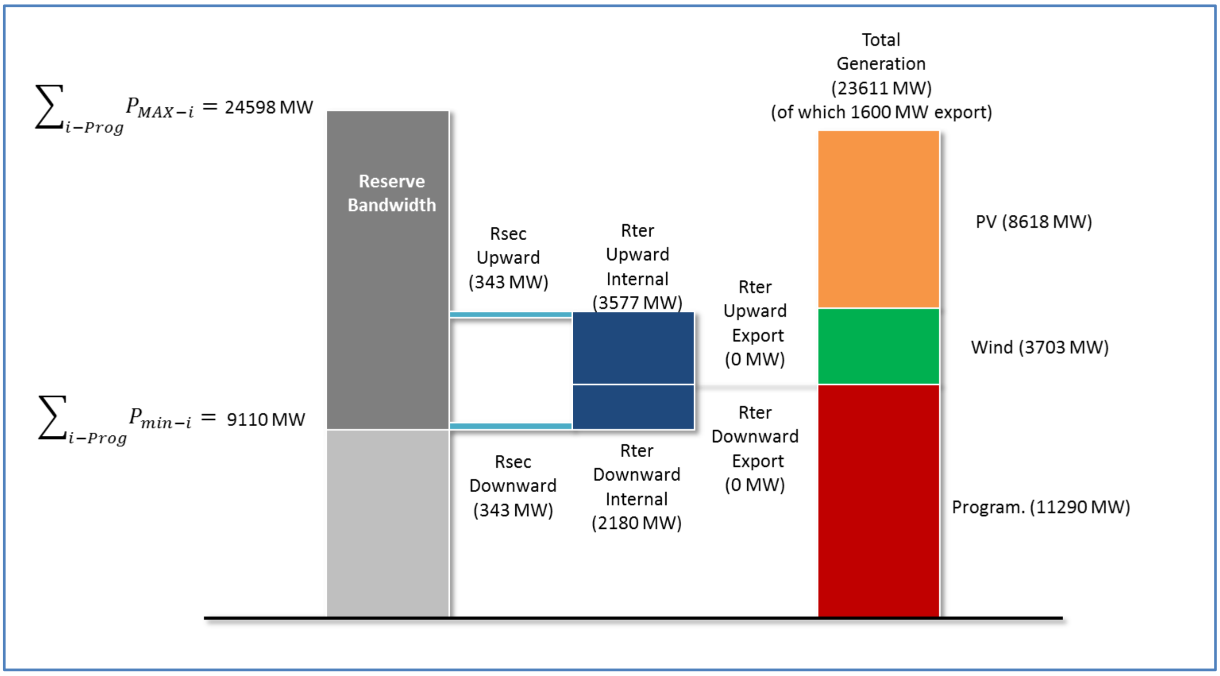


Figure 18 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, maximum export

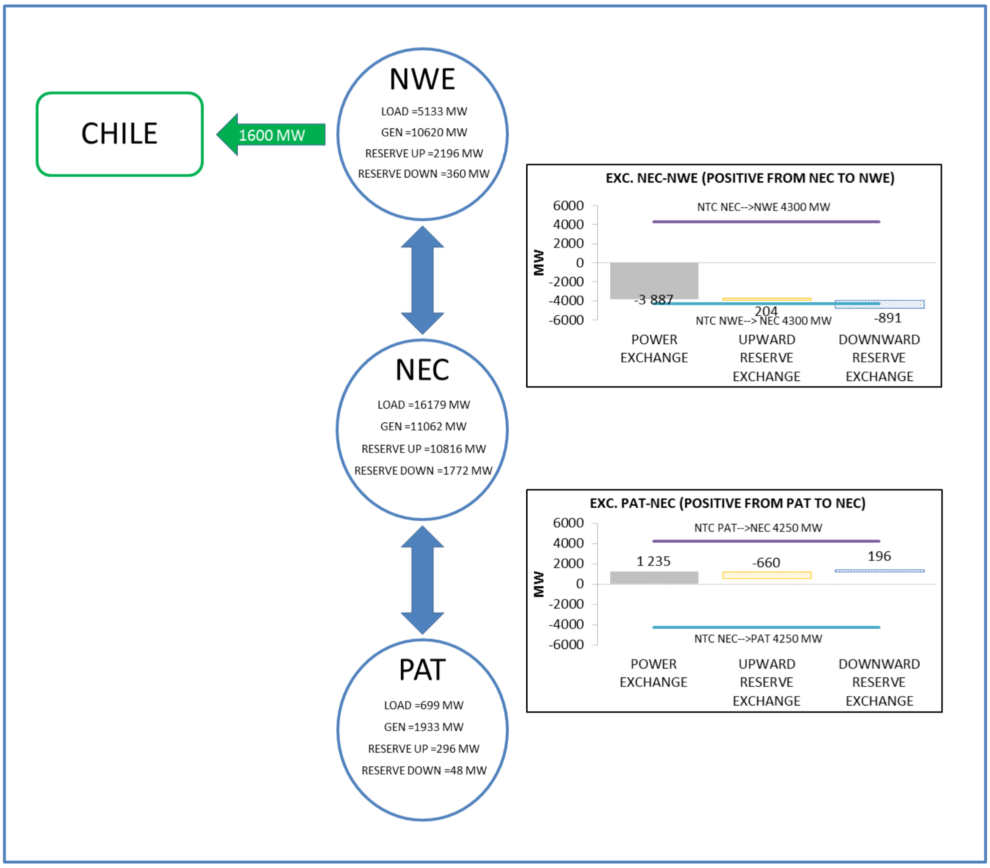


Figure 19 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, maximum export

2.3.1.4 Maximum PV installable capacity (point 5)

As last step, the maximum installable PV power without considering any production by wind power plants is calculated, even if this is not an operational condition likely to happen, as the planned wind generation at 2025 is not null.

In this very extreme condition, more than 10,600 MW of production, corresponding to more than 15,000 MW of installed PV power, can be managed by the whole Argentinian system fulfilling the reserve requirements. But due to the strong concentration of the PV resource only in NWE area, this high amount of installed power would cause significant overloads on the NWE-NEC section.

This particular condition, which increases the risk of curtailments of VRES production due to reserve and transmission constraints in the system and in the area, can happen only if the PV technology is developed. A balanced generation mix which differentiates the VRES power plants with different technologies and in different areas strongly reduces the occurrence of such extremely binding conditions.

Similarly to what was found in other cases, the possibility to export 1,600 MW to Chile increases the amount of possible PV installed power, but also increases the problems of the evacuation of the power from NWE to the rest of the system, considering also the increase of the reserve requirements.

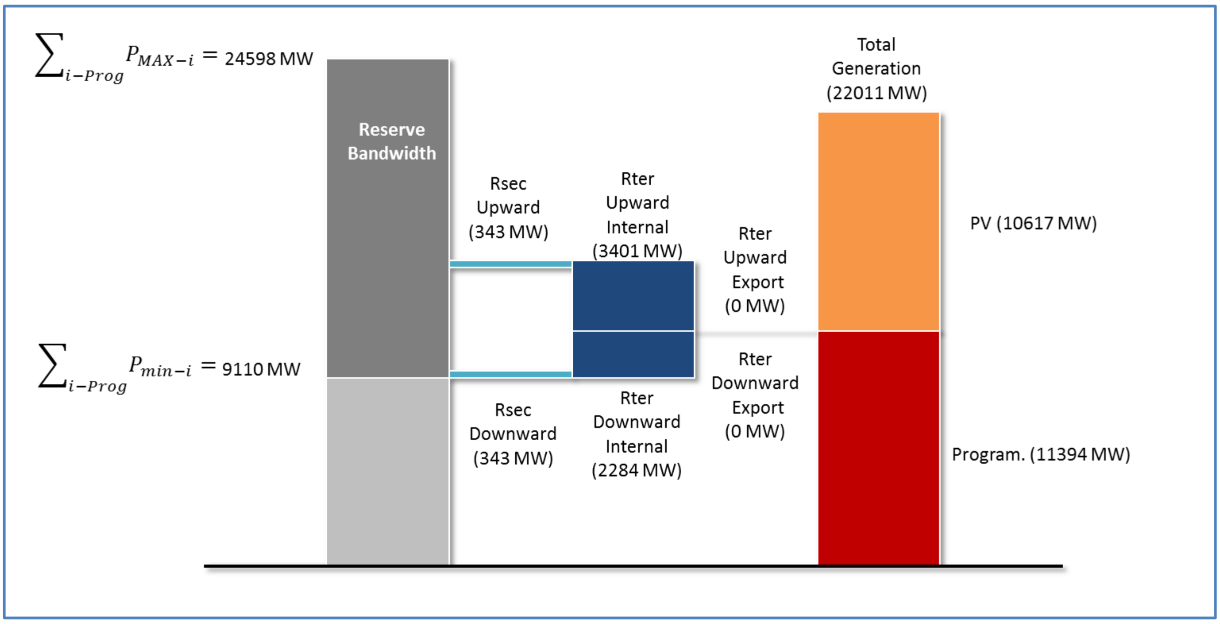


Figure 20 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum PV installed capacity, no cross-border exchanges

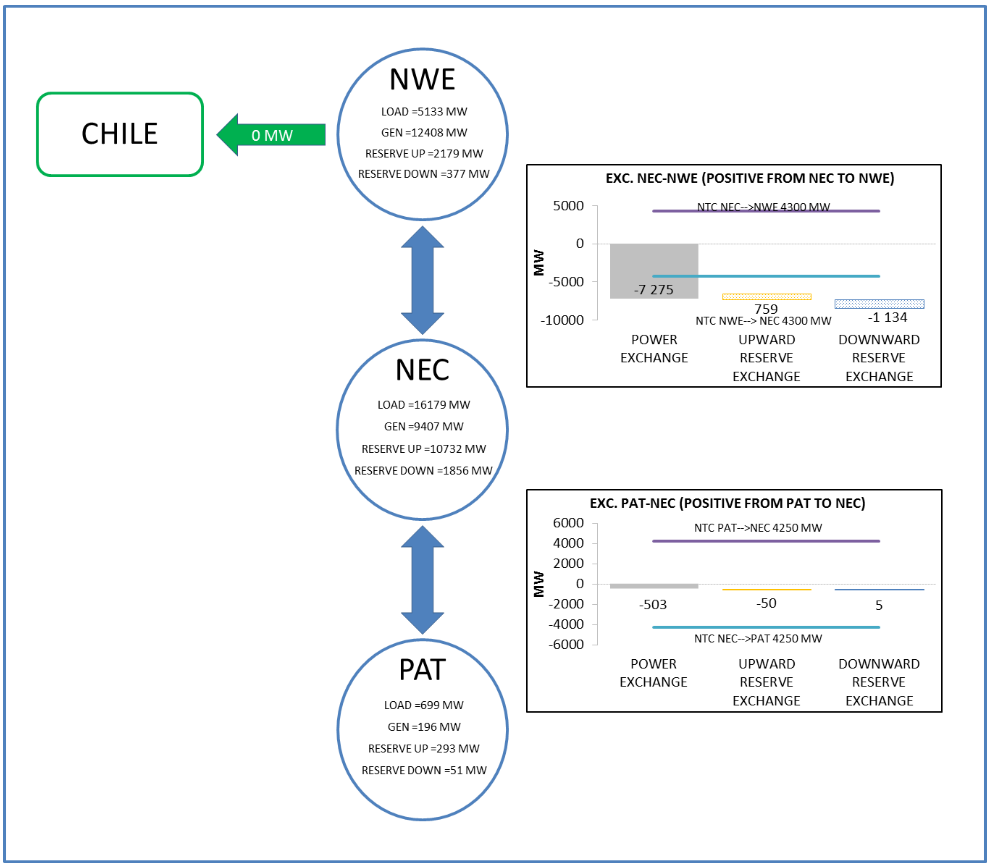


Figure 21 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum PV installed capacity, no cross-border exchanges

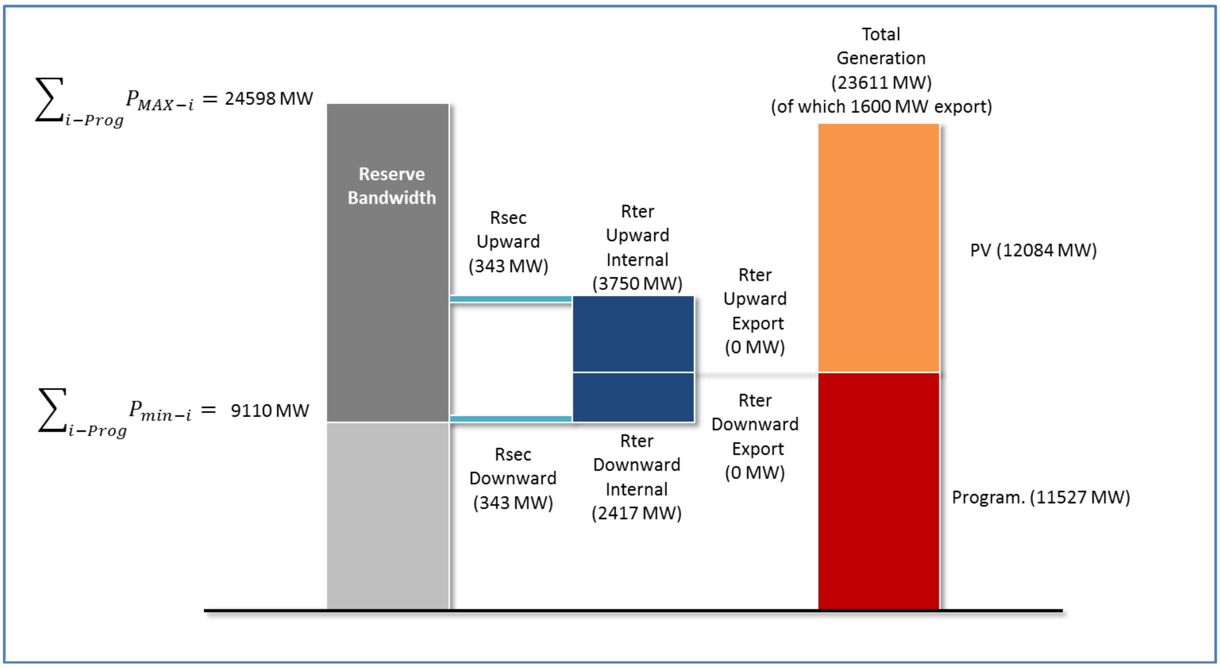


Figure 22 - Generation and reserve in Argentina - Low load and high VRES scenario, maximum PV installed capacity, maximum export

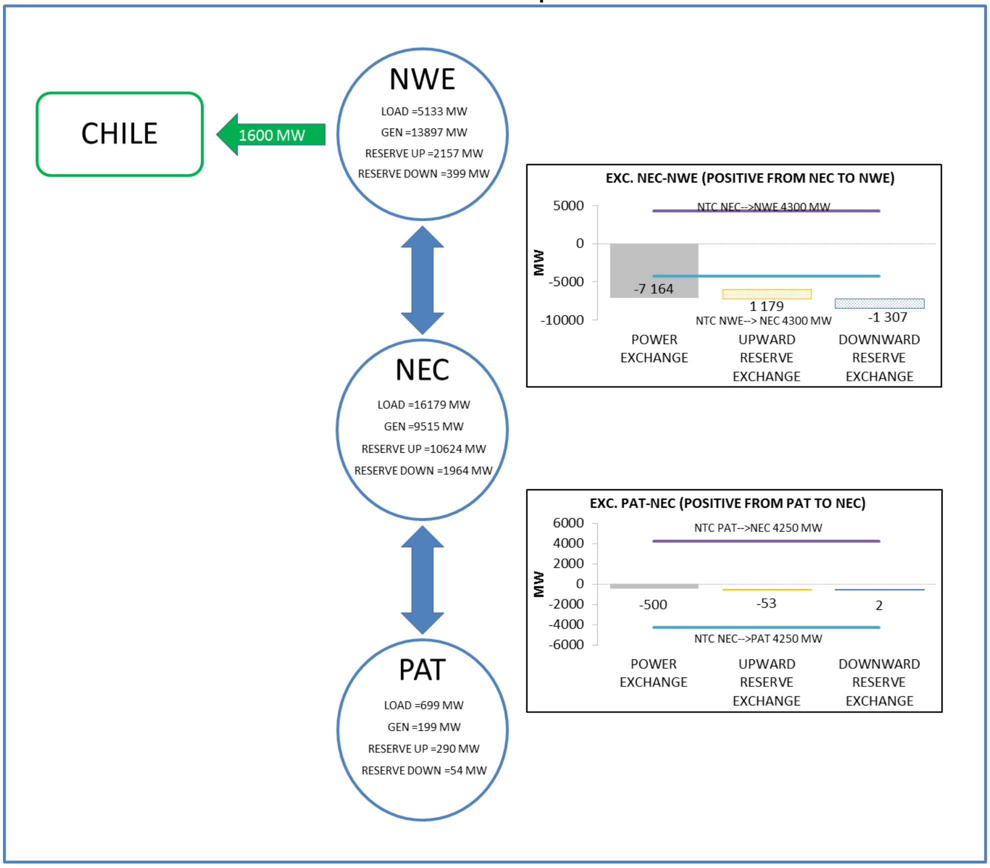


Figure 23 - Power and reserve exchanges between Argentinian areas - Low load and high VRES scenario, maximum PV installed capacity, maximum export

2.3.1.5 *Conclusions for the analysis on the Argentinian system*

A quick explanation of the main outcomes of the analysis performed on the Argentinian system has been provided in the previous paragraphs. The limits of some combinations of PV and wind power production have been calculated in order to define the area which represents the admissible amount of installable PV and wind power ensuring the fulfillment of the reserve requirements. The calculations have been performed for the isolated case and considering the possibility to export 1,600 MW towards Chile. Figure 24 summarizes the results.

The most extreme conditions of the identified area, which correspond to the parts highlighted in grey in Figure 24 where one technology is developed much more than the other, might cause the net transfer capacity between areas to be exceeded, requiring some possible reduction of VRES installed power (or a different distribution among the areas) or the improvement of the transfer capacity with network reinforcements.

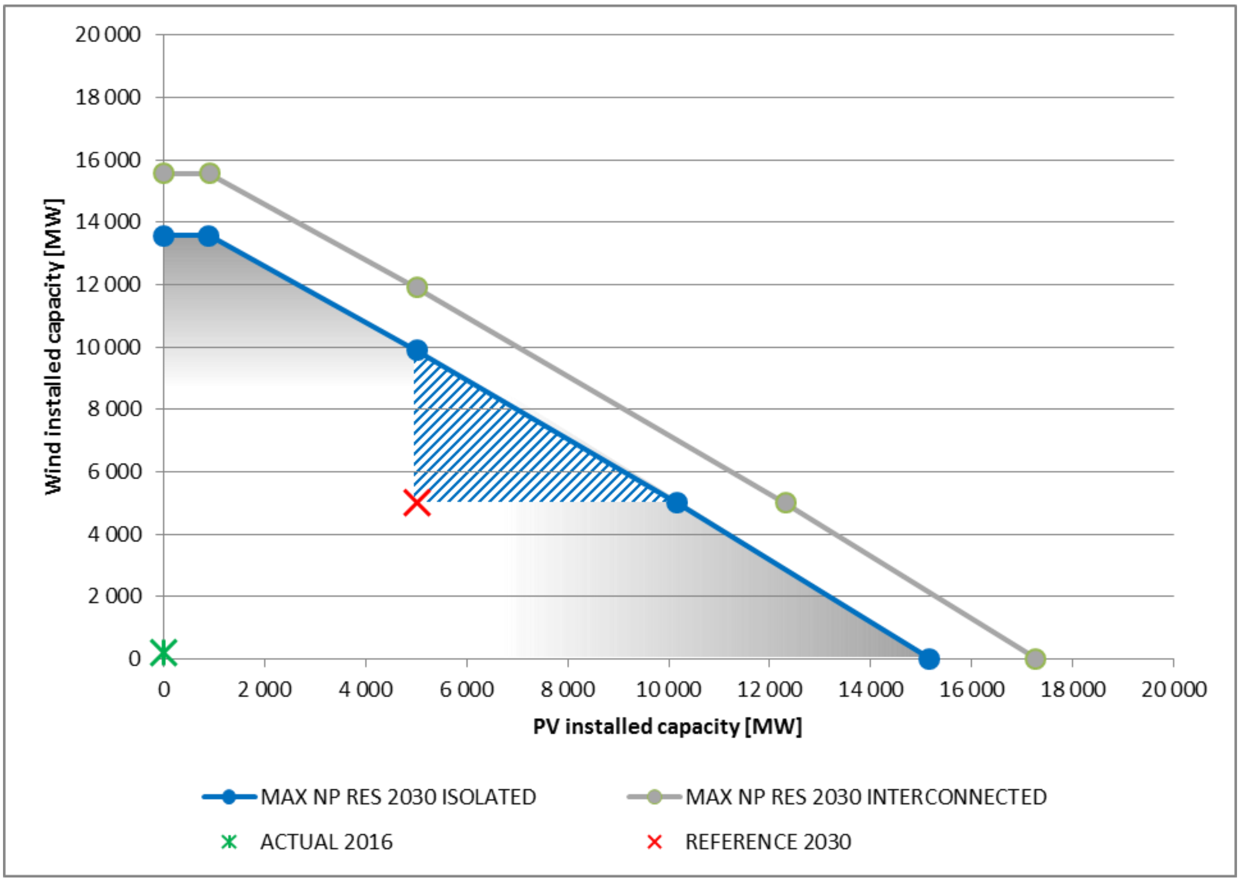


Figure 24 - resulting area of admissible PV /wind installed power fulfilling the system reserve requirements

The quantitative assessment of expected yearly wind and PV curtailment is presented in the following Chapter. On the basis of these latter results one can decide whether inter-area network reinforcements are economically justified or if the risk of curtailed wind energy can be considered acceptable.

The evaluation of the optimal technical and economic deployment of wind and PV accounting for possible inter-area network reinforcements will be performed starting from the Reference Scenario which includes the PV and wind installations according the 2025 targets. It means that the area explored for identifying the optimal soluiton is the dotted one shown in Figure 24.

2.3.2 Chile

Figure 25 shows the maximum VRES installed capacity in Chile considering different combination of Wind and PV generation. The blue line represents the values obtained considering Chile as isolated system (i.e.: "*Analysis considering the Transmission System in the Reference Scenario*"). The grey line is calculated assuming the usage of the two interconnections between Chile and Argentina (600 MW through the Salta-Andes and 1000 MW through the Gran Mendoza-Santiago) for a full export towards Argentina (i.e.: "*Analysis considering the Transmission System with the possible reinforcements defined in the Inception Report*"). It probably does not represent a possible operational condition, but provides a clear indication about a maximum value which cannot be exceeded. In the figure below the actual VRES installed capacity is also indicated as well as the installed capacity target set for 2030.

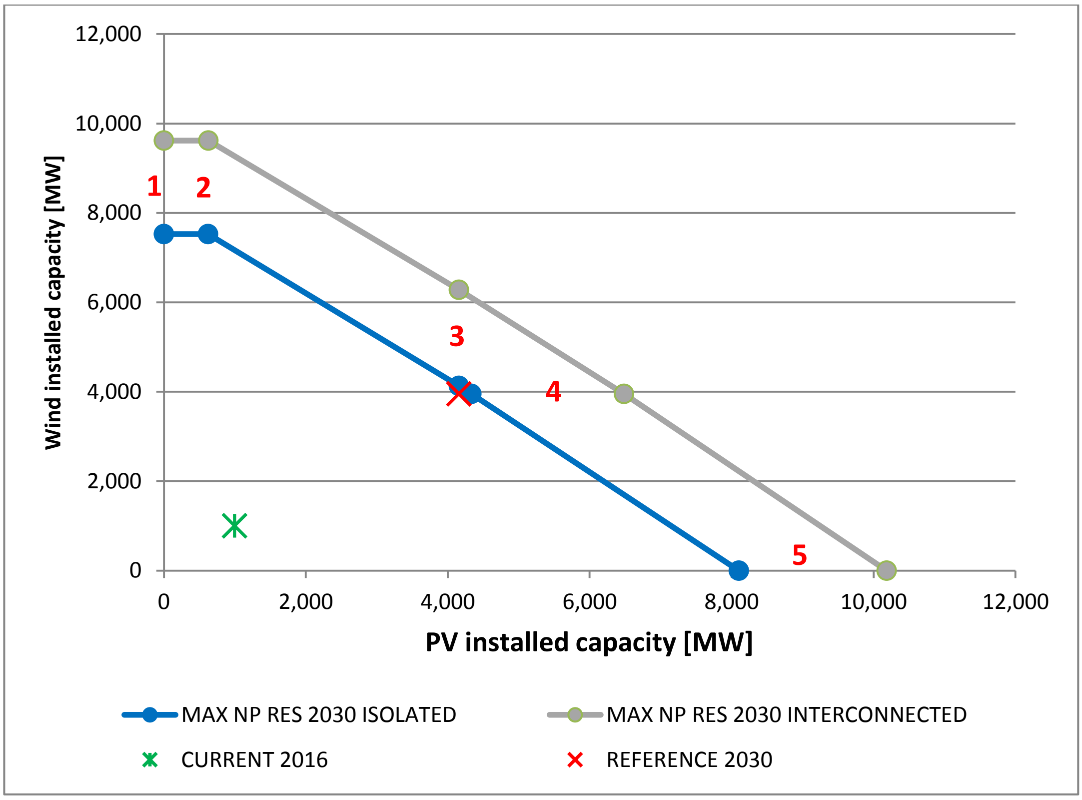


Figure 25 - VRES installed capacity limits due to system operation constraints in Chile - 2030

The boundary lines are obtained by the interpolation of the same PV-wind combination described in paragraph 2.3.1.

It can be noted a very good correspondence between the target values set by Chilean Authorities and the maximum amount of VRES installed power calculated considering the system constraints. With respect to the targets, additional 200 MW can be accepted by the Chilean system without the need of curtailments due to reserve requirements in case of low load conditions.

The following paragraphs show the results related to the most interesting points of the defined area (points 2, 3, 4 and 5), providing also details related to generation and reserve in Chilean electric system, power and reserve exchanges between the SIC and SING areas. The results are reported both considering Chile as isolated system and considering the possibility to export 1,600 MW toward Argentina.

2.3.2.1 Max. PV installable capacity in presence of max. wind installed capacity (point 2)

Figure 26 shows that with the maximum wind generation of 5,300 MW (which corresponds to 7,500 MW of installed capacity due to the given contemporaneity factor) the Chilean system can accept additional 440 MW of PV production fulfilling the reserve requirements.

Power and reserve exchanges between SIC and SING are represented in Figure 27. In this condition, the distribution of the new installed RES power (equal to the distribution of RES power plants in the Reference Scenario) does not imply the NTC limit between Chilean areas to be reached. This means that, under this condition, the reserve requirements can be overall fulfilled by using the transfer capacity between SIC and SING below its limit.

In Figure 28 and Figure 29 are shown the results taking into account the possibility of full export toward Argentina. The possibility to export power towards a neighbour Country determines a higher allowable wind generation and installed capacity (respectively up to 6,730 MW and 9,600 MW); the additional PV production that the system can accept is the same as in the isolated situation (440 MW).

Also in this case the NTC between Chilean areas limit is not reached, although the exchange is greater than in the previous case.

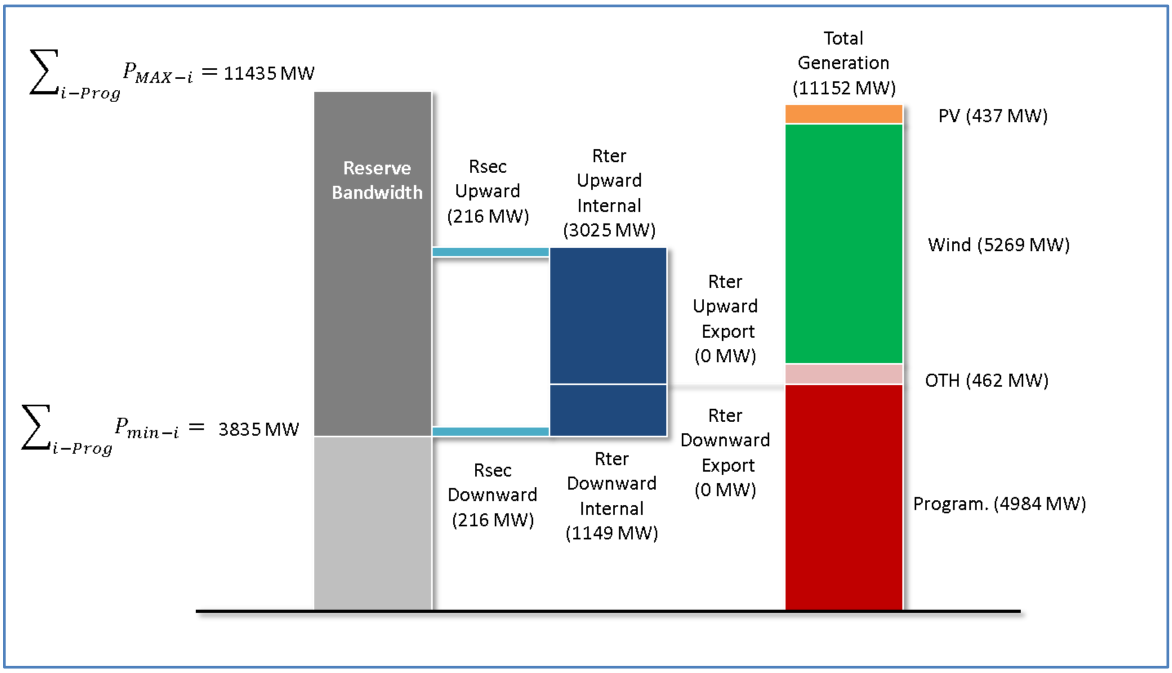


Figure 26 - Generation and reserve in Chile- Low load and high VRES scenario, maximum wind installed capacity, no cross-border exchanges

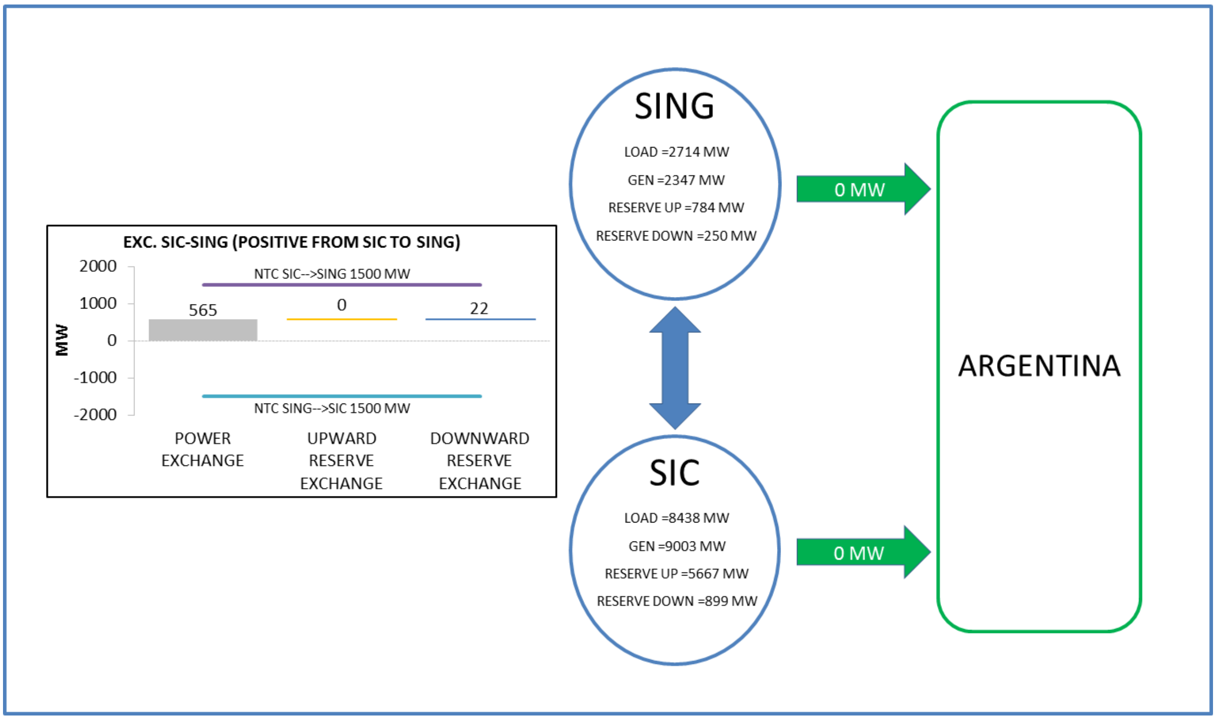


Figure 27 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum wind installed capacity, no cross-border exchanges

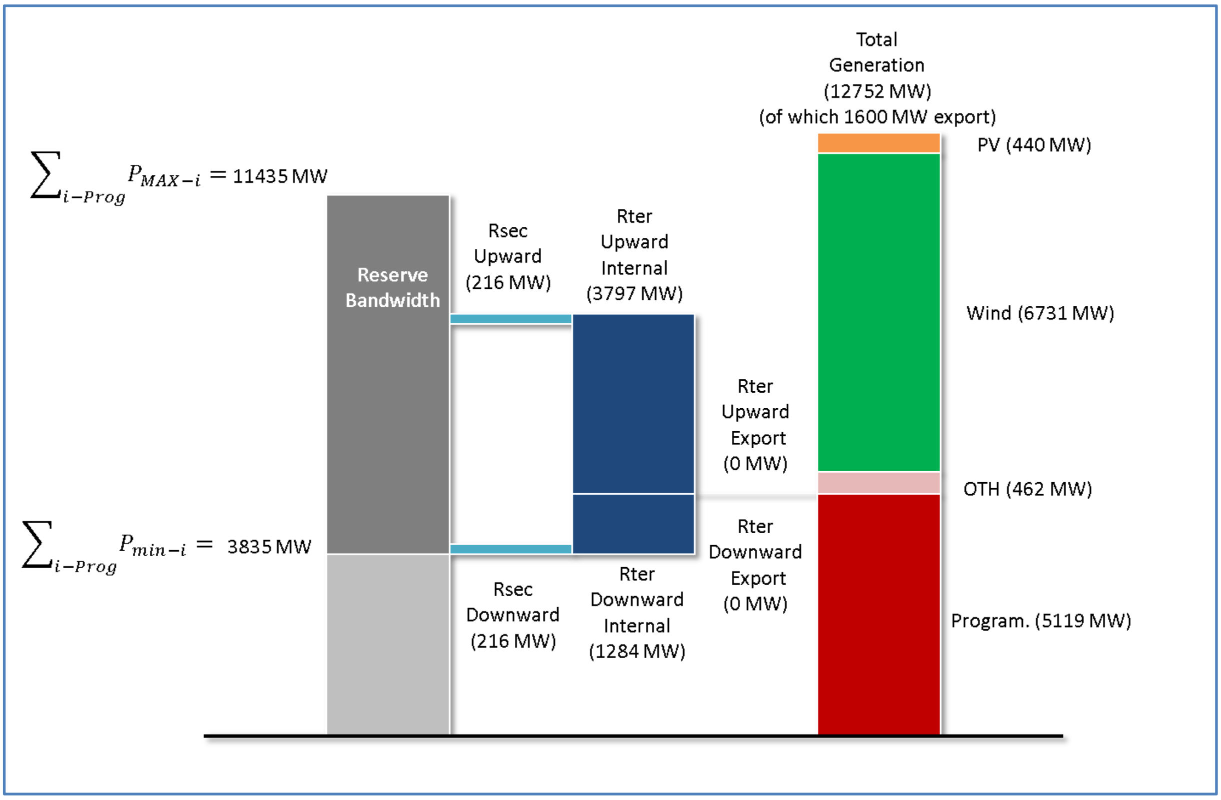


Figure 28 - Generation and reserve in Chile - Low load and high VRES scenario, maximum wind installed capacity, maximum export

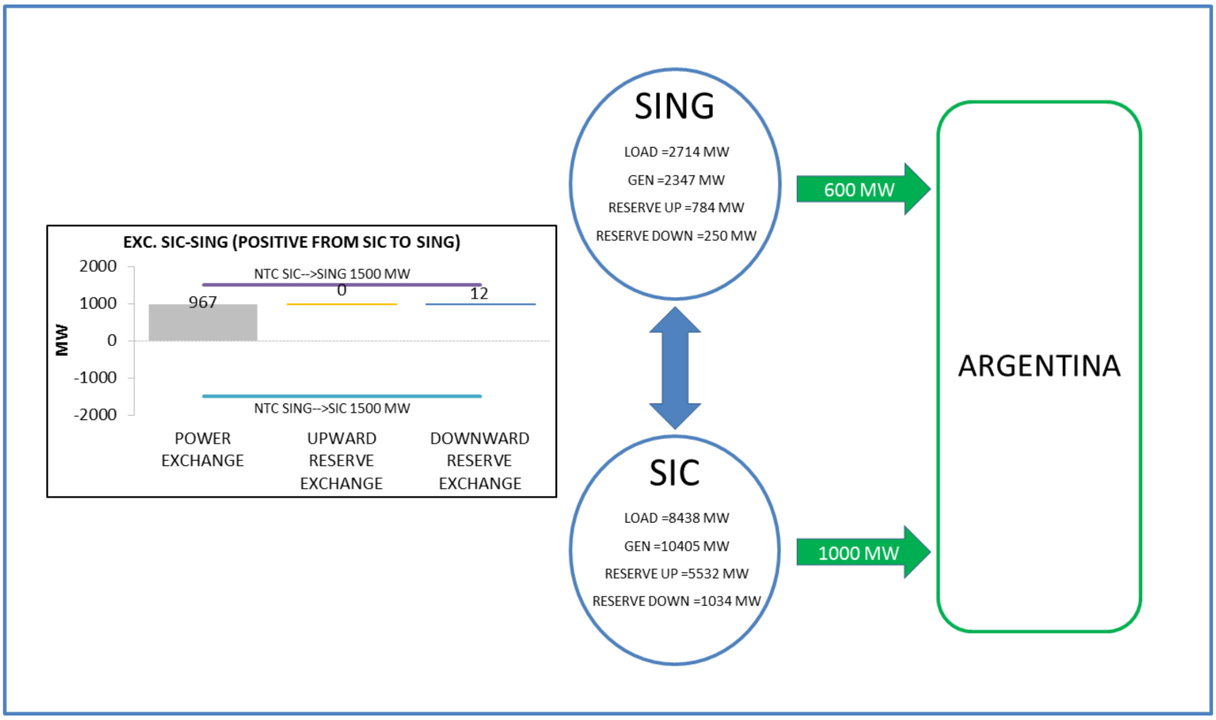


Figure 29 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum wind installed capacity, maximum export

2.3.2.2 Maximum wind installable capacity meeting PV target (point 3)

Figure 30 and Figure 31 show the maximum wind installed capacity that the Chilean system can accept in presence of 4,160 MW of PV capacity, which represents the 2030 PV target. Considering Chile as an isolated system, up to 4,100 MW of wind capacity (corresponding to 2,900 MW of production) can be installed fulfilling all the reserve requirements.

Considering the possibility of a full export toward Argentina, the amount of acceptable wind capacity increases to 6,300 MW (corresponding to 4,400 MW of production during the low load condition).

In both the conditions the NTC between SIC and SING is not exceeded, and transmission capacity is enough to ensure a secure power exchange and suitable margin dedicated to reserve for mutual support between the areas.

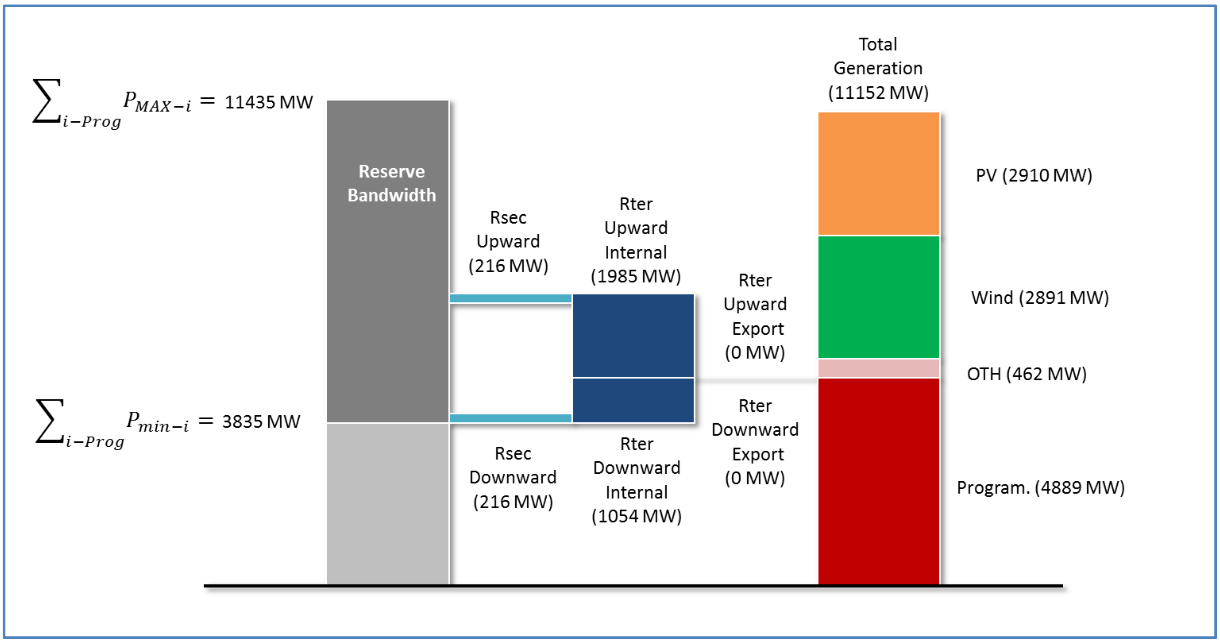


Figure 30 - Generation and reserve in Chile - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, no cross-border exchanges

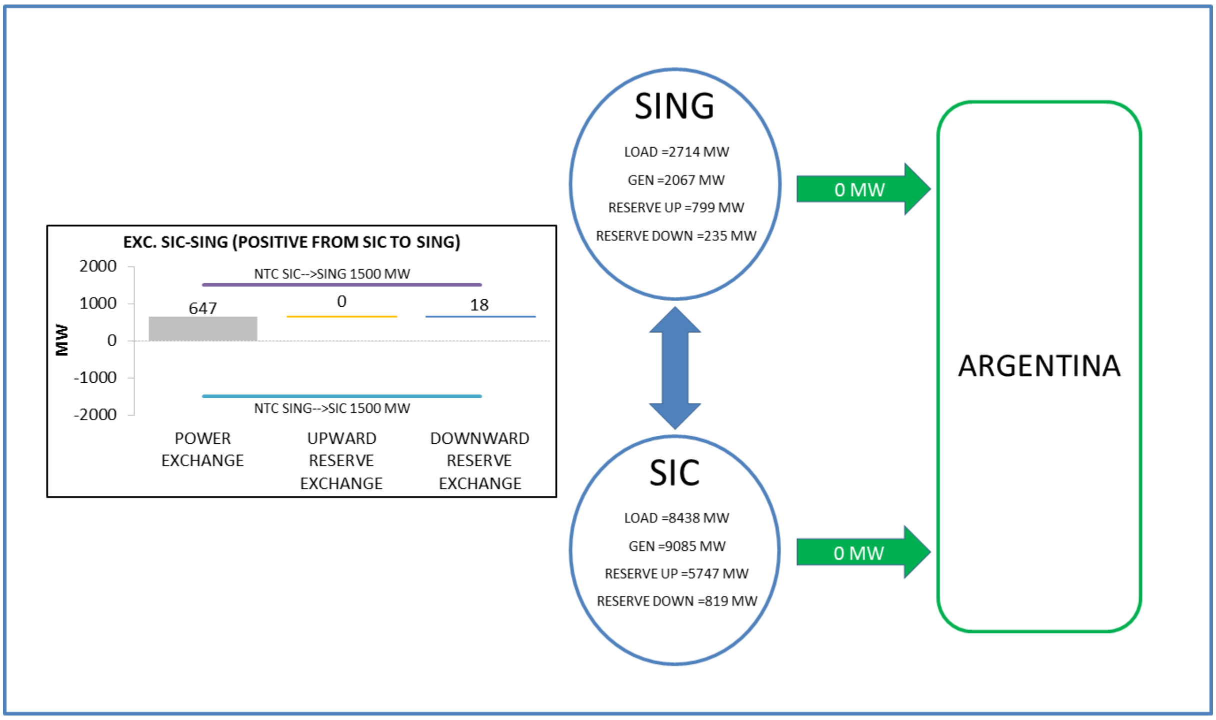


Figure 31 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, no cross-border exchanges

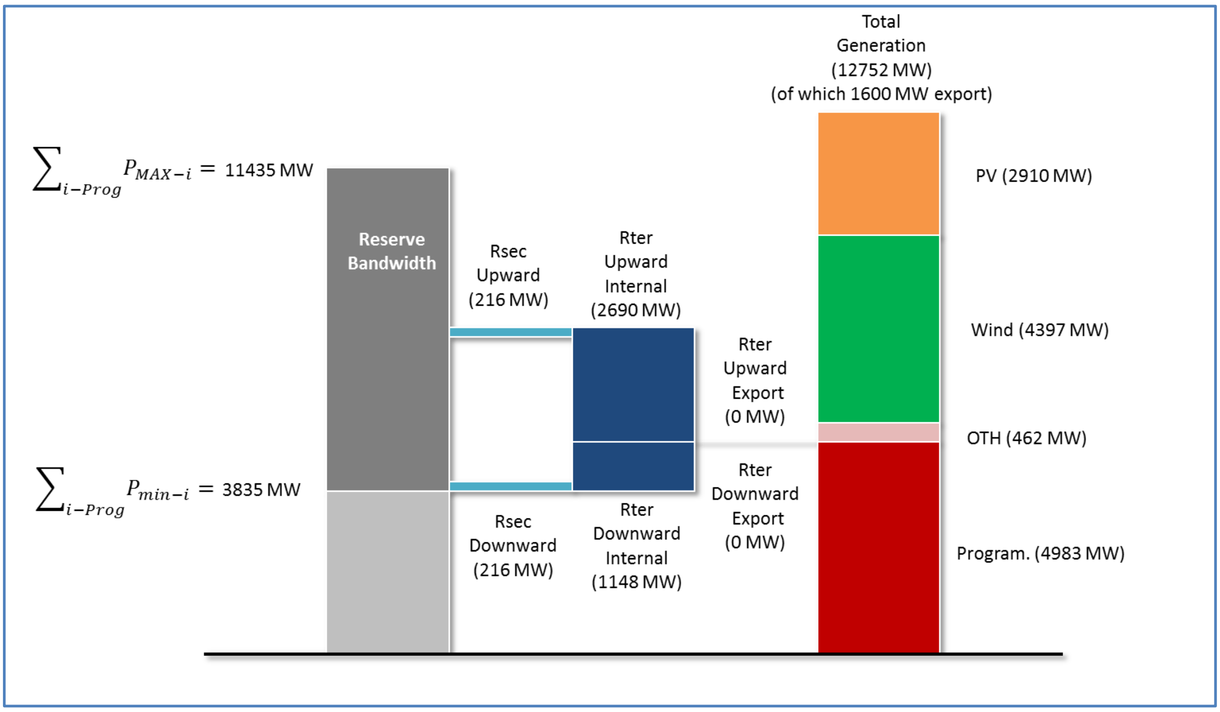


Figure 32 - Generation and reserve in Chile- Low load and high VRES scenario, maximum wind installed capacity meeting PV target, maximum export

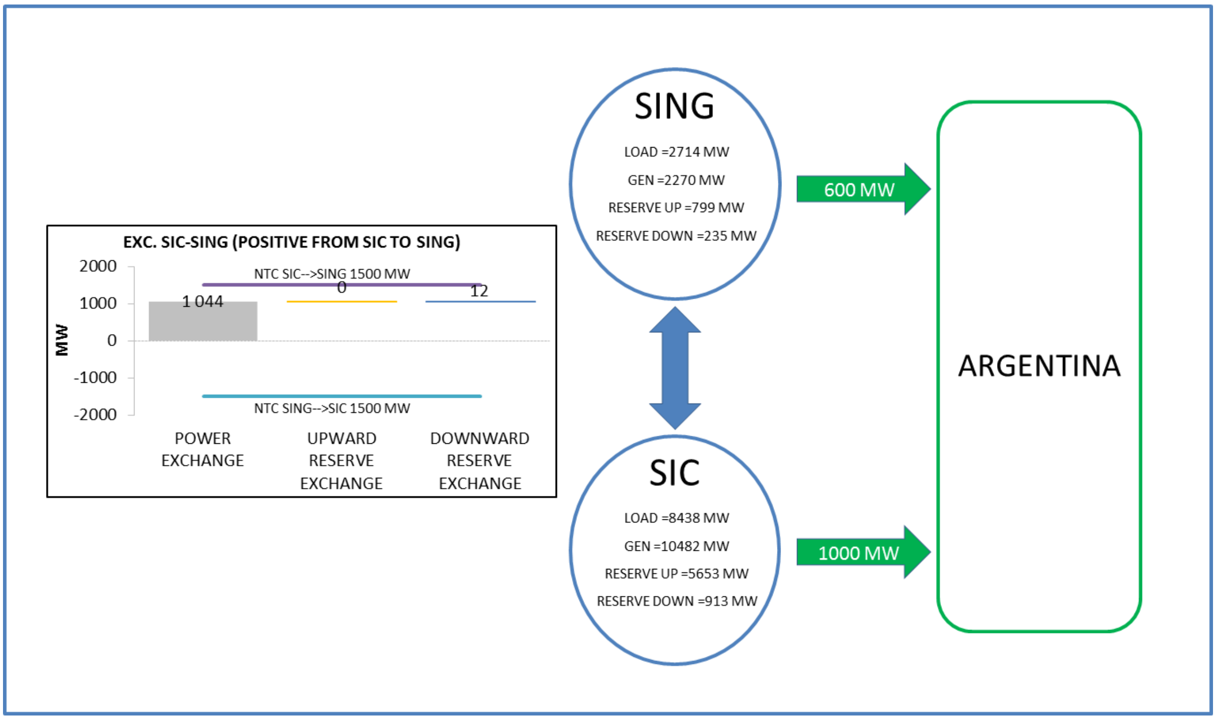


Figure 33 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum wind installed capacity meeting PV target, maximum export

2.3.2.3 Maximum PV installable capacity meeting wind target (point 4)

Considering Chile as an isolated system, when the target amount of wind installed power is considered (3,950 MW), the calculation of the maximum installable PV power indicates that the Chilean system may accept up to 4,300 MW (which corresponds to a production of 3,000 MW).

Taking into account the full export toward Argentina, the maximum installable PV increases to 6,500 MW (corresponding to 4,500 MW).

Also in these cases the NTC between SIC and SING is not exceeded, and transmission capacity is enough for a secure power exchange with a suitable margin for reserve.

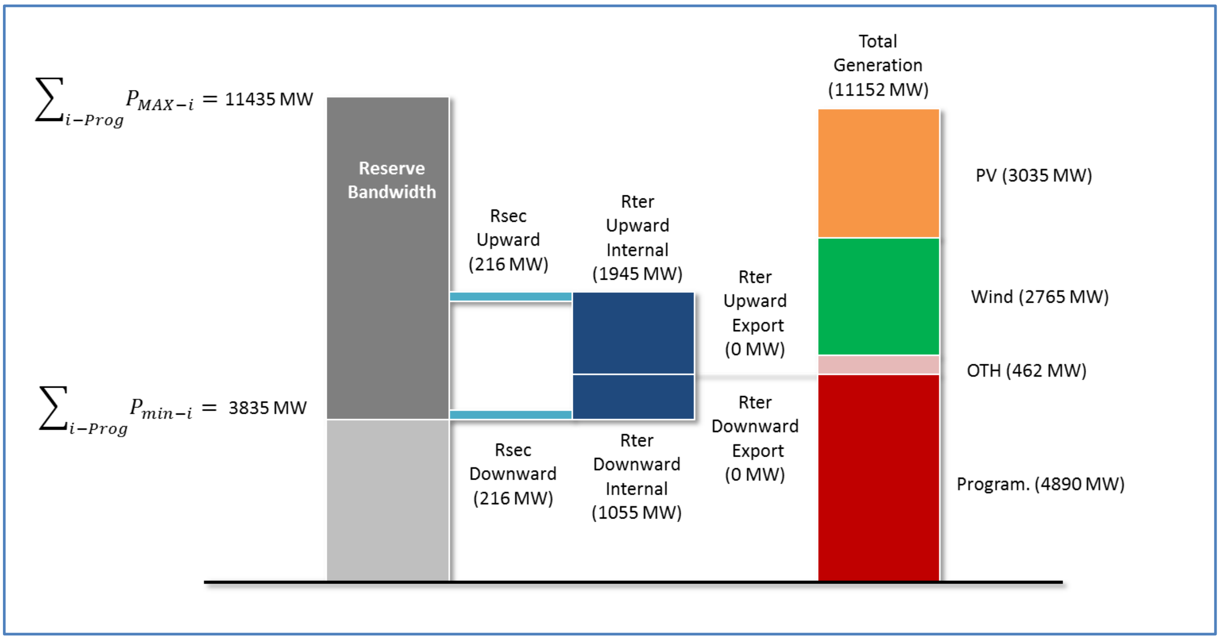


Figure 34 - Generation and reserve in Chile - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, no cross-border exchanges

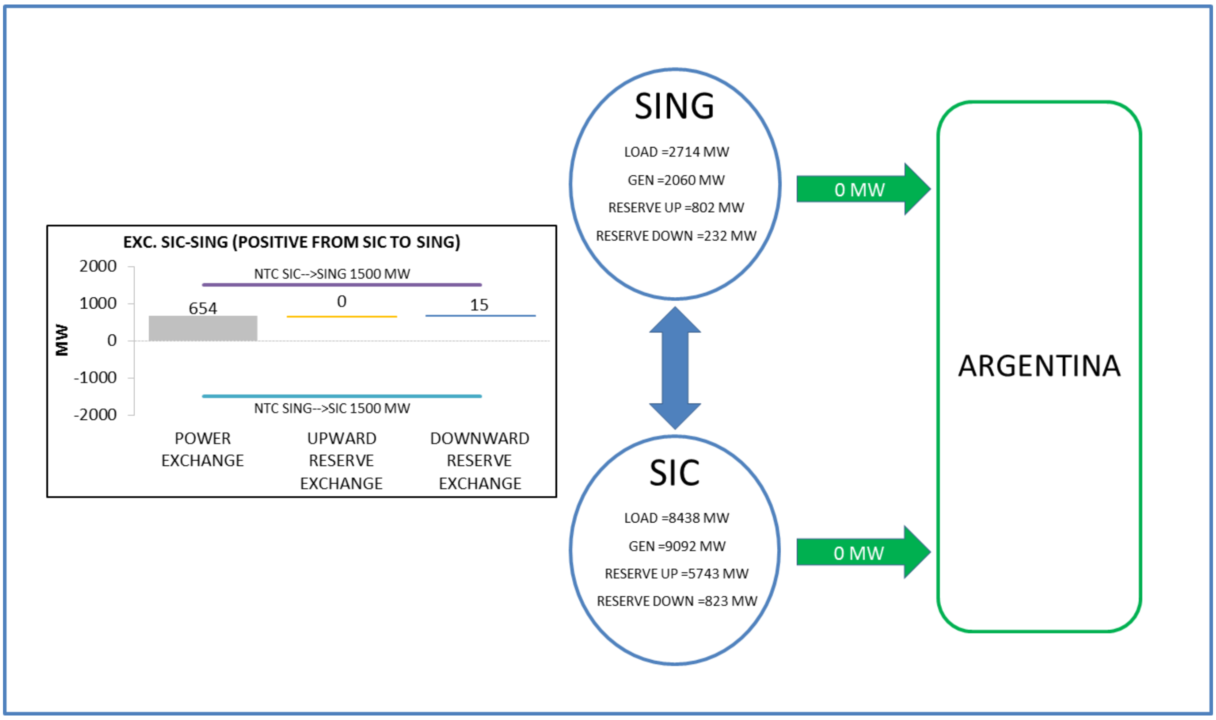


Figure 35 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, no cross-border exchanges

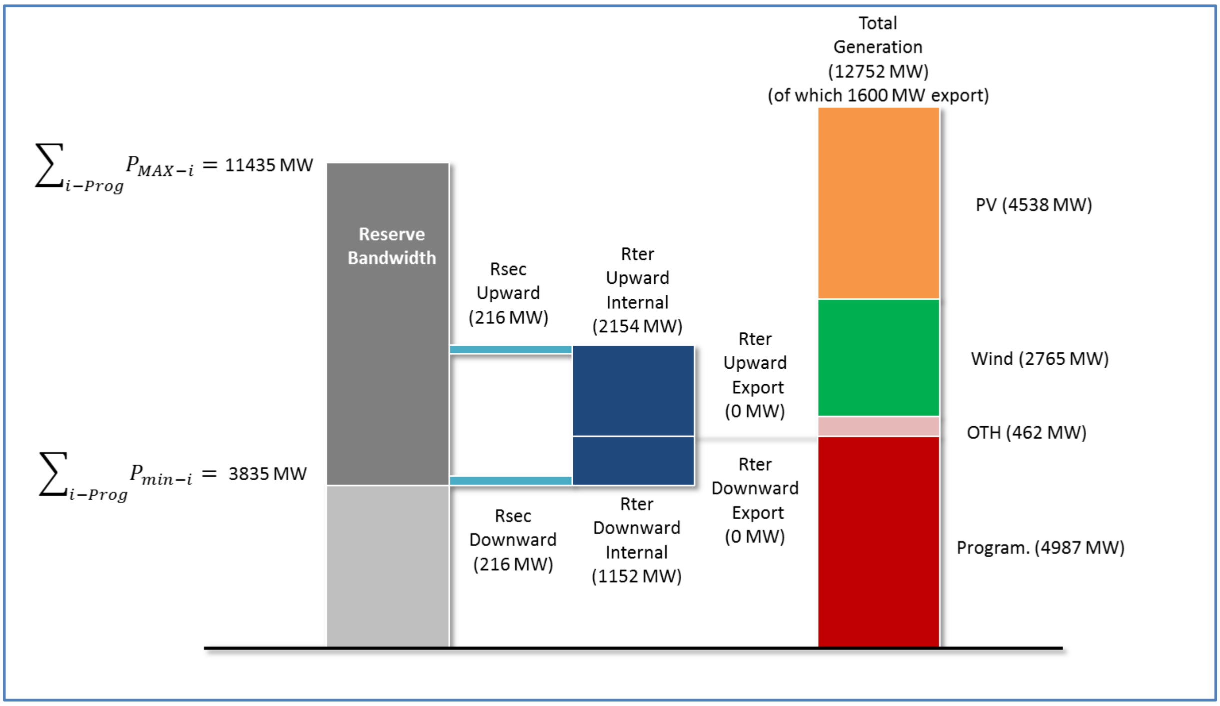


Figure 36- Generation and reserve in Chile - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, maximum export

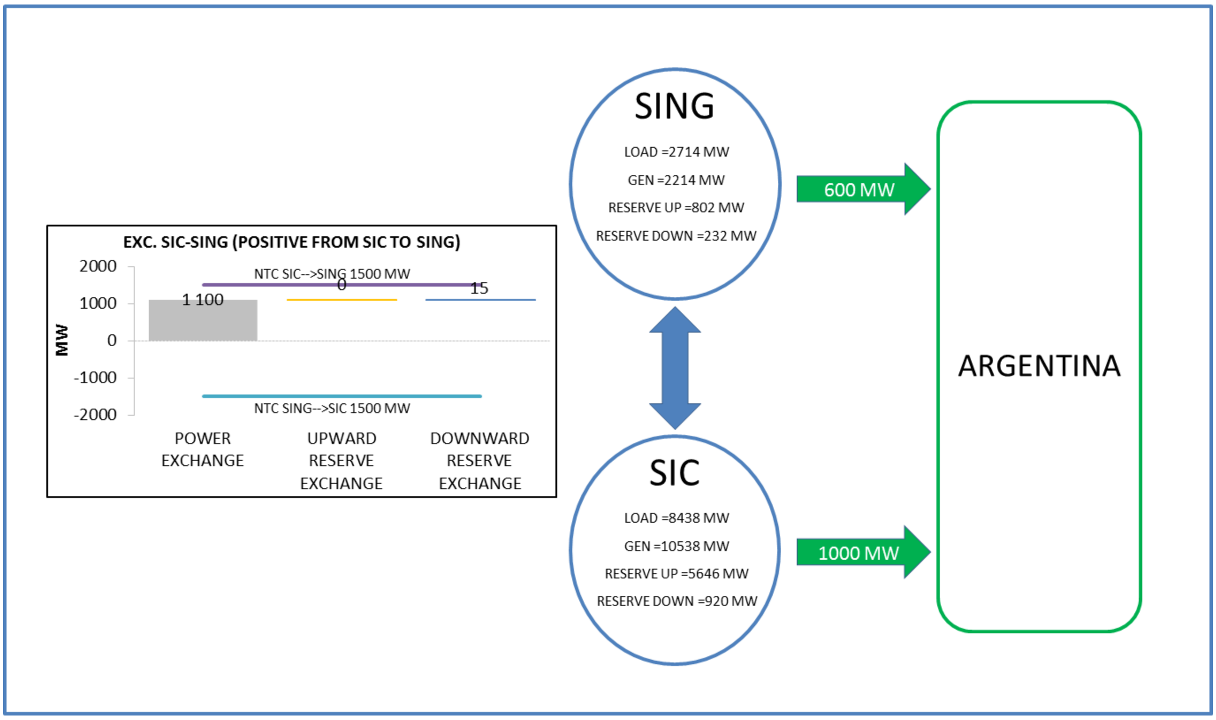


Figure 37 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum PV installed capacity meeting wind target, maximum export

2.3.2.4 *Maximum PV installable capacity (point 5)*

As a last, theoretical condition, the maximum installable PV capacity without considering any production by wind power plants is calculated.

In this very extreme condition, up to 8,100 MW (5,700 MW of production) of PV plants can be installed in Chilean system, fulfilling the reserve requirements. If the full export is considered, the PV installable capacity reaches almost 10,200 MW (7,100 MW of production).

Due to the fact that PV is installed in both SING and northern SIC regions, the NTC between the areas is not reached.

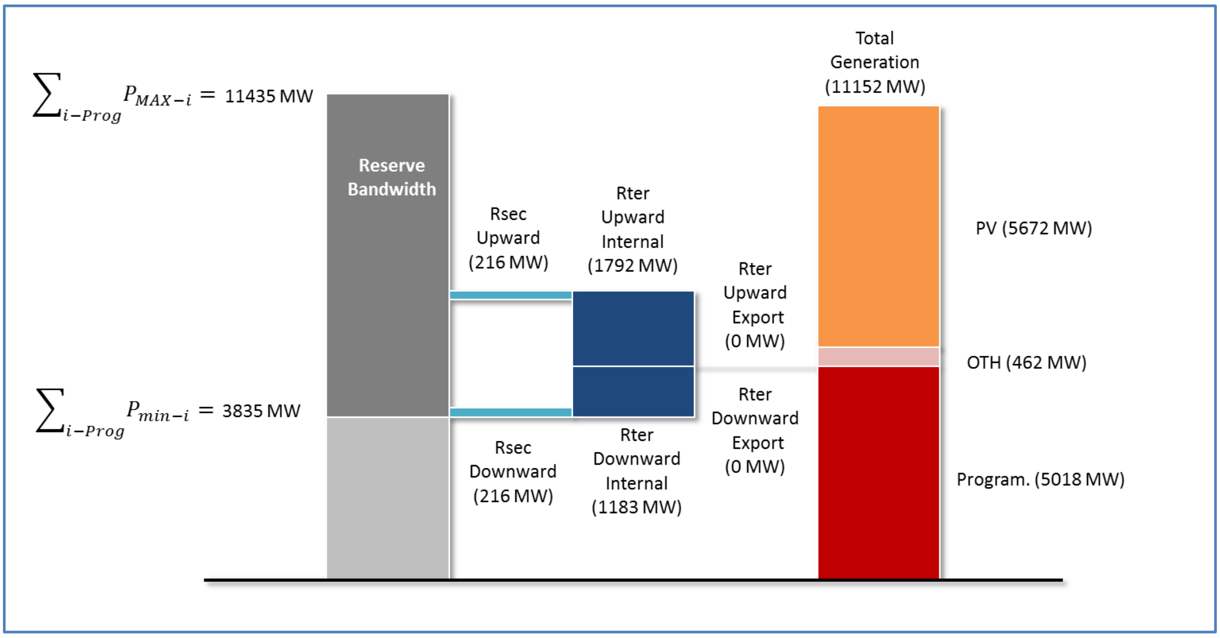


Figure 38 - Generation and reserve in Chile - Low load and high VRES scenario, maximum PV installed capacity, no cross-border exchanges

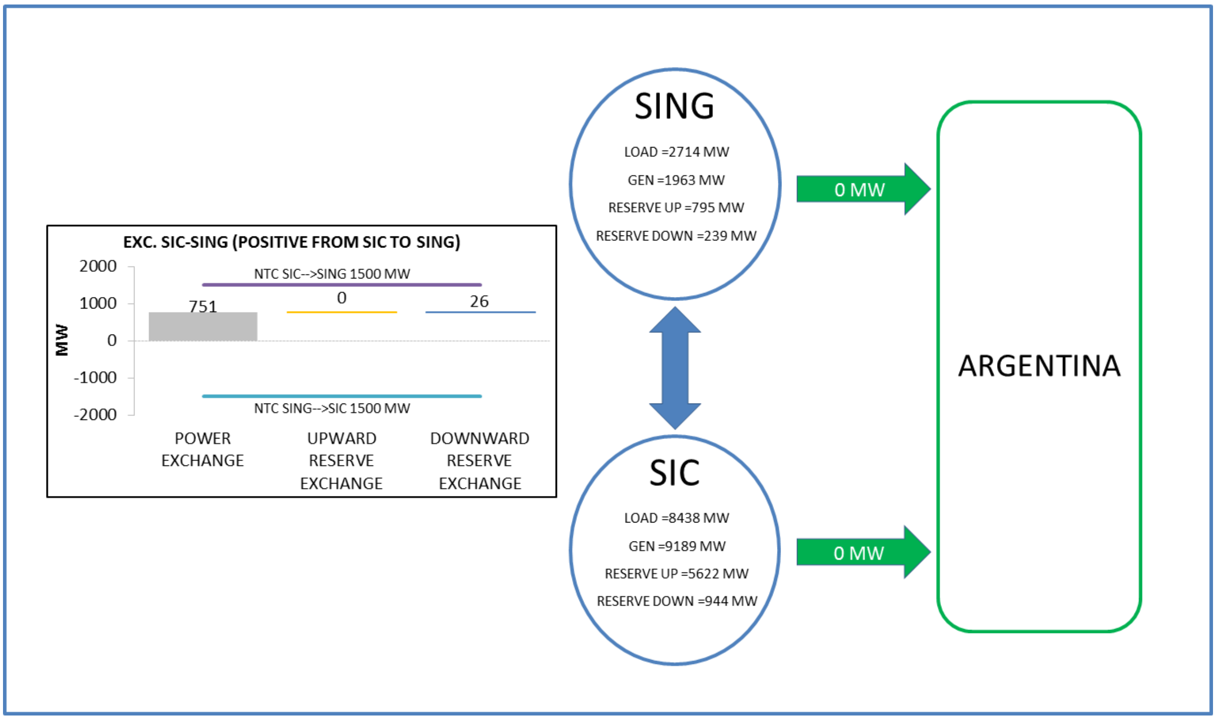


Figure 39 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum PV installed capacity, no cross-border exchanges

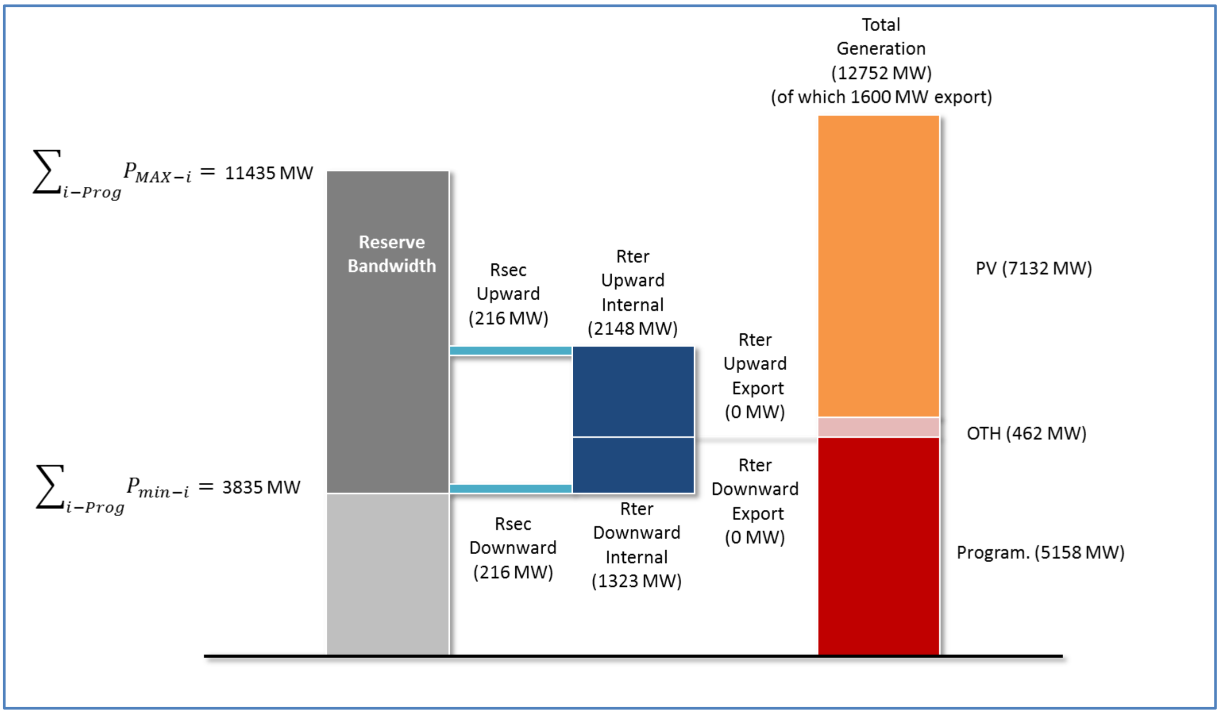


Figure 40 - Generation and reserve in Chile - Low load and high VRES scenario, maximum PV installed capacity, maximum export

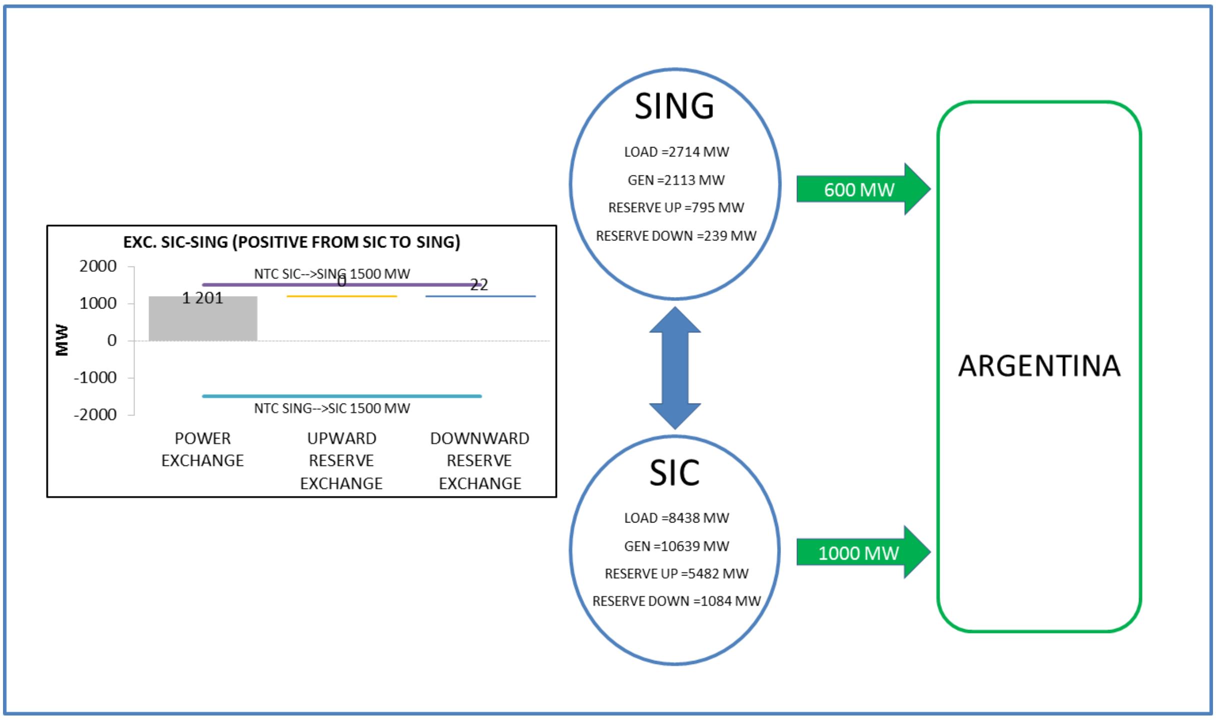


Figure 41 - Power and reserve exchanges between Chilean areas - Low load and high VRES scenario, maximum PV installed capacity, maximum export

2.3.2.5 Conclusions for the analysis on the Chilean system

In conclusion, the 2030 target established by the Chilean authorities looks coherent with the technical limits of the expected power system. The further amount of installable power is about 200 MW.
The NTC between Chile and Argentina is not a limiting factor in the maximum admissible amount of RES that can be installed in Chile.

Furthermore, interconnecting Chile with Argentina through two cross-border lines would allow increasing the variable RES generation up to 2,000 MW.
However this RES installation increase shall be coordinated with Argentina. It has been considered that the cross border exchange capacity can be used in full export during the Chilean low load and high solar irradiation condition. These hours are typically also associated with the Argentinian low load / high solar irradiation – In this condition Argentina likely could not import this amount of power.

Thus, we have jointly examined the two countries as a single electrical system verifying if the increase in the installable capacity thanks to the interconnection as calculated separately for Argentina and Chile is trustworthy.

2.3.3 Interconnected countries

The analysis on Argentina and Chile considered as an interconnected system has been carried out considering the system as a single bus-bar. It means that the NTC between the countries is neglected.

The Argentina – Chile system is considered as an isolated system: it is not possible any export towards other countries.
Figure 42 shows the maximum VRES installable capacity considering the different combination of Wind and PV generation as described in 2.3.1.

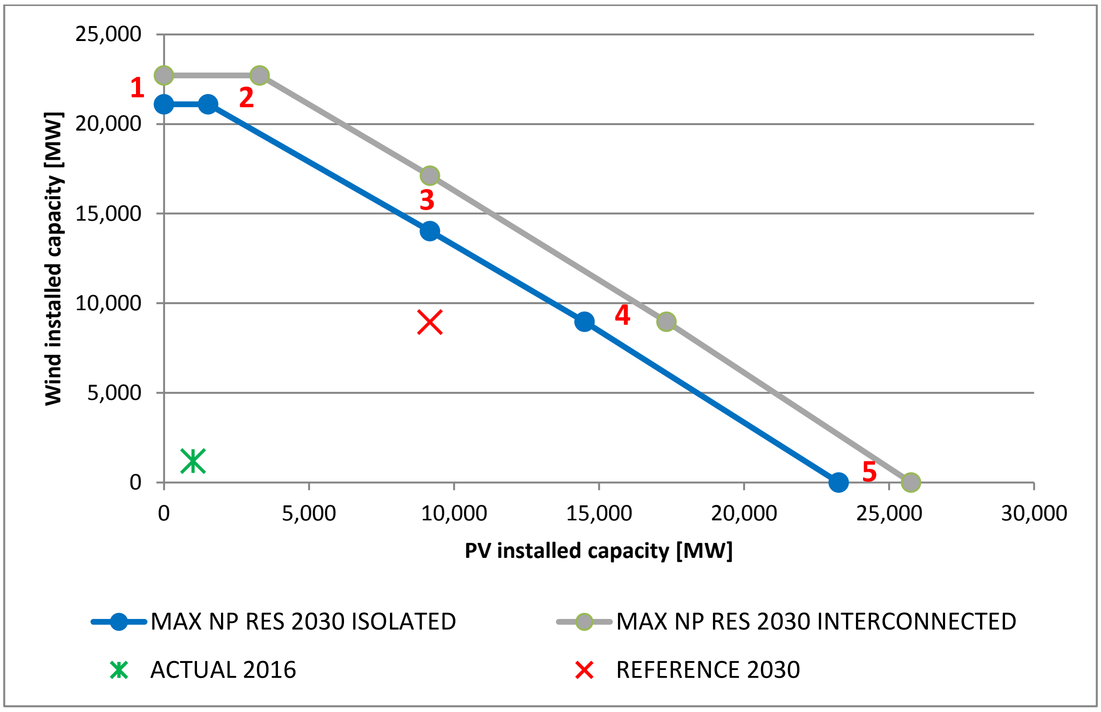


Figure 42 - VRES installed capacity limits due to system operation constraints in Chilean and Argentinian interconnected system - 2030

The blue line represents the values obtained considering both the countries as isolated system and summing the respective maximum RES values in each combination of Wind and PV generation. Each blue dot is indeed the sum of the respective values in Figure 7 and Figure 25.
Also the "Actual 2016" and "TARGET 2025" are respectively the sum of the current installed RES in both countries and the sum of 2025 target for Argentina and 2030 target for Chile.
The grey line is calculated applying the single bus bar methodology described in 2.2 to the interconnected Argentinian-Chilean system.

In the previous analysis on both Argentina and Chile, the RES acceptable increase related to the interconnection (grey line) is due to the fact that the whole NTC between countries is used in export. This is the same as an increase in the load and brings to the possibility to install a larger amount of RES in the system.

In this analysis the increase of RES associated with the interconnection of the systems is not related to the possibility to export further generation. It is instead mainly due to the greater system minimum load related to the fact that the Argentina and Chile have asynchronous minimum load conditions.
The 10th percentile of the interconnected system is calculated on a load trend that is the sum hour by hour of the load trends of the two countries. The 10th percentile of the interconnected system is greater than the sum of the 10th percentiles calculated on the Argentinian and Chilean load trends separately.

This phenomena is certainly related to the different shape of the load trends in the two countries, related to different socio economic behaviors and to the different time zones.

A greater value of low load condition creates the possibility of a larger amount of acceptable RES installation (with the fulfillment of the reserve requirements).

The numeric values of the PV-Wind combination depicted in Figure 42 are presented in the following table.

Table 8 - VRES installed capacity limits due to system operation constraints in Chilean and Argentinian interconnected system - 2030

[MW]	Sum of isolated system		Interconnected system		Variation	
Point	**Wind**	**PV**	**Wind**	**PV**	**Wind**	**PV**
1	21,105	0	22,708	0	1,603	0
2	21,105	1,525	22,708	3,304	1,603	1,779
3	14,018	9,173	17,122	9,173	3,104	0
4	8,961	14,510	8,961	17,327	0	2,817
5	0	23,270	0	25,766	0	2,496

The most interesting points are 3 and 4 – they are obtained by increasing the installed power of one technology on the basis of the target of the other one. The area between these points is the most likely to be achieved.
It is important to point out that the increase of the acceptable installed power due to the interconnection in these points is respectively 3,100 MW and 2,800 MW.
These values are remarkably lower than the sum of the increases due to the interconnection described in 2.3.1 and 2.3.2 (which are 4,200 MW in the point 3 and 4,300 MW in the point 4).

The increase in the maximum RES installed capacity due to the interconnection between Argentina and Chile illustrated in this chapter is more precise than in the previous analysis in which the interconnection is used in full export, without any regard to actual possibility for the neighbour country to import a larger amount of power during low load conditions.

The actual NTC between the two countries limits the possible distribution of the incremental RES power due to the interconnection.
If the NTC were infinite, it could be theoretically possible to install this incremental VRES power plants even in just one country (Argentina or Chile). In reality the NTC is limited and this represents an important constraint for the possible distribution.
Even considering the interconnection as available for full export (as described in the previous chapters), the maximum increase of VRES due to the interconnection is limited to about 2,000 MW in both the countries (in points 3 and 4).

In conclusion, it can be said that the distribution of the calculated increase of VRES power due to interconnections (about 3,000 MW for the whole system) is limited by the actual NTC. Increasing the NTC would mean to let this distribution to be less constrained and allow more flexibility in the decision where to install the additional plants.

3 ECONOMIC AND TECHNICAL ANALYSES TO EVALUATE OPTIMAL ECONOMIC AMOUNT OF ADDITIONAL VRES

3.1 Introduction

The objective of these analyses is to assess the impact of the expected renewable generation on the operation of the power system taking into account a detailed model of the transmission network. Power flows internally to the country and between the countries under examination are evaluated, investigating also the existing constraints.

A detailed generation and transmission model is set up and simulations of one year of operation with a probabilistic approach based on Monte Carlo method are performed increasing the amount of VRES and calculating the main technical and economic figures to allow the evaluation of the optimal solution.

The computational tool used for the simulation is GRARE (Grid Reliability and Adequacy Risk Evaluator) developed by CESI on behalf of Terna (the Italian Transmission System Operator) and widely used for reliability analyses in presence of substantial penetration of RES generation. A more detailed description of GRARE can be found in Appendix 1.

The probabilistic simulation of one operational year considers thousands of different system configurations (different load, availability of generation fleet and transmission networks, VRES power production…), weighted by their probability to happen. With this approach, the results depict the expected operation of the whole system, obtained analysing many real operational states, and evaluating detailed information of each system component.

The most interesting results are the expected benefits for the system in terms of lower generation costs, taking into account the variation of the Expected Energy Not Supplied (EENS[4]), but also the expected production of the VRES plants, considering possible curtailments due to system or transmission constraints. These curtailments, which might become necessary to solve overloads that cannot be resolved by a different dispatching of the traditional generation or to meet very low load conditions when the thermal generation is already at the minimum production, reduce the production of the new VRES plants, reducing their profitability.

Thanks to the comparison of the main results obtained by the simulations of scenarios with different amount of VRES, it is possible to define the optimal amount of additional VRES power plants and to split the different technologies or areas, looking at the configurations which provide the highest benefits to the system, taking into account also the relevant costs.

The detailed methodology applied in the study is presented in the following paragraph.

[4] EENS represents the Load that cannot be supplied during the year due to system constraints such as Lack of Power (not enough available generation in the system), Lack of Interconnection (when a higher interconnection with other areas might provide the missing power), Line Overload (when it is necessary to cut some load to resolve line overloads that cannot be resolved only with a different dispatching of generators)

3.2 Methodology

In this paragraph, the methodology applied to assess the optimal economic RES penetration accounting for possible network reinforcements is presented.

It is based on the calculation of the benefits to the system generated by the investment of the same amount of money in different technologies, and proposing higher share of the needed investments supporting the one which provides higher benefits. The procedure adopted is illustrated in Figure 43 and is made by different steps and iterations that will be described in the next paragraphs.

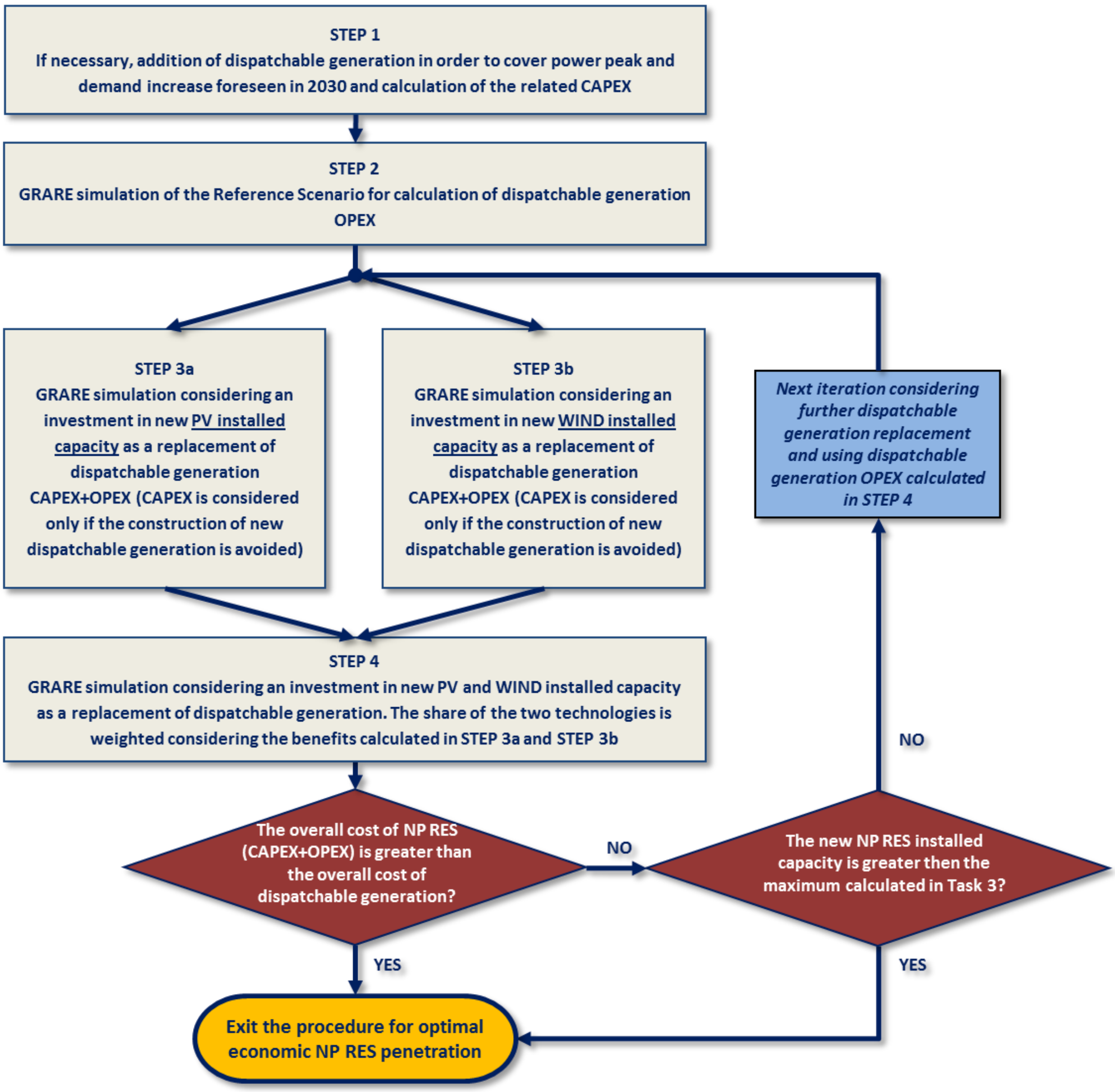


Figure 43 - Procedure for the calculation of the optimal economic VRES penetration

3.2.1 STEP 1 - Generation capacity to ensure system adequacy

The reference scenario described in [1] could determine an inadequate installed generation for peak demand supply and this creates an unrealistic situation with an excess of energy not supplied.

In fact, during the operation of the system the available generation can be significantly lower than the installed net generation capacity.
The main causes of the reduction of generation capacity during the system operation are the following:

- System service reserve: the amount of reserve provided by dispatchable units reduces the available capacity for load supply. The value of system service reserve changes hour by hour depending on the load, wind and PV generation. The system service reserve is also affected by its calculation methodology.[5] Variations of this methodology made possible by new technologies able to reduce the forecast errors or increase the dispatchability of plants (for instance with storage systems) might reduce the system reserve need.
- Line overload: In case of congestions, generation capacity could be unavailable because of its impact on line overloads. The impact is considered internally by GRARE simulations taking into account the grid in the optimization process.
- Outages: They are considered by means of fault probabilities as an input of GRARE simulations. If the Montecarlo draws determine the outage of one or more generation units, the total available capacity decreases.
- Overhauls: Maintenance of each power plant is scheduled during the year by GRARE starting from the yearly maintenance duration time provided as an input. Although GRARE aims to schedule the maintenance during low residual load periods, the unpredictable generation can determine a coincidence of maintenance and residual load peaks.
- Non usable capacity: Much of the total installed net generation capacity is given by units which are dependent from the availability of their primary sources, overall water, wind and solar radiation. When the primary source is not available also the generation capacity can't be exploited.

Figure 44 depicts the factors listed above which have an influence on the remaining available capacity.
It is important to highlight that all the components of Figure 44 are calculated on an hourly basis in the GRARE simulations. Starting from GRARE outputs, the new dispatchable capacity has been progressively added where needed until the EENS requirement has been fulfilled. An EENS limit of 10^{-5} p.u. of total yearly energy demand as been adopted in the calculation as a reference limit for energy not supplied for lack of available generation in the system. The EENS limit of 10^{-5} p.u. of total yearly energy demand considered in the study is a reference value adopted as a best practice by ENTSO-E TSOs. A higher tolerable EENS can determine a lower need of further dispatchable capacity but the system adequacy will inevitably be lower.

[5] Reserve is modelled for each hour to cover 99% of imbalance as a consequence of load, wind and solar day ahead forecast errors. Reserve will then become higher in case of high load, wind and PV at the same time.

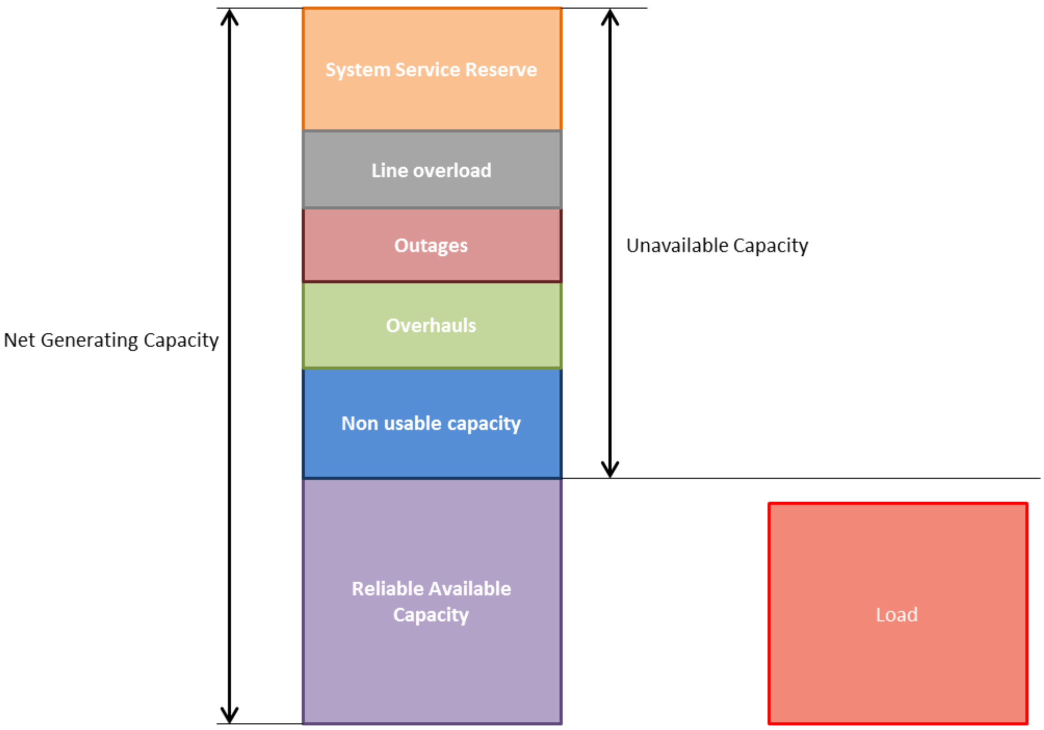


Figure 44 - Overview of different causes of generation capacity reduction during operation

Furthermore, it is important to highlight that the generation in Argentina is compliant with 2025 demand target so the demand increase from 2025 to 2030 need to be compensated by further installed generation.

For this reason the first step aims to adjust the installed dispatchable generation obtaining a more reliable reference scenario. The new dispatchable generation added to cover peak load condition are combined cycles gas turbines (CCGTs) with 800 USD/kW of capital expenditure (Table 9). The CCGT generation has been adopted as a reference for new dispatchable technology.

For generation adequacy purpose any equivalent dispatchable generation (e.g. Biomass, Concentrated Solar Power, Storage) of the same capital cost could be selected provided that the new installed capacity is sufficient to contain the EENS within the maximum acceptable value. The choice should finally be made by optimizing parameters such as flexibility, efficiency, carbon emissions and costs.

Table 9 - Cost of new dispatchable generation needed for generation adequacy

New CCGT - Target year 2030 - Costs in USD/kW	
	Argentina and Chile
CAPEX	800

The CCGT power plants are added in different areas of the countries, until problems of Lack of Power are solved to an acceptable level. As better explained in the next steps, the benefits of the new VRES power plants will be evaluated considering that investments in dispatchable power plants are anyway needed to fulfil generation adequacy and the investment in VRES allows to avoid capital expenditure in new dispatchable generation. In other words, the economic evaluations performed in this activity consider that part (or even all) the peak power and load increase foreseen at 2030 can be covered by PV and wind plants, which can substitute, at least partially, the dispatchable generation needed to ensure system adequacy. The assessment will always be based on comparison of costs and benefits, keeping a focus on the EENS which must remain in acceptable ranges.

3.2.2 STEP 2 - Construction of power system model corresponding to Reference Scenario

The second step consists in the construction of the model to be analysed.

The power systems of the countries are initially set up as isolated systems, and then they will be considered interconnected in order to evaluate the effect of the international power exchange.

The construction of the Reference Scenario is based on the information described in [1]. In addition to that, the scenario is further adjusted to obtain a reliable starting point for the evaluation of the benefits coming from an additional VRES installed capacity.

Local congestions on transmission lines, due to concentrated load increase, are identified and eliminated, including local network reinforcements which are required to supply the load. Such reinforcements are not the object of the present study, which is focused on the improvement of transmission system to ensure the optimal exploitation of VRES.

The whole transmission network is modelled to ensure a correct calculation of the power flows on the lines, but only the constraints on 500 kV and 220 kV lines are considered. It means that overloads are evaluated only on these voltage levels which are responsible of the power flows over long distances and between different areas, since the lines with lower voltage have a limited capacity and a more local effect.

Once the Reference Scenario to be simulated is defined, a run is carried out to evaluate the operation of the system in this starting condition.

The main information taken from the results are related to:

- System operational cost
- Operational costs of the new added CCGTs
- Energy production of the planned VRES plants
- Energy exchanges among areas
- Expected Energy Not Supplied (EENS)
- Line overloads
- Costs and VRES curtailments related to dispatching caused by transmission line overloads

This operational condition represents the benchmark for the evaluation of the benefits provided by VRES power plants and the outcomes of the simulation will be reported in the results section. The impact of new installed VRES identified at the end of the process can be evaluated comparing the results of STEP 2 with the results obtained in the simulation with the optimal economic VRES penetration.

3.2.3 STEP 3 - Simulation of the power system considering investment in wind and PV technology separately

The main parameters considered to calculate the amount of new VRES capacity to be considered in the third step are the annual OPEX and CAPEX of the new needed CCGT power plants, assuming that this money might be invested in PV and wind technologies. In order to find the best mix of VRES, two different simulations will be performed considering in one case a full investment in PV generation and in the other a full investment in wind generation. The economic benefits for the system are assessed in both conditions, and in a subsequent step, the results of the two simulations are used to define the best combination of the technologies, weighting the investments in PV or wind by the respective benefits provided to the system. Thanks to this approach, the resulting optimal mix considers an investment in both PV and wind, and not only in the most effective generation technology, to diversify the resources, reducing uncertainty and risks, but keeping an economic merit order.

The evaluation of the amount of MW to be installed in the simulations of the third step for the VRES plants will be defined based on the overall cost (CAPEX+OPEX) of the conventional generation to be replaced. As can be seen in Figure 43 the Step 3 is part of an iterative process which considers progressive replacement of conventional generation until it is economically viable.

The amount of replaced conventional generation to be assessed in each iteration strictly depends on the characteristics of the power system and has been defined considering mainly:

- The amount of new conventional generation added in the Step 1. E.g. in Argentina in each iteration the replacement of 1,000 MW of new CCGT has been considered because of the high amount of new conventional generation, which is potentially avoided CAPEX for VRES
- The amount of expected new installed VRES, which can be estimated looking at the upper bound limit defined in previous analysis. For instance, a limited space for further installation of VRES in Chile has been highlighted compared to the 2030 target. In this case a limited amount of conventional generation replacement has been considered already in the first iteration.

Once the amount of conventional generation to be replaced is defined, the correspondent overall annuity cost can be calculated as the sum of:

- the annuity of the CAPEX, calculated with the formula

$$EAC_{i,t} = \frac{(Discount\ Rate) * (CAPEX_i)}{1 - \frac{1}{(1 + Discount\ Rate)^n}}$$

  Where *n* is the economic life of the new CCGT (20 years).

- the average of the OPEX of all the new CCGT power plants calculated in the Step 2 (for the first iteration) or in the Step 4 (for the next iteration).

The investment in new CCGT is replaced by PV (simulation 3a) or wind plants (simulation 3b), for a quantity which requires the same investment, or equivalent yearly annuity.

The costs of the investments in VRES technologies are considered as defined in [1], par. 2.4 and are reported in Table 10.

Table 10 - CAPEX and OPEX of VRES generation

Solar PV - Target year 2030 - Costs in USD/kW		
	Chile	Argentina
CAPEX	670	860
O&M (per year)	11.5	11.5

Onshore Wind - Target year 2030 - Costs in USD/kW		
	Chile	Argentina
CAPEX	1145	1180
O&M (per year)	52	48

The calculation of the annuity is made using the same formula adopted for the conventional generation but considering the following economic life of the assets ([1], par. 2.5.3):

Table 11 - Economic life of different generation technologies

	Technology		
	PV (Utility scale) Crystalline or TF	Wind	Gas Combined Cycle
Life of the facility [years]	30	20	20

Discount rates are considered equal to 10% for Argentina and 7.5% for Chile.
Two new GRARE simulations (Step 3a and 3b) are performed in order to understand which the most profitable technology is with the following differences compared to the reference case:

- replacement of conventional generation with an equivalent investment in further PV power plants located in the most convenient power system nodes;
- replacement of conventional generation with an equivalent investment in wind generation located in the most convenient power system nodes.

The results of the two simulations must be compared. In both cases the avoided cost of energy for the whole system with respect to the base case must be calculated in the following way:
Benefits = Δ OPEX (dispatching costs) – Δ EENS
As the comparison is performed assuming same investment cost for both PV and wind, the technology with highest operational benefits is more profitable.
Finally, in order to consider also the EENS in the economical evaluations, a value of 2,000 $/MWh has been considered.

3.2.4 STEP 4 - Simulation of the power system considering an effective combined investment in WIND and PV technology

The benefits for a total investment in each of the two technologies separately can be measured as a reduction of system operational costs ($Benefits_{PV}$ and $Benefits_{wind}$) and it can be calculated by comparing the results of the reference case with the results of the two simulations of Step 3.
The final simulation of each iteration is performed in the Step 4 starting from the base case, without the replaced conventional generation and considering the combined investment in PV and wind calculated in a proportional way with respect to the benefits caused to the system, i. e. if wind has twice benefits than PV, the investment in VRES in the Step 4 scenario will be 2/3 in wind generation 1/3 in PV generation. In this way it is kept the same investments that would be required also to install and operate the new replaced CCGT and there is a diversification of the VRES technologies keeping an economic merit order between them.
The new PV and Wind plants are installed in the area with highest potential. For example in Argentina, PV is distributed on the main nodes of NWE area, while the wind is distributed on the nodes along the coasts, starting from south.
In Chile the situation is a bit more complex, and if the curves for the same technology in different areas are not so different, it is possible to divide the new plants in the areas.

3.2.5 Iterations

The steps 3a, 3b and 4 are repeated until one of the following conditions is reached:

- Further addition of VRES in not viable, thus the total cost of new installed wind and PV technologies (CAPEX+OPEX) is greater than the avoided CAPEX in conventional generation (if present) plus system operation cost reduction.
- The new VRES installed capacity calculated after the Step 4 reaches the upper bound limit calculated in Chapter 2.

As mentioned the amount of conventional generation to be replaced in each iteration as well as the new VRES to be considered is calibrated considering the specific characteristics of the power system allowing to obtain the optimal solution in about 2-3 iterations.

When the process ends the following information about the optimal economic VRES penetration can be obtained and compared with the outcomes of the reference case:

- System operational cost
- Operational costs of the new added CCGTs
- Energy production of the planned VRES plants
- Energy exchanges among areas
- Expected Energy Not Supplied (EENS)
- Line overloads
- Costs and VRES curtailments related to dispatching caused by transmission line overloads
- LCOE of Renewable resources

3.2.6 LCOE of Renewable resources

The levelised cost of electricity (LCOE) is a parameter adopted for the comparison of different generation technologies and their economic viability. The LCOE is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of a renewable plant including all the costs over its lifetime, namely:

- Capital costs
- Operations and Maintenance cost

In this study, the LCOE is calculated using the cost per year of owning and operating an asset over its entire lifespan (CAPEX annuity + OPEX) using the assumed discount rates (10% for Argentina, 7.5% for Chile), which essentially reflect consideration of the opportunity cost of capital. These equivalent annual costs are then divided by the expected yearly production of the plants, resulting from the simulations. More in detail the formula that describes the LCOE is given here below:

$$LCOE = \frac{CAPEX\ annuity + OPEX}{Yearly\ energy\ generated\ in\ the\ simulation}$$

CAPEX and OPEX used in the LCOE calculation are the ones already presented in Table 10.

Once the LCOE is obtained for the PV and wind technologies in the two countries, some sensitivities are performed to assess the impact that variations of CAPEX or interest rate can have on the LCOE, keeping the expected annual generation constant.

3.2.7 Role of Transmission

Starting from the results of previous activities (optimum PV and Wind installation in isolated countries, with defined NTC between areas), the possible impact of investments on transmission lines, both inter-area and inter-countries will be evaluated.
The analysis is done based on the evaluation of the benefit in terms of system costs' reduction, determined by the network reinforcements.

3.2.7.1 Inter-Area transmission lines in isolated country

The first step consists in considering the inter-area reinforcement, still with isolated countries.
This has to be performed only in case critical congestions happen on inter-area sections or close to them, which cause high redispatching costs or RES curtailments. In case there are no congestions and in case the country limit for VRES installation has been reached, no new line is needed.

To perform this analysis, the most loaded lines in the optimal scenario are identified for each section, and network reinforcements are defined in order to enhance the transmission capacity and reduce congestions. The type of network reinforcement and the increase of the transfer capacity have to be determined case by case depending on the type of the network element which causes the congestion.
Starting from the optimal scenario a further GRARE simulation is performed as sensitivity in order to assess the impact of the new grid reinforcements evaluating energy not supplied, generation costs and VRES curtailment. The results section will show a monetization of the benefits for each reinforcement, in particular the value of the maximum limit for the investment in the reinforcement in order to have a benefit for the system can be used as a parameter for investment decisions. Once the cost of the project is known, the planned reinforcement is viable if the cost is lower than the maximum limit for the investment (over this limit the benefits will not pay back the investment).

3.2.7.2 International Interconnection lines

After internal reinforcements have been identified, the focus is moved on international interconnection lines.
A GRARE simulation will be run on the interconnected countries considering the planned international interconnection lines: Salta-Andes up to full power and the 500kV line from the area of Santiago to the area of Gran Mendoza.
The main outcomes of the analysis of the cross-border transmission lines are the following:

- Reduction of costs for the whole system (costs increase in exporting area, decrease in importing area)
- Power flows and possible congestion rent on the international interconnection lines
- Estimated Levelised Cost of Transmission (LCOT) of the lines.

LCOT of the line (CAPEX annuity + OPEX) is a parameter used to evaluate the minimum value of the energy exchanged that allows the transmission infrastructure project to be viable and it is calculated with the following formula:

$$LCOT = \frac{CAPEX\ annuity + OPEX}{yearly\ Energy\ flowing\ on\ the\ line}$$

If the price differential between the interconnected countries is greater than the LCOT, it is convenient to build new interconnection lines. A new simulation must be performed considering:

- A new interconnection line and an increased NTC
- New installed VRES

3.3 Main information about scenario

Some modifications of the reference scenario defined in [1] have been deemed necessary for Argentinian and Chilean systems in order to obtain a suitable system adequacy. The applied changes are aimed at ensuring that the assessment of VRES optimal penetration, that is the focus of the overall study, is not affected by constraints that are not related to the VRES installed capacity at 2030, for instance due to overall lack of generation or due to local network congestions.

Argentina

The starting point for the definition of the Argentinian generation and transmission systems is the planning done by CAMMESA at 2025. With respect to it, the following interventions have been performed:

- ***generation adequacy***: 7,500 MW dispatchable generation have been introduced in the system to cope with the power peak and the demand increase foreseen from 2025 to 2030. They have been modelled with 15 CCGTs 500 MW each, which are then partially replaced by VRES plants up to the optimal economic amount;
- ***local network improvements***: few transformer stations have been reinforced to avoid overloads caused by localized increase of load.

Chile

The definition of the reference scenario is based on the already available plan of the Chilean system up to 2030. Some adjustments have been deemed necessary to ensure a good reliability of the system and the focus

- ***Generation adequacy***: 2,800 MW dispatchable generation (8 CCGTs, 350 MW each) have been introduced to keep a good reliability of the system. They are necessary because the planned generation increase, strongly focused on PV and wind plants (6 GW out of planned 6.9 GW are VRES power plants) is not enough to cover the power peak and demand increase
- A big part of the existing **oil power plants** have been modified reducing the costs, simulating a switch to gas or the replacement with other more economic generation plants
- Some ***improvements of the 220kV lines*** have been considered in the areas where a strong growth of the load causes network congestions, which are not due to VRES power plants. Few other reinforcements have been introduced to allow some already planned VRES power plants to evacuate the generated power.

3.3.1 Argentinian generation fleet

At the end of 2016, as already said in the inception report [1], the total installed capacity of Argentinian generation fleet is equal to 33,970 MW. Only 1% of the total capacity is available from RES power plants (about 200 MW); 66% is from thermal and nuclear power plants while the 33% from hydro power plants. Table 12 shows the installed capacity in 2016 and the capacity factor[6] for each technology.

Table 12 - Generation installed capacity at the end of year 2016

Source/ *Technology*	Installed Capacity [MW]	Capacity Factor [%]
Thermal	**20,763**	**50%**
Steam Turbine	*4,451*	*41%*
Gas Turbine	*5,251*	*38%*
CCGT	*9,227*	*67%*
Diesel Engine	*1,834*	*15%*
Nuclear	**1,755**	**50%**
Hydro	**11,240**	**39%**
RES	**212**	**45%**
Wind	*187*	*33%*
PV solar	*8*	*20%*
Biogas	*17*	*100%*
TOTAL	**33,970**	

As well explained in the inception report [1], the additional capacity expected by CAMMESA for the year 2025 is about 20 GW:

- 10 GW of wind and PV power plants. 5 GW of wind farms mainly located in the Atlantic coast (Patagonia, Comahue and Buenos Aires) and 5 GW of PV power plants located in the north west areas of the Country (Noroeste and Cuyo);
- Additional 2.5 GW of hydro power plants, developing large-scale hydroelectric projects in Patagonia, Comahue and Cuyo;
- Third nuclear power plant in Atucha;
- Addition of about 7 GW of thermal capacity in the short and medium term, completing combined cycles and other current projects.

In this way the total capacity installed in Argentina within 2025 is 54 GW.

[6] The capacity factor of a power plant, or group of power plants, is the ratio between the actual output over a period of time (typically one year) and the potential output if the operation at full nameplate capacity could be possible continuously over the same period of time

Table 13 - Additional capacity to reach CAMMESA targets 2025 (CESI elaboration)

Source	Additional capacity 2017-2025 [GW]
Hydro	2.5
Thermal	6.8
Nuclear	0.8
Wind	4.8
PV	5.0
Biogas/Biomass	0.1
TOTAL	20

The list of the main hydro, thermal and nuclear power plants is showed in Table 14. Most of new thermal installed capacity is located in the electrical regions of Litoral (42%), Gran Buenos Aires (17%) and Buenos Aires (10% of conventional installed capacity + 745 MW nuclear power plant Atucha III). Patagonia will house the third biggest hydro complex of the country, after Yaciretá and Salto Grande: "La Barrancosa-Cóndor Cliff" project will include Néstor Kirchner and Jorge Cepernic hydro power plants (total 1,310 MW).

According with wind and solar radiation potentials, wind farms already forecasted by CAMMESA are located in the South East regions while PV power plants in the North West regions.

Table 14 - Main hydro and thermal projects in the period 2017-2025

Power Station Name	Type/ Technology	Province	Region	Pinst. [MW]
NÉSTOR KIRCHNER	Hydro	Santa Cruz	Patagonia	950
CHIHUIDOS I	Hydro	Neuquén	Comahue	640
JORGE CEPERNIC	Hydro	Santa Cruz	Patagonia	360
LOS BLANCOS I-II	Hydro	Mendoza	Cuyo	440
GUILLERMO BROWN	CCGT	Buenos Aires	Buenos Aires	900
BELGRANO II	CCGT	Buenos Aires	Buenos Aires	840
ATUCHA III	Nuclear	Buenos Aires	Buenos Aires	745
BRIGADIER LOPEZ	CCGT	Santa Fe	Litoral	420
VUELTA DE OBLIGADO	CCGT	Santa Fe	Litoral	280
EL BRACHO	OCGT	Tucuman	Noroeste	270
MATHEU ARAUCARIA ENERGY	OCGT	Buenos Aires	Gran Buenos Aires	260
RIO TURBIO	ST	Santa Cruz	Patagonia	240
MATHEU APR ENERGY S.R.L.	OCGT	Buenos Aires	Gran Buenos Aires	215
ZARATE ARAUCARIA ENERGY	OCGT	Buenos Aires	Buenos Aires	210
A.G. RENOVA TIMBÚES	CCGT	Santa Fe	Litoral	205
LOMA CAMPANA 1-2	OCGT	Neuquén	Comahue	205
GRAL ROJO RÍO ENERGY	OCGT	Buenos Aires	Buenos Aires	150
EZEIZA ALBANESI	OCGT	Buenos Aires	Gran Buenos Aires	150
LUJÁN ARAUCARIA ENERGY	OCGT	Buenos Aires	Buenos Aires	130

3.3.1.1 *CESI assumptions on generation*

As described in paragraph 3.2.1, the first step of the methodology aims to introduce new dispatchable generation in order to fulfil the adequacy requirements. The main causes of the reduction of generation capacity during the system operation are reported in Figure 45 along with a qualitative indication of the range in which they are included during the simulated year. The values reported in Figure 45 refer to the system as described by MINEM in 2025 forecast, then before the addition of further dispatchable units in step 1 of the methodology. It is important to highlight that Figure 45 reports qualitative ranges for each cause while the exact value is calculated hour by hour in the GRARE simulations. Starting from GRARE outputs, the new dispatchable capacity has been progressively added where needed until the EENS requirement has been fulfilled.

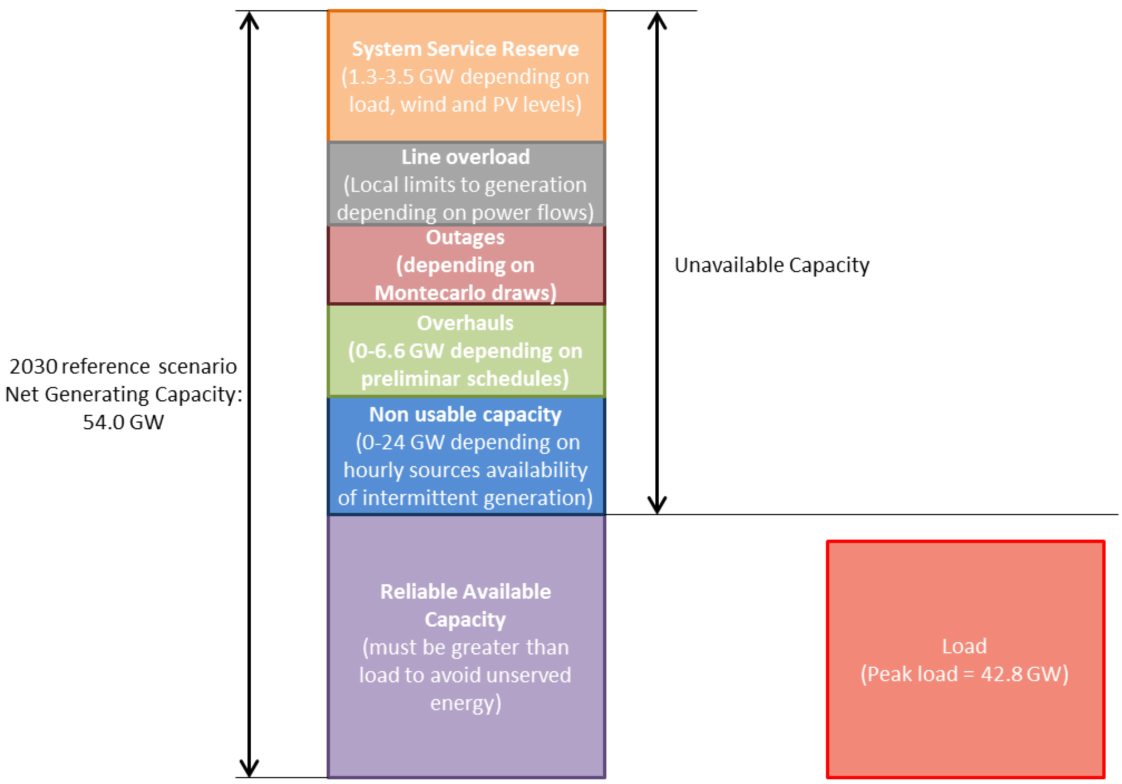


Figure 45 - Generation capacity reduction during operation in Argentina

A first run of GRARE was carried out without the power plants added by CESI in order to investigate potential problems on the network: this simulation highlighted a not negligible value of Expected Energy Not Supplied (325 GWh – about the 0.14% of the total energy demand) because of the lack of power in the system: in other words the GRARE simulation shows that in some hours during the year the available power is not sufficient to cover the load demand and therefore the system has to cut the load to satisfy the power balance.

After iterative simulations of Argentinian power system it has been calculated the further need of 7,500 MW dispatchable capacity in order to comply with the requirement of an EENS lower than 10^{-5} p.u. of total energy demand.

According to the methodology described in paragraph 3.2.1 the following CCGTs with 500 MW of installed capacity were used as a reference and placed by CESI: in particular these power plants were directly connected to the 500 kV network and located near the buses with high levels of load. Obviously the major part of the new CCGTs was installed in the Buenos Aires area, as the Table 15 shows.

Table 15 - CCGTs added by CESI

N°	BUS	VOLTAGE [kV]	MARKET AREA
1	GRAN MENDOZA	500	NWE
2	HENDERSON1	500	NEC
3	HENDERSON2	500	NEC
4	HENDERSON2	500	NEC
5	CASLINGASTA	500	NWE
6	ABASTO	500	NEC
7	EZEIZA	500	NEC
8	EZEIZA2	500	NEC
9	RODRIGUEZ2	500	NEC
10	RODRIGUEZ2	500	NEC
11	CAMPANA	500	NEC
12	CAMPANA	500	NEC
13	BELGRANO	500	NEC
14	RECREO	500	NWE
15	ABASTO	500	NEC

Regarding the renewable generation, the following tables show for PV and wind power plants the connection points to the 500 kV network: in this case the installed capacity is not defined a priori as explained in the methodology chapter and it depends on the GRARE simulations.
As the tables highlight, in order to maximise the energy production, the renewable power plants are located on the basis of the geographic characteristics of Argentina: just for this reason, all PV power plants are installed in the North of Argentina where the solar radiation is more intense, while the wind power plants are located in the South and along the Atlantic coast that are the most windy zones of Argentina.

Table 16 - PV power plants added by CESI

N°	BUS	VOLTAGE [kV]	MARKET AREA
1	ARROYO CABRAL	500	NWE
2	EMBALSE	500	NWE
3	LAVALLE	500	NWE
4	SAN FRANCISCO	500	NWE
5	LUJAN	500	NWE
6	CATAMARCA	500	NWE
7	ALMAFUERTE	500	NWE
8	MONTE QUEMADO	500	NWE
9	MALVINAS ARGENTINAS	500	NWE
10	SANTIAGO DEL ESTERO	500	NWE
11	EL BRACHO	500	NWE

Table 17 - Wind power plants added by CESI

N°	BUS	VOLTAGE[kV]	MARKET AREA
1	NPMADRYN	500	PAT
2	COMODORO	500	PAT
3	RSCRUZ	500	PAT
4	ESPERANZA	500	PAT
5	CHOLO CHOEL	500	NEC
6	B.BLANCA	500	NEC
7	GUIBROWN	500	NEC
8	VIVORATA	500	NEC

3.3.2 Argentinian load at target year

In 2016 the energy demand in Argentina was equal to 132.9 TWh[7]; only +0.6% compared with 2015 demand. The most recent information published by the Ministerio de Energía y Mineria (MINEM) of Argentine Republic about the energy demand forecast are included in the document "Escenarios Energéticos 2025" published in December 2016 [3]. No official data has been published yet on demand expected in 2030.

As explained in the inception report [1], in order to estimate the energy demand in 2030, CESI compared MINEM forecast with a demand forecast carried out with a top-down model based on GDP and population. With this approach the energy demand expected in 2030 is 235.7 TWh. The comparison between the MINEM curve and the CESI curve allowed an estimate of 4.2% growth rate based on MINEM forecast for the period 2016-2025 and an estimate of 3.7% growth rate for a the final curve based on CESI forecast for the 2026-2030 period. The final curve will be adopted as reference to assess the demand to be used for the analyses: 229.9 TWh in 2030.

[7] Demand of MEM agents (distributors and big users), including the distribution losses and excluding export, consumption of pumping power plants and transmission network losses.

The total consumption covered by generation power plants includes the demand of customers and also the network losses: for the 2030 scenario, it is reasonable to assume that investments in the electric system will contribute to reduce distribution losses down to 7% of the generation output. Assuming 3% of transmission losses, the overall T&D network losses reach 10% of generation output in 2030.

3.3.2.1 Peak power demand

Another important parameter for the demand forecast of a Country is the maximum power demand expected in one hour over a period of one year, i.e. the peak power demand (MW). In 2016 the peak power demand registered in Argentina was 25,380 MW, with a growth rate 6% of peak power demand with respect to 2015.

MINEM didn't provide the forecast of peak power demand in its official document [3], nevertheless CAMMESA provided the peak power demand expected in 2025 (35,537 MW). In the period 2016-2025, the average annual growth rate needed to reach the peak power demand indicated by CAMMESA (35,537 MW) is 3.8%; applying this value also in the period 2026-2030 we assessed a peak power demand in 2030 that is equal to 42,845 MW.

3.3.3 Argentinian transmission network

The model network used for the analyses was developed on the basis of CAMMESA network database (PSS/E format) of the Argentine electric power system for peak load scenario 2025, including 10,000 MW of RES power plants. This network model includes the strengthening lines needed for the secure management of the system at 2025 with high RES penetration. No network developments are already planned from 2025 to 2030.

Lastly, to increase the transfer capacity between Patagonia and Gran Buenos Aires, four alternative network reinforcements were proposed by CAMMESA: CESI selected the new 3,500 MW HVDC between Puerto Madryn e Plomer since, taking into account the high RES penetration, with this reinforcement the transfer capacity between Patagonia and Gran Buenos Aires is the highest possible (5,000 MW).

Table 18 shows the lines that form the sections with the summer and winter limits in normal (N) and contingency (N-1) conditions, these last were rounded down. N-1 contingency condition considers the worst outage of one line and the power limit calculated in this condition represent the maximum NTCs of the sections[8]. Two poles are expected for the new HVDC link "Puerto Madryn – Plomer", therefore the worst N-1 condition in NEC-PAT section is the loss of one pole (1,750 MW).

[8] The NTC value can be further reduced by operational constraints, such as an uneven loading of the lines belonging to the section.

Table 18 - Section limits in normal and contingency conditions

Line Name	Reg.From–Reg.To	Vn [kV]	Length [km]	Summer Limit [MW]	Winter Limit [MW]
SECTION NWE–NEC					
Monte Quemado – Chaco	*NOA-NEA*	*500 AC*	*263*	*1,732*	*1,970*
San Francisco – Santo Tomé	*CEN-LIT*	*500 AC*	*120*	*1,732*	*2,158*
Arroyo Cabral – Rosario Oeste	*CEN-LIT*	*500 AC*	*250*	*866*	*1,732*
Rio Diamante – Los Blancos – Gran Mendoza	*CUY-CUY*	*500 AC*	*103*	*1,732*	*1,750*
	Limit in normal condition (N)			**6,050**	**7,600**
	Limit in contingency condition (N-1)			**4,300**	**5,450**
SECTION NEC–PAT					
Puerto Madryn – Choele Choel (1st)	*PAT-COM*	*500 AC*	*354*	*1,263*	*1,732*
Puerto Madryn – Choele Choel (2nd)	*PAT-COM*	*500 AC*	*354*	*1,263*	*1,732*
Puerto Madryn – Plomer (HVDC)	*PAT-GBA*	*600 DC*	*1,800*	*3,500*	*3,500*
	Limit in normal condition (N)			**6,000**	**6,950**
	Limit in contingency condition (N-1)			**4,250**	**5,200**

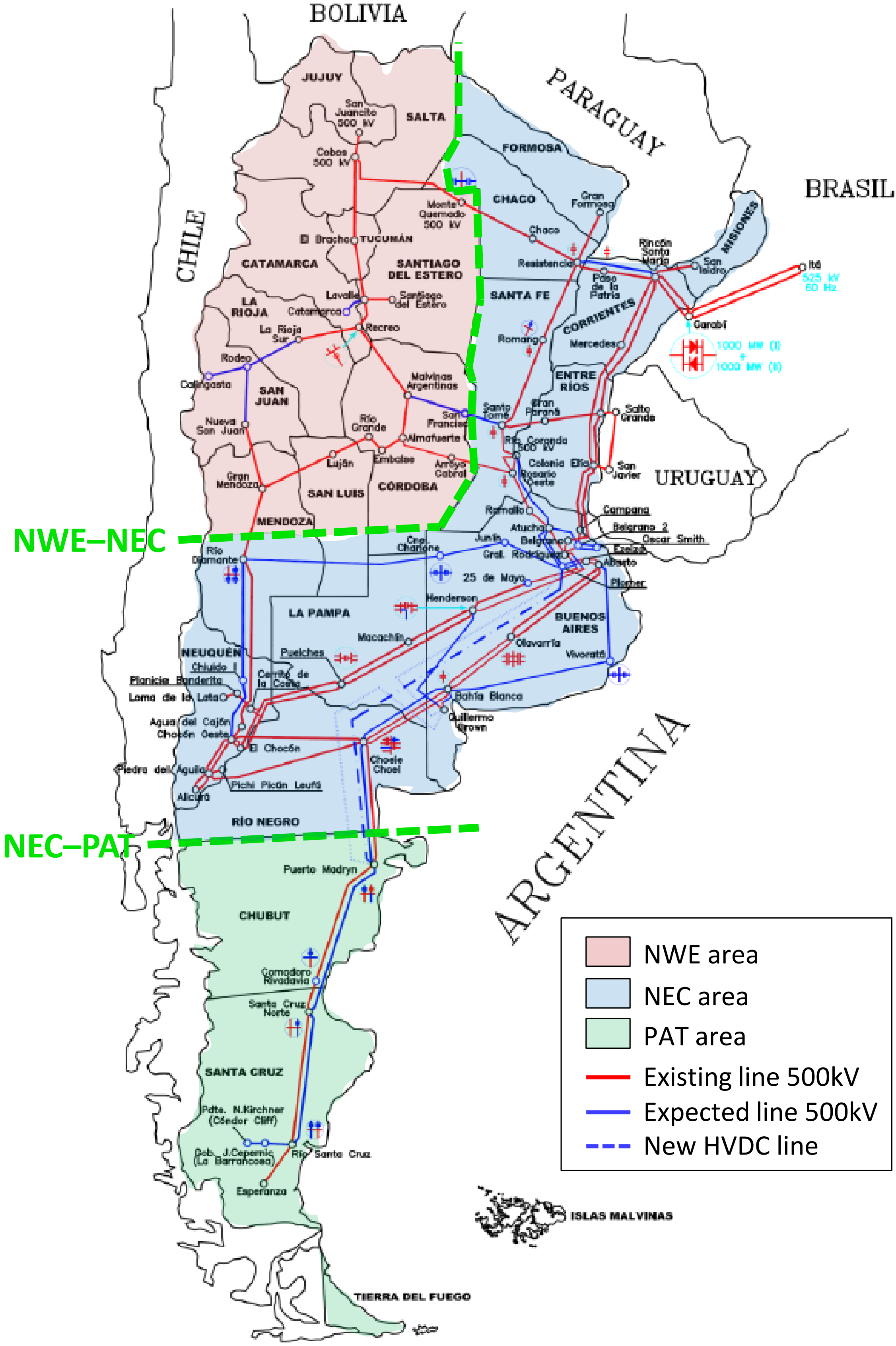


Figure 46 - Macro areas of Argentine electric system 2030

3.3.3.1 *CESI assumptions on transmission network reinforcement*

In addition to the network reinforcements foreseen by CAMMESA, some other reinforcements were added by CESI in order to solve the most important overloads highlighted by the first run of GRARE simulation: in particular after updating the load, some transformers were overloaded during the year and therefore four new transformers were added to the network.
The Table 19 summarizes the network reinforcements added by CESI:

Table 19 - Transformers added by CESI

N°	SUBSTATION	VOLTAGE [kV]	POWER [MVA]	MARKET AREA
1	GRAN MENDOZA	500/220	300	NWE
2	ABASTO	500/220	800	NEC
3	RIO DIAMANTE	500/220	600	NEC
4	PUERTO MADRYN	500/330	450	PAT

Regarding new lines, no new lines were added by CESI.

3.3.4 Chilean generation fleet

At end of December 2016 the installed capacity in SING and SIC amounted to 21,900 MW. Coal-fired plants accounted for 22% of total installed capacity and gas for 22%. Oil-fired generation represents the 14% of the total installed capacity, but the energy generated by this technology has dropped in the recent years; as can be seen in Table 20 the capacity factor in 2016 was 7% corresponding to 1.9 TWh of the total energy produced.

Table 20 - Generation installed capacity at the end of the year 2016

Source/ Technology	Installed Capacity [MW]	Capacity Factor [%]
Coal	4,782	77%
Natural Gas	4,907	28%
Oil	3,039	7%
Hydro	6,602	34%
Wind	1,030	25%
Solar	1,050	28%
Biomass	459	66%
TOTAL	21,869	

As well explained in the inception report [1], the reference for the generation expansion plan of Chile is the development plan published by the Coordinador Eléctrico National [2]: according to this document, about 7 GW of new capacity are expected in service in the period 2017-2030 reaching 29 GW of installed capacity. New entrants are foreseen for the following technologies:

- Solar generation: 3.1 GW of additional capacity, mainly located in the northern part of the SIC (Atacama Region);
- Wind generation: 2.9 GW of additional capacity, mainly located in the southern part of the SIC and in the second and third regions;

- Hydroelectric generation: additional 0.4 GW, of which 200 MW with installed capacity lower than 20 MW (small hydro). All the projects are located in the southern part of the SIC (VII,VIII, IX, XIV regions);
- Thermal generation: one 360 MW combined cycle is expected to start operations in the Valparaìso region. 40 MW of geothermal capacity will be added in VII region;
- Biomass generation: only three projects are considered viable for a total amount of 70 MW.

Table 21 - Additional capacity 2017-2030

Source	Additional capacity 2017-2030 [GW]
Hydro	0.4
Thermal	0.4
Wind	2.9
Solar	3.1
Biomass	0.1
TOTAL	**6.9**

The list of the main thermal, wind and solar projects to be considered in the Reference Scenario 2030 is shown in Table 22.

Table 22 - Main projects in the period 2017-2030

Project Name	Type/ Technology	Region	Pinst. [MW]
AURORA	WIND	X	130
SARCO	WIND	III	168
CICLO_COMB_VR_1	THERMAL	V	360
SOLAR_CARDONES_2	SOLAR	III	200
SOLAR_CARDONES_4	SOLAR	III	200
SOLAR_CPINTO_2	SOLAR	III	200
SOLAR_CARDONES_5	SOLAR	III	200
SOLAR_CARDONES_6	SOLAR	III	200
SOLAR_CPINTO_3	SOLAR	III	200
SOLAR_DALMAGRO_2	SOLAR	III	200
SOLAR_CPINTO_4	SOLAR	III	200
SOLAR_CPINTO_5	SOLAR	III	200
SOLAR_CRUCERO_2	SOLAR	II	120
MALLECO	WIND	IX	270
CABO_LEONES_II	WIND	III	204
EOL_PUELCHE_SUR	WIND	X	132
CERRO_TIGRE	WIND	II	142.2
SOL_DE_VALLENAR	SOLAR	III	250
EOL_LOS_GUINDOS	WIND	VIII	376

Project Name	Type/ Technology	Region	Pinst. [MW]
TCHAMMA	WIND	II	195
MALGARIDA_II	SOLAR	III	168
CABO_LEONES_III	WIND	III	124
INCA_DE_VARAS	SOLAR	III	120
CAMAN	WIND	XIV	150
EOL_ESPERANZA	WIND	X	202
EOL_COIHUE	WIND	VIII	216
EOL_SANTA_FE	WIND	VIII	204

3.3.4.1 CESI assumptions on generation

Some changes have been deemed necessary with respect to the Reference Scenario defined in [1].
The first important CESI assumption interests the existing oil generation: currently this type of generation has a really small capacity factor (7% in 2016): in other words this type of generation is the last called in the unit commitment and it is used only to cover the peaks of the load.
Although these power plants are not so used, they have a really very high cost that affect the average value of the energy cost in Chile and in particular it is certainly higher than in Argentina.
Since these power plants could be reasonably decommissioned within 2030 (small capacity factor, high maintenance costs, high carbon dioxide emission and other pollutants), it has been decided to switch the fuel from oil to gas: with this decision, the cost of each power plant has been reduced to the range 60 – 120 USD/MWh, maintaining the same merit order the generators had with the oil fuel, i.e. the most expensive one in the original configuration with oil fuel remain the most expensive one also when costs are reduced.
After that, according to the methodology reported in paragraph 3.2.1, generation has been assessed in order to fulfil the adequacy requirements.
The main causes of the reduction of generation capacity during the system operation are described in paragraph 3.2.1 and Figure 47 reports a qualitative indication of the range in which they are included during the simulated year in Chile. The values reported in Figure 47 refer to the system as described in the development plan published by the Coordinador Eléctrico National in 2030 forecast (Base scenario), then before the addition of further dispatchable units in step 1 of the methodology. It is important to highlight that Figure 47 reports qualitative ranges for each cause while the exact value is calculated hour by hour in the GRARE simulations. Starting from GRARE outputs, the new dispatchable capacity has been progressively added where needed until the EENS requirement has been fulfilled.

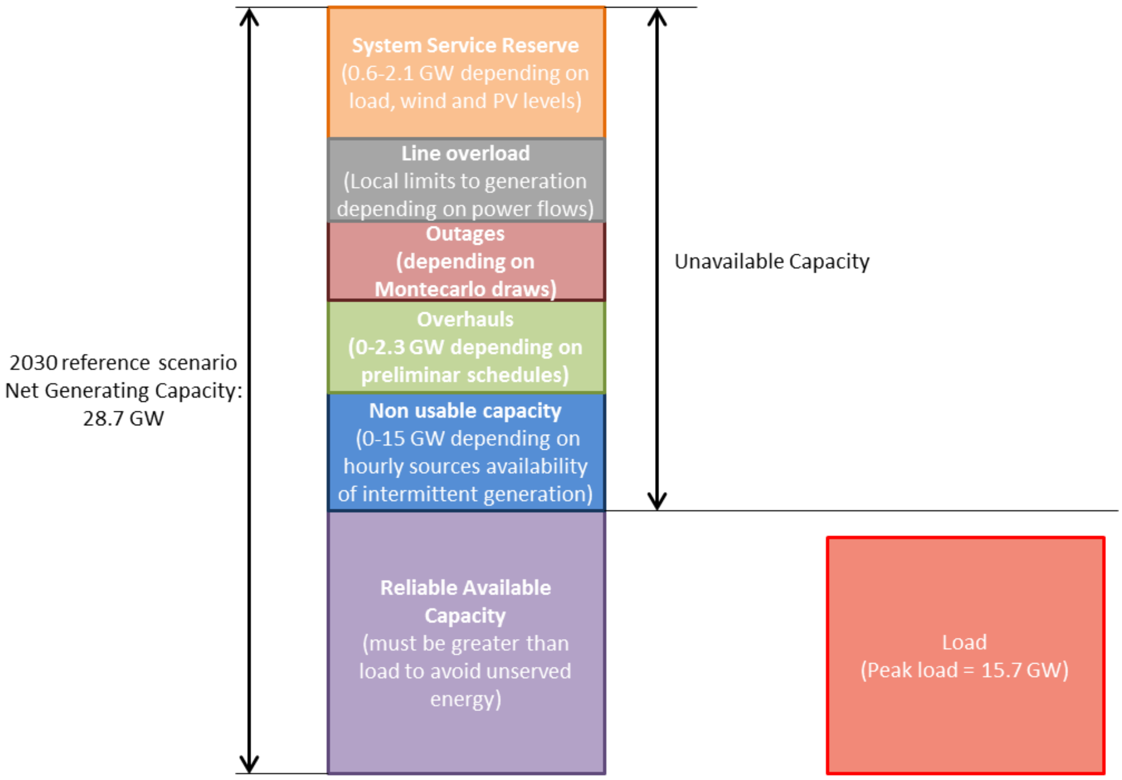


Figure 47 - Generation capacity reduction during operation in Chile

A first run of GRARE was carried out without the power plants added by CESI in order to investigate potential problems on the network: this simulation highlights a value of Expected Energy Not Supplied (340 GWh – about the 0.3% of the total energy demand) because of lack of power in the system: in other words the GRARE simulation shows that in some hours during the year the available power is not sufficient to cover the load demand and therefore the system has to cut the load to satisfy the power balance.

Figure 48 shows in which hours of the day the energy not supplied for lack of power is concentrated. Lack of power is concentrated in the first half of the year when the availability of hydro is low (the wet season is concentrated in the second half of the year).

It is interesting to note that almost all of the EENS is concentrated during the evening - night time since the load is enough high, hydro generation is low (as said above, EENS is concentrated in dry season) and the photovoltaic generation is not present.

In the first hours of day, EENS is really low mainly because the load is low, while during the daytime hours, EENS is low because the growth of the load is compensated by the growth of the photovoltaic.

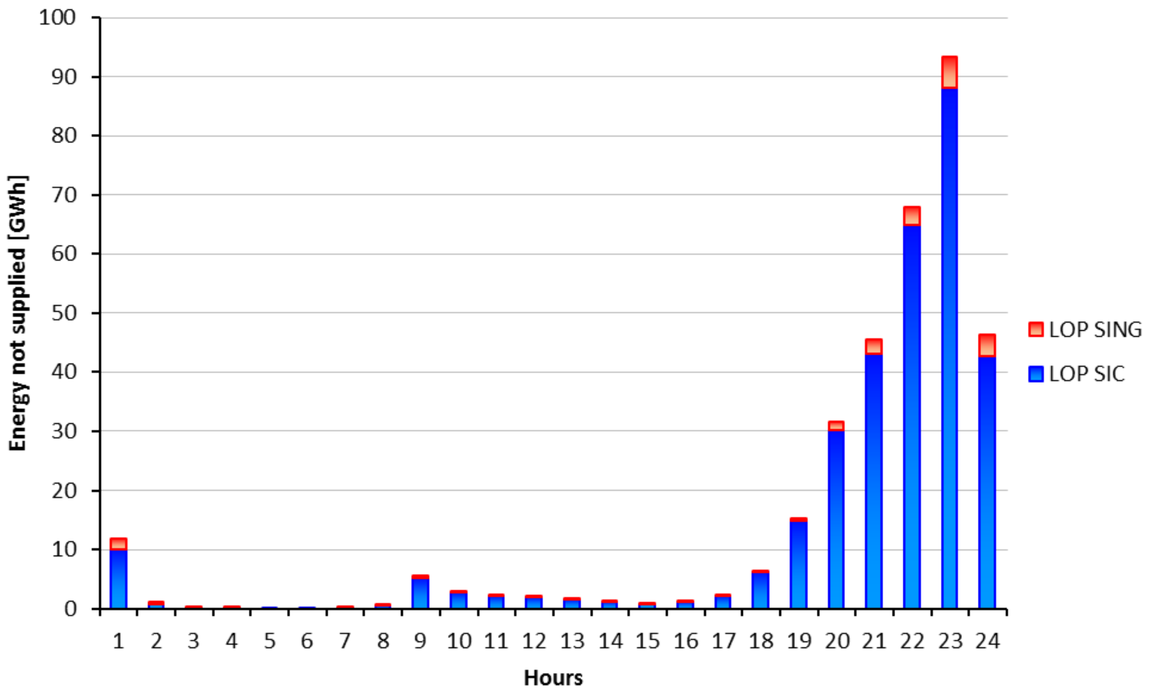


Figure 48 - Expected energy not supplied in Chile (no power plants added by CESI in service)

After iterative simulations of Chilean power system it has been calculated the further need of 2,800 MW dispatchable capacity in order to comply with the requirement of an EENS lower than 10^{-5} p.u. of total energy demand.

According to the methodology described in paragraph 3.2.1, eight CCGTs with 350 MW of installed capacity were used as a reference and placed by CESI: in particular these power plants were placed in buses very meshed and near to buses with high levels of load.

Table 23 - CCGTs added by CESI

N°	BUS	VOLTAGE [kV]	MARKET AREA
1	KIMAL	220	SING
2	KIMAL	220	SING
3	POLPAICO	500	SIC
4	POLPAICO	500	SIC
5	MAITENCILLO	220	SIC
6	CHARRÚA	500	SIC
7	CHARRÚA	500	SIC
8	CARDONES	220	SIC

Regarding the renewable generation, the following tables show for PV and wind power plants the connection points to the 500 kV network: in this case the installed capacity is not defined a priori as explained in the methodology chapter and it depends on the GRARE simulations.

As the tables highlight, in order to maximise the energy production, the renewable power plants are located on the basis of the geographic characteristics of Chile: just for this reason, all PV power plants are installed in the North region where the solar radiation is more intense, while the wind power plants are located in the South and along the Pacific coast that are the most windy zones of Chile.

Table 24 - PV power plants added by CESI

N°	BUS	VOLTAGE [kV]	MARKET AREA
1	LOS CHANGOS	500	SING
2	CUMBRE	500	SIC
3	NUEVA CARDONES	500	SIC
4	PAN DE AZÚCAR	500	SIC
5	POLPAICO	500	SIC

Table 25 - Wind power plants added by CESI

N°	BUS	VOLTAGE [kV]	MARKET AREA
1	PAN DE AZÚCAR	500	SING
2	CHARRÚA	500	SIC
3	CIREULOS	220	SIC
4	CUMBRE	500	SIC

3.3.5 Chilean load at target year

The continental electric power system of Chile is composed by four main electric systems:

- SING: Sistema Interconectado del Norte Grande
- SIC: Sistema Interconectado Central
- SEA: Sistema Eléctrico de Aysén
- SEM: Sistema Eléctrico de Magallanes

SING and SIC systems are the most relevant because they include about 99.4% of the national energy demand. The interconnection of these systems is ongoing and will be completed in the second half of 2017 forming a single interconnected system named SEN (Sistema Eléctrico Nacional) while SEA and SEM systems will remain isolated. Due to their very low demand, 0.2% and 0.4% of national demand respectively, in the following SEA and SEM are neglected and any reference to the Chilean demand is referred only to the SEN system.
In 2016 the energy demand in Chile (SING+SIC) was equal to 66.7 TWh[9]; only 0.5% compared with demand 2015. The most recent information published by the Comisión Nacional de Energía (CNE) about the energy demand forecast are included in the document “Informe Definitivo De Previsión De Demanda 2016-2036 SIC–SING” published in January 2017 [2]. CNE provided the demand forecast up to 2036 including details about regulated customers and free customers. The energy demand expected in 2030,

[9] Net consumption, excluding export, consumption of pumping power plants and T&D network losses.

which was assumed for the Reference Scenario in the current project, is 108.6 TWh; 27.5 TWh are expected in SING system and 81.1 TWh in SIC system [2].
For 2030 scenario, T&D network losses were assumed equal to 7% of generation output in the target year 2030: 4% due to distribution network and 3% for the transmission network.

3.3.5.1 Peak power demand

In 2016 the peak power demand in SIC and SING was 9,701 MW (excluding T&D losses), with a growth rate of 3.2% with respect to the 2015 demand5.
CNE didn't provide the forecast of peak power demand in its official document [4]. The most recent forecast of peak power demand is published by the Coordinador Eléctrico Nacional [5]: 15,745 MW are expected in 2030 with an energy demand equal to 109 TWh, this last is in accordance with CNE demand forecast.

3.3.6 Chilean transmission network

In January 2017, CEN published an updated version of the transmission development plan ("Propuesta De Expansión De Transmisión Del Sistema Eléctrico Nacional 2017" [2]). This plan covers the period 2016-2036 and it represents the most recent plan, which was provided to the CNE for a public consultation from all stakeholders and the next final approval.
Together with the main document, CNE provided also the network database (DigSilent format) of Chilean electric power system used for the analyses included in the transmission development plan[10]. This network model includes the strengthening needed in the long-term for the secure management of the system with a big amount of VRES. The database was used as reference model for the network analyses object of this project. Referring to the limited sections, CESI proposed the interconnection SIC-SING as the main limited section inside SEN system.

Table 26 - Section limits in normal and contingency conditions

Line Name	From–To	Vn [kV]	Length [km]	Summer Limit [MW]	Winter Limit [MW]
SECTION SING-SIC					
Encuentro – Cardones (1st)	*SING-SIC*	*500 AC*	*600*	*1,500*	*1,500*
Encuentro – Cardones (2nd)	*SING-SIC*	*500 AC*	*600*	*1,500*	*1,500*
			Limit in normal condition (N)	**3,000**	**3,000**
			Limit in contingency condition (N-1)	**1,500**	**1,500**

3.3.6.1 CESI assumptions on transmission network reinforcement

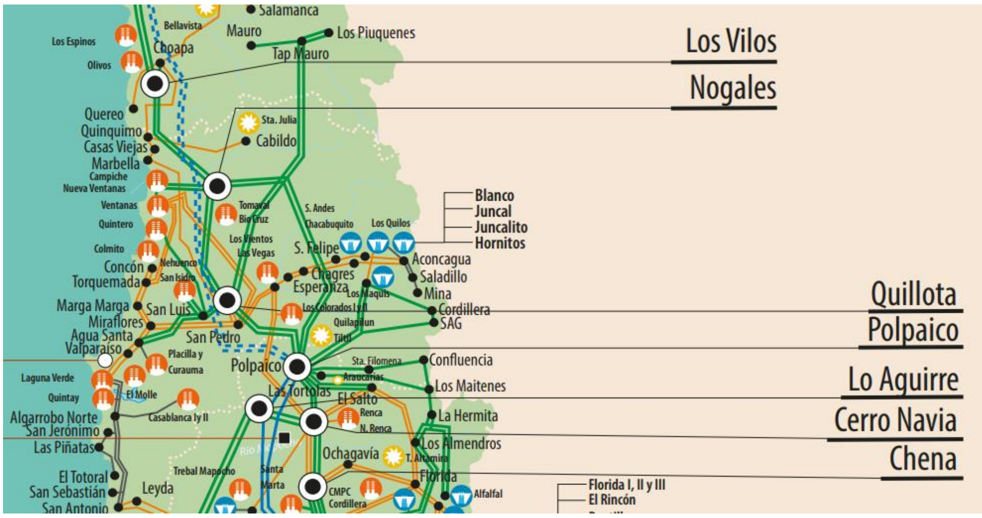
In addition to the network reinforcements foreseen by CEN, some other reinforcements were added by CESI in order to solve the most important overloads highlighted by the first run of GRARE simulation: in particular, after the updating of the load, some reinforcements are necessary because the existent lines don't have an adequate capacity to supply the updated load and therefore they have to be reinforced to avoid important or prolonged overloads on the network elements.

[10] Base de Datos DigSilent PF Zona Norte. DigSilent file "PETx-2017_V1.pfd"

Hereinafter a list of reinforcements is presented: in particular it is referred to the lines that directly supply a load and therefore the overload on these lines can't be solved by a generation redispatching but only by load curtailment. In order to avoid this, a reinforcement in necessary.

- **Polpaico – Tap El Manza – Tap Chicureo – Salto**, the corridor 220 kV between Polpaico and El Salto was reinforced because on the 110 kV network under the 220 kV bus of El Salto there is an important load (Santiago city). The length of this corridor is about 50 km.
- **Cautín – Temuco,** the link between Cautín and Temuco was reinforced because of the load growth on the 110 kV network under the 220 kV bus of Temuco and Temuco aux. The length of this line is 2 km.
- **Kimal – Maria Elena – Lagunas**, the capacity of the lines between Kimal and Lagunas isn't able to cover the updated load in the 220 kV of Lagunas, therefore a reinforcement is necessary. The length of the reinforcement line is 175 km.
- **Kimal – Chuquicamata**, the capacity of the lines between Kimal and Chuquicamata isn't able to cover the updated load in the 220 kV of Chuquicamata, therefore the link between these two buses have to be reinforced. The length of the reinforcement line is 75 km.
- **Collahuasi – Encuentro**, also in this case the capacity of the line between Collahuasi and Encuentro is not adequate to supply the updated load in Collahuasi and therefore a reinforcement is necessary. The length of the reinforcement line is 200 km.
- **Encuentro – El Tesoro – Esperanza**, the capacity of the line among Encuentro, El Tesoro and Esperanza is not able to cover the load placed in El Tesoro and in Esperanza. For this reason a reinforcement line is necessary and its length is 100 km.
- **Quillota – Olmu – Polpaico**, Quillota is a station in which arrives all power generated by the power plants placed along the coast, while Polpaico is a station with a high load (city of Santiago) and in which a connection with the 500 kV network is present.

  Therefore really high power flows are direct from Quillota to Polpaico and a reinforcement line is necessary in order to avoid an important load curtailment.



The length of the reinforced line is about 50 km.

Lastly, in the following, a list of the reinforcements necessary to solve constraints due to renewable power plants already included in the reference scenario are presented:

- **Carrera Pinto – San Andrés – Cardones – Maitencillo**, the 220 kV corridor between Carrera Pinto and Maitencillo has to be reinforced because of important power injection of PV power plants in the buses of this corridor. The length of the reinforcement is about 200 km.
- **Terminal 2 – Duqueco – Tap El Rosal – Charrúa**, the 220 kV corridor between Terminal 2 and Charrúa has to be reinforced because of power injection of renewable power plants (one wind farm with maximum power of 270 MW and PV power plant with 90 MW of maximum power). In Charrúa a connection with the 500 kV network is present. The length of the reinforcements is 90 km.
- **El Pelicano – El Romero**, in this case the reinforcement line between El Pelicano and El Romero is necessary in order to avoid energy renewable curtailment. The length of the reinforced line is 2 km.

3.4 Results of Reference scenario

This chapter illustrates the results of the BAT scenario (starting from the Reference scenario described in paragraph 3.3 and reaching the configuration with optimal economic amount of additional VRES) for each country considered as isolated (Argentina and Chile) and for the case with the two systems interconnected.
All the results are obtained by simulations performed with a sample of 10,400 tests (equivalent to a simulation of 200 Monte Carlo years which are then summarized in one resulting operational year) to assure the convergence of the analysis.
The evaluation of the results is based mainly on the comparison of the following key information:

- average annual value of Expected Energy Not Supplied (EENS), assigned to the relevant cause (lack of power, lack of interconnection, lines and transformers overload) and for each area. It is reported because the introduction of VRES replacing thermal power plants might reduce the adequacy of the generation fleet, increasing the EENS which must be given a penalization;
- solar and wind power plants production and curtailments due to overgeneration and overloads;
- thermal generation costs for each area;
- list of network constraints which increase the cost of generation because impede the full exploitation of the cheapest plants;
- a synthesis of energy exchanges and saturation hours for each interconnection.

The evaluation of the benefits introduced by some variation in the generation fleet or in the network is performed comparing the operational costs (which are mainly the thermal generation costs and the penalization related to the EENS) with the investment costs required by the introduced change (for instance, cost of the investment needed for the installation and operation of the new VRES power plants, or avoided costs for the not needed thermal power plants replaced by VRES ones).
The evaluation is carried out on an annual basis, calculating the annuity of the investments as defined in 3.2.3. This method allows the comparison of the benefits obtained from different scenario and the selection of the most convenient one.

The key information described above are reported in many tables. The following glossary explains the meaning of some words and enables a correct interpretation of the values included in the tables.

General information:

- Before redispatching: it means that the result refers to the system operation obtained after a first optimized dispatching which considers the limits of power exchanges between areas but does not consider the detailed transmission network model within the areas. It corresponds to the supply of the load in every area with the hydro, VRES and imposed generation plus the cheapest thermal power plants, fulfilling power exchange constraints between areas.
- After redispatching: it means that the result refers to the system operation obtained after the changes in the power generation dispatching with respect to the first optimized one (the one "before redispatching"), required to solve overloads on transmission lines which might be present when the detailed transmission network is considered. In general, it corresponds to a more expensive operation because cheap generation selected in the first optimized dispatching must be replaced by more expensive one, because of the presence of network congestions.

During redispatching, thermal generation can be increased or decreased within its technical limits, while imposed and VRES generation can only be reduced and replaced by more expensive thermal one.

Tables with information relevant to the Expected Energy Not Supplied

- Lack of Power: this value provides the information about the amount of load which cannot be supplied due to lack of generation available in that moment in the whole system. This can be caused by unavailability of plants because of maintenance or faults.
- Line Overload: this value expresses the amount of load which must be curtailed to solve overloads which cannot be resolved with the redispatching of the generators. Load is curtailed in the nodes which have highest impact on the power flow through the overloaded line.
- Lack of interconnection: this value shows the amount of load which must be curtailed in an area due to not enough interconnection capacity with other areas. It differs from the lack of power because some power would be available in the system in other areas, but cannot be transferred to the area with missing generation due to interconnection limits.

Tables with information relevant to generation production and costs:

- Reduction Min. Tec. Gen.: the results reported under this label show the variation of the hydro, imposed and VRES generation which is necessary in conditions of low load and overgeneration. When all the required thermal power plants are already operating at the minimum power, but the production, including imposed, hydro and VRES one, remains higher than the load, it is necessary that these latter generation are also reduced, to meet the load level.
- DP: it indicates the Delta Production which a generator is required to apply during the redispatching process. “DP>0” means that the generator increases its production with respect to the first optimized dispatching (valid only for thermal power plants), “DP<0” means that the generator reduces its production.

3.4.1 Argentina

In this paragraph the main results as regard Argentina are presented. First of all the results of Reference scenario are illustrated; then scenario with optimal economic amount of additional VRES is analysed and compared with the reference one. Some further cases aimed at evaluating the possible benefits gained removing some network constraints are then presented and discussed.

3.4.1.1 Reference scenario

The simulation of the ***Reference scenario*** shows

- ***Good adequacy*** of the analysed system, with EENS due to lack of power or line overload a bit above 0.5 GWh, equal to around $2x10^{-6}$ of the total load
- Overall ***generation costs*** close to ***9000 M$***, which include the costs due to redispatching to solve curtailments equal to 13 M$. This corresponds to an average cost of generation equal to about 38 $/MWh[11]
- Expected ***generation by PV*** power plants around 12,300 GWh (2,440 EOH) and a curtailment of 44 GWh in the NWE area, corresponding to less than 0.4% of the overall production.
- Expected ***generation by wind*** power plants close to 20,000 GWh (about 4,030 EOH) and a negligible curtailment of 3 GWh, equal to $1.5x10^{-4}$ of the overall wind production
- Main ***lines expected to be congested*** are
    - Recreo – Malvinas, expected to be at its limit for about 1,500h
    - Rio Diamante – Charlone – Junin, expected to be at its limit for about 500h

  These lines are close to the section NWE-NEC
- Nearly no cases where the power flows through the ***sections*** between areas are at the NTC limit

The operation of the Argentinian system in the Reference scenario, isolated from the neighbouring countries, has been simulated. The main results are presented in this paragraph.

From Table 27, which shows the EENS, expressed as MWh/year, split by area and reason, it can be seen that he system has a generally good generation adequacy. The greatest part of EENS is concentrated in NWE and it is due to lack of power, probably due to the high penetration of PV production which is not as reliable as thermal one and in case of unexpected low production can cause a lack of power. Line overloads that are not solved with a redispatching of the generation produce 50 MWh/year of EENS, mainly concentrated in NEC.

Table 27 - Expected Energy Not Supplied - Argentinean Reference scenario

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	2	45	0	47
TOTAL NWE	472	5	2	479
TOTAL PAT	0	0	0	0
TOTAL	**474**	**50**	**2**	**526**

[11] This value does not represent the average price at which the energy is sold, which is higher, as determined in every condition by the cost of the unit which is marginal. It indicates the average costs of the energy production.

Table 28 shows the total energy produced in each area and the related costs, which are only due to thermal power plants. In this reference scenario total costs are around 9000 M$/year, of which only a very small part due to redispatching costs (13 M$/year).

Table 28 - Total production and fuel costs - Argentinian Reference scenario

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	17,1675	7,081	0	-29	254	14
NWE	46,610	1,761	0	-516	305	0
PAT	18,741	142	0	-14	0	-1
TOTAL	**237,026**	**8,984**	**0**	**-559**	**559**	**13**

As regard PV generation (Table 29), total production is around 12,300 GWh/year and it is mainly concentrated in NWE. Considering that the total installed capacity is 5 GW, the equivalent operating hours (EOH) are approximately 2,450. The energy curtailed after redispatching phase is equal to 44 GWh/year, that is less than 0.4% of total production. The curtailments are needed in case the redispatching of only thermal generators is not enough to solve network congestions. This might happen when all the thermal generation in one area is already operating at the minimum value, but still there are constraints on the lines which evacuate the power from that area.

Table 29 - Total production of PV plants - Argentinian Reference scenario

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	0	0	2,443
NWE	12,253	0	-44	0	2,443
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**12,296**	**0**	**-44**	**0**	**2,443**

As regard wind generation (Table 30), total production is around 19,940 GWh/year and it is almost equally divided between NEC and PAT; only a small part of the production (less than 4%) is in NWE. Considering that the total installed capacity is 5 GW, the equivalent operating hours are a bit higher than 4,000. The energy curtailed after redispatching phase is negligible.

Table 30 - Total production of Wind plants - Argentinian Reference scenario

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	9,108	0	0	0	3,700
NWE	773	0	-3	0	2,551
PAT	10,057	0	0	0	4,604
TOTAL WIND GENER.	**19,938**	**0**	**-3**	**0**	**4,029**

Table 31 summarizes energy exchanges through the defined areas. Power flow is mainly from PAT to NEC and from NEC to NWE. The interconnections are not saturated during the year. The loading of interconnections, evaluated as energy/limit is the following:

- from PAT to NEC: 26%; from NEC to PAT: 0%
- from NEC to NWE: 30%; from NWE to NEC: 5%.

Table 31 - Interconnections - Argentinian Reference scenario

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
PAT	NEC	4,250	4,250	9,682	9	9,643	10	0	0
NEC	NWE	4,300	4,300	11,313	1,922	11,375	1,773	0	0

The following table shows the main lines which are expected to operate at their maximum transmission capacity, ordered from the greatest to the smallest expected duration in hours per year. For each line the overload duration (h/year) is reported.
It is worth noting that these lines are close to the sections between NWE and NEC.

Table 32 - Main expected overloaded lines – Argentinian Reference scenario

BUS 1	BUS 2	TOTAL [h/Year]
RECREO	REC.MALV	1,432
MALVINAS.RE	REC.MALV	811
RIOJASUR	RECREO.LA	510
CHN.RDI	RDA.CHN	461

The following Figure 49 provides a visual summary of the operation of the Argentinian system in the reference scenario, highlighting the generation mix per areas, the energy exchanges between areas and the curtailed VRES production and amount of thermal energy to be redispatched to solve network congestions.

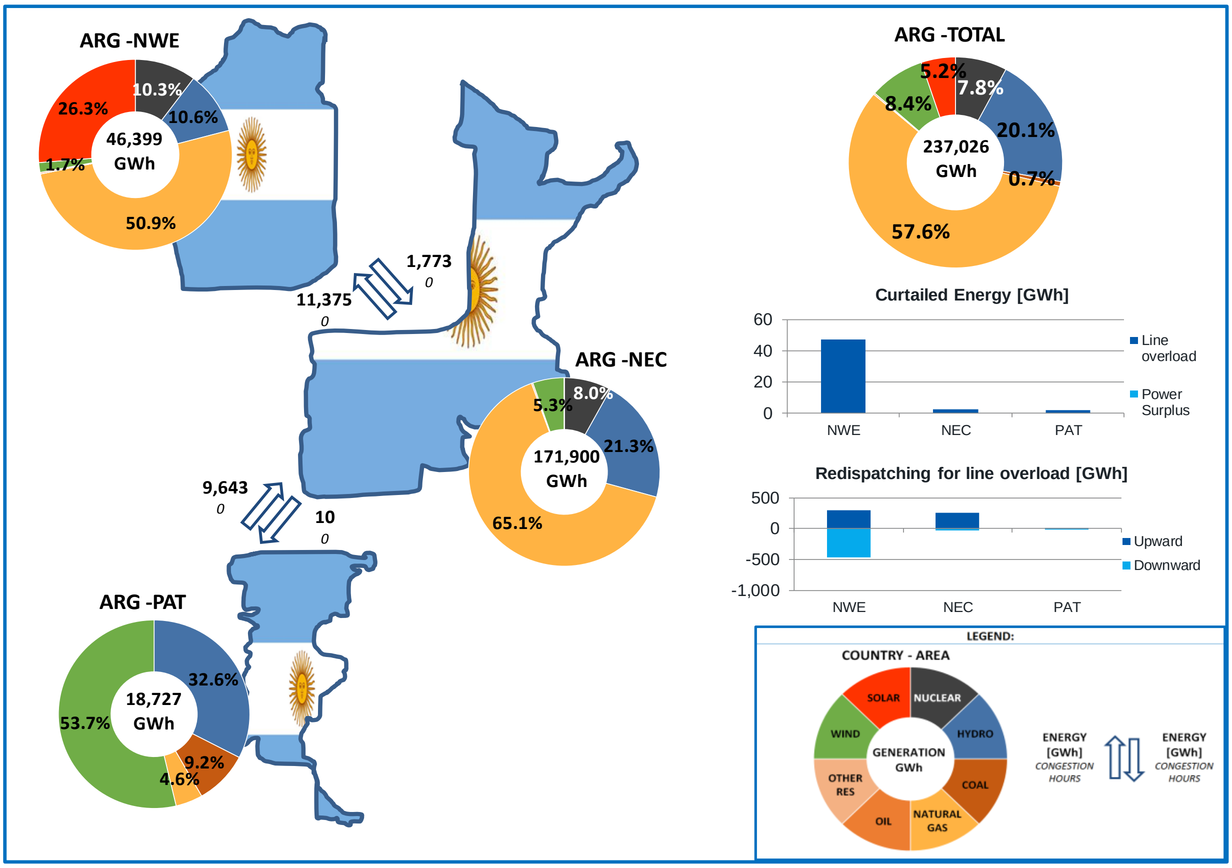


Figure 49 - Total production and energy exchanges – Argentinian Reference scenario

3.4.1.2 Scenario with optimal economic amount of additional VRES

At the end of the computational process depicted in Figure 43, the ***optimal amount of additional VRES*** with respect to the installed power already considered in the Reference scenario is about ***3,000 MW of PV*** and ***2,000 MW of wind*** power plants. The investment in such technologies provides benefits for the system higher than 150 M$/year (thanks to savings in the generation costs and avoided investments in 2,000 MW of new CCGT, higher than investment costs and increased EENS). The ***expected LCOE*** for PV is 44.3 $/MWh, and for wind 41.7 $/MWh.

The amount of additional power turns out to be quite balanced because in general wind power plants have a lower LCOE and higher production but PV is cheaper in terms of annuity per installed MW, so more power plants can be installed with a lower amount of money.

By the target year 2030 the installation of ,8000 MW PV and nearly 7,000 MW wind, for a total VRES installed power of 15,000 MW, turns out to be technical and economic feasible. The amount of installed power considered divided by area is reported in the following Table.

Table 33 Total VRES installed power in the scenario with optimal economic amount [MW]

AREA	PV installed power	Wind installed power
NEC	18	3,467
NWE	8,034	302
PAT	0	3,191

It is worth underlining that the above limits can be attained without any substantial modification of the EHV transmission grid already planned until 2025. Some overloads that may occur during the target year can be solved by generation redispatching and in some case through limited load shedding actions. Anyhow, this latter action ensures the compliance with the system adequacy.

In this new scenario:

- The ***EENS*** due to lack of power or line overload increases to nearly 3.5 GWh, equal to around 1.7×10^{-5} of the total load
- Overall ***generation costs*** decrease to 8,331 M$ thanks to the VRES production which replaces thermal generation. The part of costs due to the presence of network congestions increases to 74 M$ (+61 M$ with respect to the Reference scenario), due to higher expected overloads. The overall costs correspond to an average production cost equal to 35 $/MWh
- Expected ***generation by PV*** plants higher than 19,300 GWh, but the EOH decreases below 2,400h due to curtailments which increase up to 440 GWh (about 2% of total PV production)
- Expected ***generation by wind*** power plants close to 29,000 GWh (more than 4150 EOH) and a curtailment of 42 GWh (0.1% of the total wind generation)
- Some very limited ***VRES curtailments*** due to overgeneration in low load conditions appear, as predictable since the total VRES amount is equal to the upper bound limit defined in Chapter 2, which was focused on the maximum allowable generation in low load conditions
- The number of lines expected to become bottlenecks increases and the main ones belonging to or close to the sections between areas are
    - Rio Diamante – Charlone – Junin, expected to be at its limit for more than 1,800h
    - Recreo – Malvinas, expected to be at its limit for about 1,600h
- The ***NTC limit of the section NWE - NEC*** is reached in some cases, summing up to about 120 hours from NWE to NEC, while the interconnection PAT – NEC is not saturated during the year.

The analysis performed following the procedure described in Figure 43 provides an optimal amount of additional VRES installations in Argentina equal to about 3,000 MW in PV and 2,000 MW in wind power plants. These new plants replace 4 CCGTs among the ones added to cover the peak demand and load increase in the Reference scenario (see 3.3.1.1), for a total of 2,000 MW.
Table 34 provides the detail of the added PV and wind installed power in each area with respect to the Reference scenario and the final resulting values.

Table 34 - Additional and total VRES installed power in the Scenario with optimal economic amount [MW]

AREA	PV installed power		Wind installed power	
	Added to reference scenario	Total	Added to reference scenario	Total
NEC	0	18	1,006	3,467
NWE	3,036	8,034	0	302
PAT	0	0	1,007	3,191

The results of the simulation of one year of operation of the system with this new amount of VRES installed power are shown in detail below.

The system with the increased VRES production and the removal of 4 CCGTs maintains a good adequacy, even if higher values of EENS are obtained with respect to the Reference scenario. Table 35 shows the EENS, expressed as MWh/year, split by area and cause.
As for the reference scenario, the greatest part of EENS is concentrated in NWE and it is due to lack of power. The absence of 2,000 MW of CCGT replaced by PV and wind power plants is the main reason of the increase of EENS due to Lack of Power (from 474 MWh to 3,342 MWh).
The new scenario shows also an increase of EENS due to line overload (from 50 MW/year to 376 MW/year), because the lower number of available CCGTs and the higher generation from VRES reduce the flexibility of the system so solve network congestions.

Table 35 - Expected Energy Not Supplied - Argentinian optimal scenario

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	80	326	0	406
TOTAL NWE	3,262	34	17	3,313
TOTAL PAT	0	16	0	16
TOTAL	**3,342**	**376**	**17**	**3,735**

Table 36 sums up the total annual production and the thermal costs.
With respect to the costs of the Reference scenario reported in Table 28, the total thermal costs decrease considerably (- 667 M$/year with respect to the Reference scenario, equal to a reduction of nearly 7.5%) which is the result of a lower initial costs before redispatching (- 727 M$/year because part of the load is supplied by the new VRES plants and not by thermal plants, with considerable savings on the fuel costs)

and a greater cost of the redispatching needed because of some network constraints and line overloads (+ 60 M$/year).

Table 36 - Total production and fuel costs - Argentinian optimal scenario

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	165,028	6,542	0	-416	2,145	119
NWE	50,253	1,581	8	-1,752	128	-42
PAT	23,188	134	2	-127	22	-3
TOTAL	**238,469**	**8,257**	**10**	**-2,295**	**2,295**	**74**

In Table 37 the results in term of PV generation for the optimal amount of additional RES are presented; Table 38 shows the difference of total PV production respect to Reference scenario.
There is an increase of almost 7,040 MWh/year in the annual production – so 57% more than the annual production of reference scenario. Since the 3,000 MW of additional PV plants are deployed in NWE area, the increase is totally in this area.
The energy curtailed after redispatching phase increases to approximately 440 GWh/year (equivalent to a bit more than 2% of the produced energy). A small amount of curtailments (8 GWh) is also present in conditions where the load is low and the thermal generation is operating at the minimum production. This is due to the fact that the amount of additional VRES installed is equal to the limit found during analysis performed in Chapter 2, which indicates a risk of curtailment in overgeneration conditions.
The increase of the curtailments has the effect to reduce in the equivalent operating hours with respect to the Reference scenario (almost 50 hours).

Table 37 - Total production of PV plants - Argentinian optimal scenario

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-8	0	1,989
NWE	19,690	8	-435	0	2,396
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**19,733**	**8**	**-443**	**0**	**2,395**

Table 38 - Difference of total production of PV plants between Argentinian optimal scenario and the Reference one

DIFFERENCE RESPECT TO THE REFERENCE SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	0	0	-8	0	-454
NWE	7,437	8	-391	0	-47
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**7,437**	**8**	**-399**	**0**	**-48**

In Table 39 wind production results of the optimal scenario are presented; Table 40 shows the difference of total wind production respect to Reference scenario.
The annual wind production reaches almost 29,000 MWh, with an increase of 45% with respect to the reference scenario. There is a relative increase in the curtailed energy after the redispatching phase, but the curtailed energy is still negligible with respect to the total generation. It is interesting to point out that the equivalent operating hours globally increase if compared to the Reference scenario because the additional wind power plants are installed in areas with higher potential, equally deployed in Patagonia and in NEC areas (1,000 MW of additional capacity in each one). The EOH reach almost 4,160, with an increase of about 130 hours.

Table 39 - Total production of Wind plants - Argentinian optimal scenario

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	13,525	0	-7	0	3,898
NWE	773	0	-32	0	2,455
PAT	14,687	2	-3	0	4,601
TOTAL WIND GENER.	**28,985**	**2**	**-42**	**0**	**4,158**

Table 40 - Difference of total production of Wind plants between Argentinian optimal scenario and the Reference one

DIFFERENCE RESPECT TO REFERENCE SCENARIO					
WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	4,417	0	-7	0	198
NWE	0	0	-29	0	-96
PAT	4,630	2	-3	0	-3
TOTAL WIND GENER.	**9,047**	**2**	**-39**	**0**	**129**

Table 41 gathers information on the interconnections in the optimal scenario. Looking at the variations with respect to the Reference scenario, it can be highlighted that there is an increase of 42% in the power flow from PAT to NEC area: this growth is due to the additional wind farm production in Patagonia which is exported to the North. As regard interconnection NEC – NWE, energy exchanges increase in both directions: from NWE to NEC the growth is significant, and it is related to the higher PV production in NWE area, while the increase from NEC to NWE is due to the absence of a CCGT in NWE, which then needs to import more energy when PV production is absent. Even if it happens a limited time in the year, it is worth highlighting that the power exchange across the NWE-NEC section reaches the limit defined with the NTC.

The average loading of interconnections is the following:

- from PAT to NEC: 37%; from NEC to PAT: 0%
- from NEC to NWE: 33%; from NWE to NEC: 13%.

Table 41 - Interconnections - Argentinian optimal scenario

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
PAT	**NEC**	4,250	4,250	13,846	7	13,726	7	0	0
NEC	**NWE**	4,300	4,300	12,488	6,637	12,540	5,065	2	117

Scenario with optimal economic amount of additional VRES shows the following main lines which are expected to operate at their technical limit, ordered from the greatest to the smallest expected duration. For each line the overload duration (h/year) is reported.

With respect to the overloads found in the Reference scenario, an increase of the expected constraints can be observed, in particular for the line Rio Diamante – Charlone – Junin.

Table 42 - Main expected overloaded lines - Argentinian optimal scenario

BUS 1	BUS 2	TOTAL [h/Year]
CHN.RDI	**RDA.CHN**	1,808
RECREO	**REC.MALV**	1,592
MALVINAS.RE	**REC.MALV**	1,334
SCN_500	**COMODORO**	757
CHN.JUN	**JUNIN**	747

Figure 50 shows the generation mix per areas, the energy exchanges between areas and the curtailed VRES production and thermal redispatching needed to solve network congestions in the scenario with the optimal amount of VRES installations. The comparison with Figure 49, which provides the same information for the Reference scenario, highlights the increase of the PV and wind production in the system and the relevant reduction of thermal generation, and an increase of the operations required to solve network constraints.

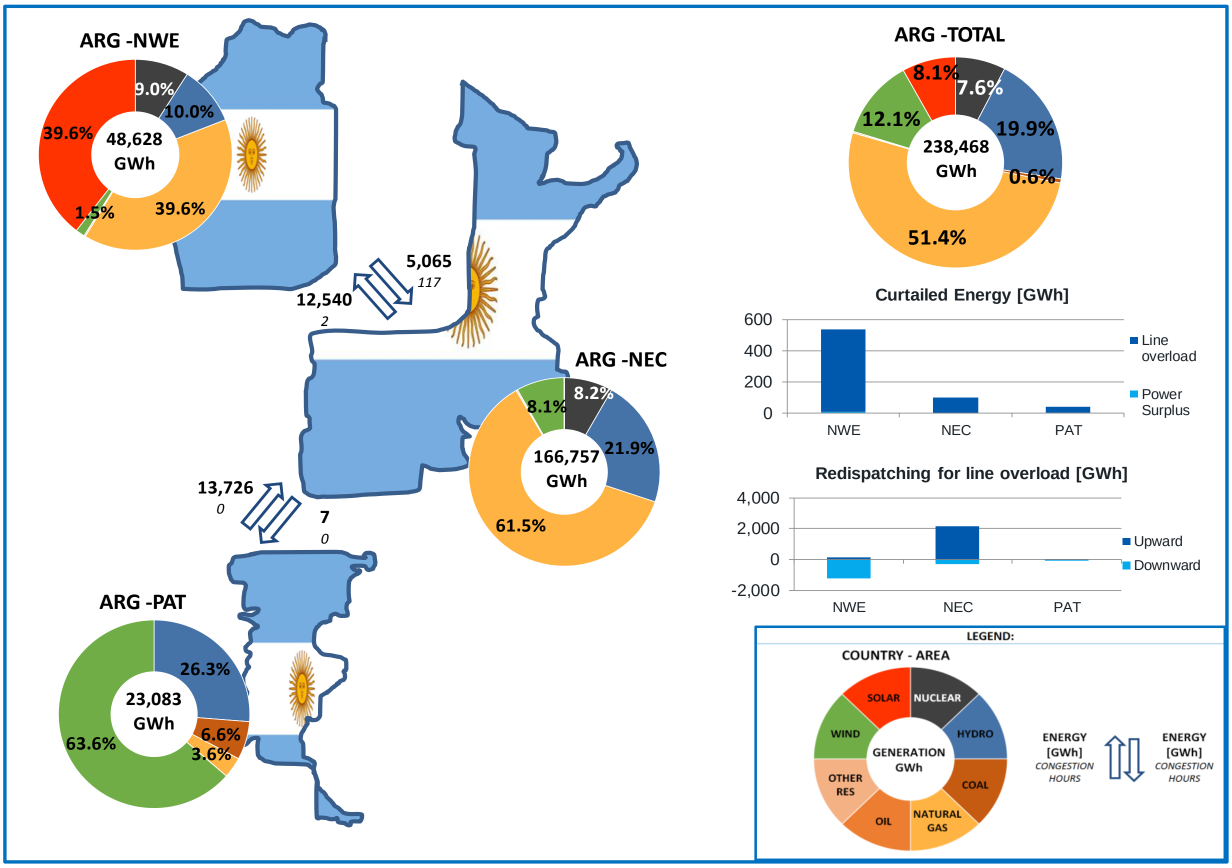


Figure 50 - Total production and energy exchanges – Argentinian scenario with optimal VRES amount

The analysis of the results obtained by the simulation of the operation of the system with the additional 5000 MW of VRES power plants is completed with a table that summarizes the total benefit evaluated with respect to the Reference scenario, so expressed as a difference between optimal scenario and the reference one.

Table 43 shows the difference, in MW, of the installed VRES and the CCGTs that can be avoided because replaced by VRES. Then, the table reports the main differences in terms of:

- total thermal generation variation, already considering the needed redispatching
- RES curtailment variation;
- EENS variation.

These values are expressed in GWh/year.

For each of the previous information, economic benefits are presented. All the savings (or costs) are evaluated calculating the relevant annuity, in order to allow a direct comparison, and include:

- the investment and operating costs needed for the additional VRES;
- the avoided costs of the investment in CCGT power plants which can be replaced by the new additional VRES;
- total thermal generation costs variation;
- the variation of the cost of EENS.

Please note that the cost associated to VRES production curtailment is already included in total thermal generation costs variation, because during the redispatching more thermal generation is needed and paid if VRES generation is reduced. All the costs and savings are expressed in M$/year. Benefit has been evaluated for each MW of additional VRES too.

Table 43 - Total benefit - Argentinian optimal scenario with respect to Reference scenario

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	5,050	-688
NEW CCGT AVOIDED	2,000	+188
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-14,421	+666
RES CURTAILMENT	448	-
TOTAL EENS	3	-6
TOTAL BENEFIT	**-**	**+160**

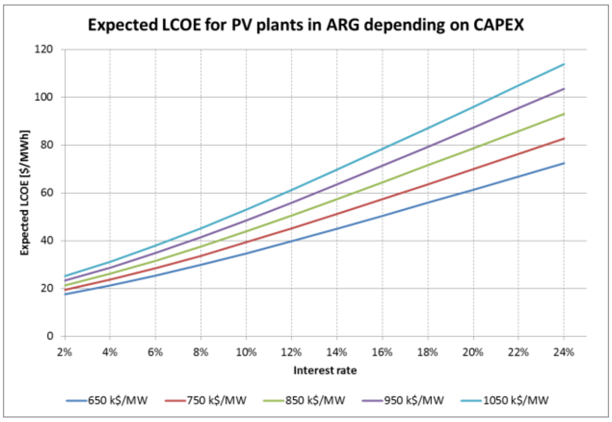
BENEFIT/MW VRES [kUSD/year]	**+32**

It is worth underlining that in the analysed case, the cost of the investment in new VRES power plants is comparable to (but a bit higher than) the savings in the thermal generation costs. The benefits for the system comes mainly from the fact that the installation of VRES plants allows not to invest in other technologies, such as CCGT, which would be anyway needed to supply the load.
In other words, VRES technologies show their most important impact on benefits not because they replace thermal plants already existing, but because they avoid the costs for the construction and operation of new ones to meet load increase over the years.

Finally, based on the results presented above, it is possible to calculate the expected LCOE for the PV and wind power plants added to the 2025 targets in Argentina.
Considering the CAPEX and OPEX reported in Table 10, the resulting values are:

- LCOE for PV power plants: 44.3 $/MWh
- LCOE for wind power plants: 41.7 $/MWh

Some sensitivities calculations have been also performed to assess the variation of the LCOE depending on CAPEX and interest rate. They are carried out keeping the same production for each technology resulting in the optimized scenario and presented above and changing CAPEX and interest rate, which cause variations in the annuity of the investment and consequently different LCOE.
Figure 51 clearly shows the dependency of LCOE from CAPEX and interest rate.



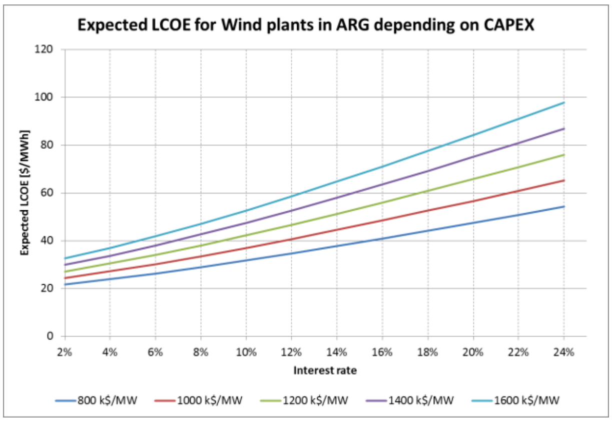


Figure 51 - Expected LCOE variations depending on CAPEX and interest rate

In the final scenario with the optimal amount of VRES additional installations, the expected overloads on some lines close to inter-area sections have increased, causing costs needed to solve network congestions considerably higher than the ones in the reference scenario (+60 M$). For this reason some further simulations have been carried out to evaluate the impact of some possible actions aimed at solving this problem. The analysis has been focused on the overloads related to the power flows between NWE and NEC, as they cause the curtailment of about 440 GWh of PV production, which cannot be injected in the system.

As listed in the Table 42, the most congested lines in this scenario are:

a. Recreo – Malvinas (RECREO - REC.MALV and MALVINAS.RE - REC.MALV)), expected to be overloaded about 1,600 hours
b. Rio Diamante – Charlone – Junin (CHN.RDI - RDA.CHN and CHN.JUN – JUNIN), expected to be overloaded more than 1,800 hours

Figure 52 shows the position of these lines in the Argentinian system.

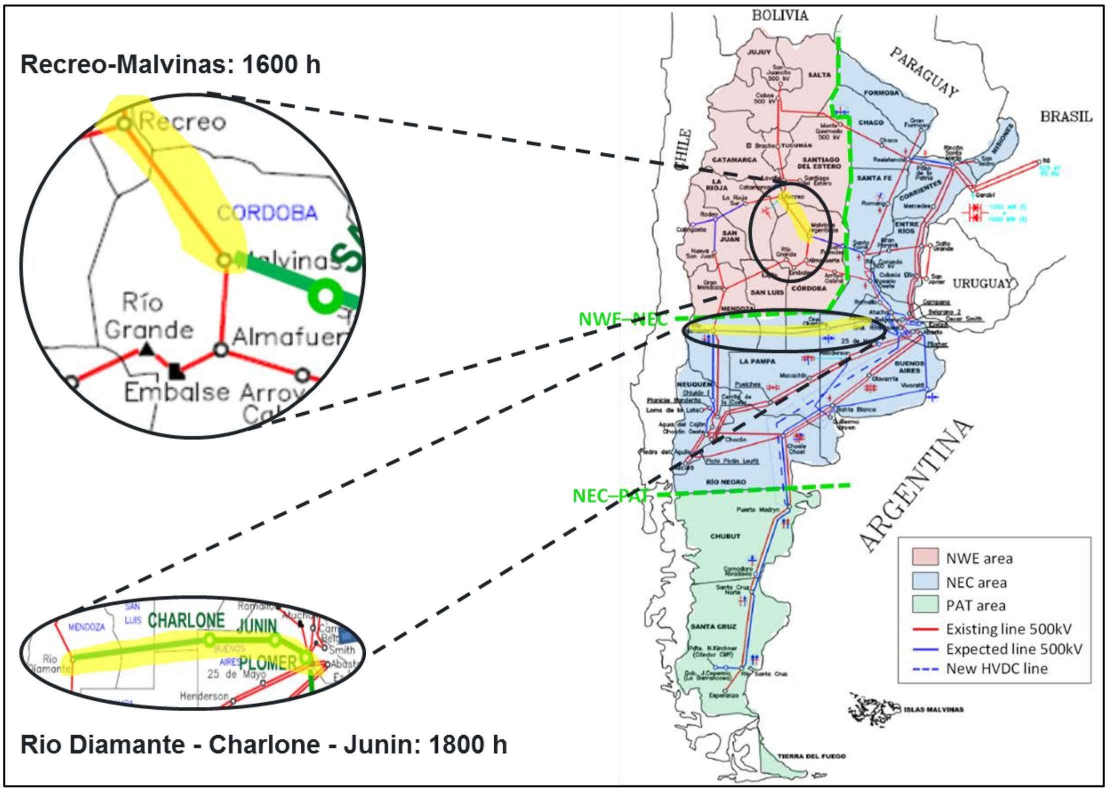


Figure 52 - Main congested lines in Argentinian system with optimal amount of new VRES power plants

Three main approaches have been identified to reduce congestions:

- network improvement, simulated increasing the transmission capacity of the overloaded lines
- lower PV installation in the critical areas, replaced by an equivalent investment in wind power plants
- different distribution of PV power plants in the areas, considering that the producibility can lower in other locations

The following paragraphs provide a comparison of the benefits for the system in the different cases.

3.4.1.3 *Assessment of possible network reinforcements*

In order to evaluate the benefits for the system in case the bottlenecks are reduced, simulations with an increased transmission capacity for these lines have been carried out.

For the definition of the possible reinforcement, the following information has been considered:

- Recreo – Malvinas: it is an existing line with a transmission capacity actually limited to 1,088 A. Based on the information available in [6], the real capacity of the conductor is 1,750 A but the current is kept to lower values due to other constraints, such as a limitation of the Current Transformer. For this reason, the hypothesis for the line strengthening is to use the real capacity of the conductor, assuming that possible local restrictions are removed (e.g.: replacement of CT).
- Rio Diamante – Charlone – Junin: these lines are going to be built in the next years, so the hypothesis is to consider an increased capacity based on standard values for other similar lines.

The following table shows the transmission capacity of the lines assumed in optimal scenario and the ones established in order to perform the sensitivities described in this paragraph.

Table 44 - Network reinforcement

BUS 1	BUS 2	Original Scenario Imax [A]	Reinforced Scenario Imax [A]
CHN.RDI	**RDA.CHN**	1,000	2,000
RECREO	**REC.MALV**	1,088	1,750
MALVINAS.RE	**REC.MALV**	1,251	1,750
CHN.JUN	**JUNIN**	1,000	2,000

Three different calculations have been run to identify the benefits of each single intervention and of the two together:

1. Increase of capacity of Recreo – Malvinas lines;
2. Increase of capacity of Rio Diamante – Charlone – Junin lines;
3. Increase of capacity of both Recreo – Malvinas and Rio Diamante – Charlone – Junin lines.

The following table summarizes the three cases:

Table 45 - Line limits [A] considered in the sensitivity calculations

SENSITIVITY	CHN.RDI - RDA.CHN	CHN.JUN – JUNIN	RECREO - REC.MALV	MALVINAS.RE - REC.MALV
SENSITIVITY 1	1,000	1,000	1,750	1,750
SENSITIVITY 2	2,000	2,000	1,088	1,251
SENSITIVITY 3	2,000	2,000	1,750	1,750

In all the sensitivities the VRES installed capacity has not changed since the maximum technical limit was already attained.

The key results arising from the ***interventions on the congested lines*** are:

- ***System Reliability***: the EENS is not significantly influenced by the removal of the bottlenecks. Only the Rio Diamante – Junin line has a small effect on the EENS, reducing it by 2%.
- ***Generation costs***: there are significant savings in costs needed to solve network congestions when applying all interventions, equal to about $ 70 million per year. The intervention on only one line generates lower savings, equal to $ 22 million for the Recreo – Malvinas and $ 45 million for the Rio Diamante - Charlone – Junin. These results also show that the two congestions are quite independent, as the sum of the single benefits is pretty similar to the benefits obtained with both interventions.
- ***PV generation***: Strong positive impact on avoided PV curtailment is shown. With both interventions, the curtailments are nearly reduced from 440 to 0 GWh. In case of single interventions, the improvement of the line Recreo – Malvinas allows to avoid nearly 360 GWh of PV generation curtailment, while the other reduces the curtailments by 228 GWh.
- ***Wind generation***: also wind production curtailments are reduced, but the absolute values are smaller than PV because of the lower curtailments in the scenario without interventions on the lines.
- ***Interarea energy exchanges***: the bottlenecks had no impact on PAT-NEC section, so their removal does not modify the energy exchanges between these two regions. On the contrary, the energy exchanges on NEC-NWE cutset increases by more than 1,500 GWh from NWE to NEC in particular thanks to the improvement of the Rio Diamante - Charlone – Junin line.

The detailed results of the sensitivities which consider improved transmission capacity for the lines are reported below. The results are compared with the scenario with optimal amount of VRES, indicated as optimal scenario, to evaluate overall benefits. Only the information after redispatching are shown, as the first optimal dispatching does not change with the modification of the transmission capacity of the lines.

Concerning the EENS, only the improvement of the Rio Diamante - Charlone – Junin line allows a slight reduction of the load curtailments required to solve the overloads when the generation redispatching is not sufficient (- 45 MWh, corresponding to about 1.5% of the total EENS). The removal of the constraint on the Recreo – Malvinas line does have no effect on the EENS, because the overloads were always resolved with the redispatching activity.

Table 46 sums up the results in terms of total production and thermal generation costs in the three different cases compared to the optimal scenario described in 3.4.1.2.
The need of redispatching is reduced considerably both in terms of energy to be redispatched and in terms of related costs. The improvement of the transmission capacity of the line Recreo – Malvinas allows a cost saving equal to 22 M$/year, while the intervention on the Rio Diamante - Charlone – Junin line reduces the redispatching costs by 45 M$/year. If the two improvements are applied together, the redispatched energy and the costs become less than one twentieth of the original values.

Table 46 - Total production and fuel costs - assessment of possible network development

Scenario	ALL GENERATORS AREA	VARIATION AFTER REDISPATCHING GWh/year DP < 0	GWh/year DP > 0	M$/year
0) Optimal scenario	NEC	-416	2,145	119
	NWE	-1,752	128	-42
	PAT	-127	22	-3
	TOTAL	**-2,295**	**2,295**	**74**
1) 1750 A on Recreo - Malvinas	NEC	-659	2,125	104
	NWE	-1,372	7	-49
	PAT	-122	22	-3
	TOTAL	**-2,153**	**2,154**	**52**
2) 2000 A on Rio Diamante - Charlone - Junin	NEC	-68	213	11
	NWE	-786	712	19
	PAT	-95	24	-1
	TOTAL	**-949**	**949**	**29**
3) 1750 A on Recreo - Malvinas 2000 A on Rio Diamante - Charlone - Junin	NEC	-12	79	4
	NWE	-16	17	1
	PAT	-95	27	-1
	TOTAL	**-123**	**123**	**4**

In Table 47 the results related to the PV productions are presented; Table 48 shows the differences with respect to optimal scenario. A strong effect on the PV production curtailments can be observed for the Recreo – Malvinas line, which allows a higher PV production by nearly 360 GWh, but also the improvement of the Rio Diamante - Charlone – Junin line reduce the PV curtailments by 220 GWh.
The two interventions together brings the risk of PV curtailments to negligible values.

Table 47 - Total production of PV plants - assessment of possible network development

Scenario	PHOTOVOLTAIC GENERATORS AREA	VARIATION AFTER REDISPATCHING GWh/year DP < 0	GWh/year DP > 0	EOH h/year
0) Optimal scenario	NEC	-8	0	1,989
	NWE	-435	0	2,396
	PAT	0	0	-
	TOTAL	**-443**	**0**	**2,395**
1) 1,750 A on Recreo - Malvinas	NEC	-11	0	1,818
	NWE	-74	0	2,440
	PAT	0	0	-
	TOTAL	**-85**	**0**	**2,439**

Scenario	PHOTOVOLTAIC GENERATORS AREA	VARIATION AFTER REDISPATCHING GWh/year DP < 0	GWh/year DP > 0	EOH h/year
2) 2,000 A on Rio Diamante - Charlone - Junin	NEC	0	0	2,443
	NWE	-215	0	2,423
	PAT	0	0	-
	TOTAL	**-215**	**0**	**2,423**
3) 1,750 A on Recreo - Malvinas 2,000 A on Rio Diamante - Charlone - Junin	NEC	0	0	2,443
	NWE	-2	0	2,449
	PAT	0	0	-
	TOTAL	**-2**	**0**	**2,449**

Table 48 - Difference of total production of PV plants respect to optimal scenario

DIFFERENCE RESPECT OPTIMAL SCENARIO				
Scenario	**PHOTOVOLTAIC GENERATORS**	**VARIATION AFTER REDISPATCHING**		**EOH**
	AREA	**ΔGWh/year DP < 0**	**ΔGWh/year DP > 0**	**Δh/year**
1) 1750 A on Recreo - Malvinas	NEC	-3	0	-171
	NWE	361	0	44
	PAT	0	0	-
	TOTAL	**358**	**0**	**44**
2) 2000 A on Rio Diamante - Charlone - Junin	NEC	8	0	454
	NWE	220	0	27
	PAT	0	0	-
	TOTAL	**228**	**0**	**28**
3) 1750 A on Recreo - Malvinas 2000 A on Rio Diamante - Charlone - Junin	NEC	8	0	454
	NWE	433	0	53
	PAT	0	0	-
	TOTAL	**441**	**0**	**54**

The combined reinforcements on both Recreo – Malvinas and Rio Diamante - Charlone – Junin practically cancel the PV curtailment and allows the equivalent operating hours to reaches almost its theoretical value (2,450).

In Table 49 the results related to wind productions are presented; Table 50 shows the differences respect to optimal scenario.

Table 49 - Total production of Wind plants - assessment of possible network development

Scenario	WIND GENERATORS AREA	VARIATION AFTER REDISPATCHING GWh/year DP < 0	VARIATION AFTER REDISPATCHING GWh/year DP > 0	EOH h/year
0) Optimal scenario	NEC	-7	0	3,898
	NWE	-32	0	2,455
	PAT	-3	0	4,601
	TOTAL	**-42**	**0**	**4,158**
1) 1,750 A on Recreo - Malvinas	NEC	-10	0	3,898
	NWE	0	0	2,561
	PAT	-3	0	4,601
	TOTAL	**-13**	**0**	**4,162**
2) 2,000 A on Rio Diamante - Charlone - Junin	NEC	0	0	3,900
	NWE	-6	0	2,541
	PAT	-3	0	4,601
	TOTAL	**-9**	**0**	**4,163**
3) 1,750 A on Recreo - Malvinas 2,000 A on Rio Diamante - Charlone - Junin	NEC	0	0	3,900
	NWE	0	0	2,561
	PAT	-3	0	4,601
	TOTAL	**-3**	**0**	**4,164**

Table 50 - Difference of total production of Wind plants respect to optimal scenario

DIFFERENCE RESPECT OPTIMAL SCENARIO				
Scenario	WIND GENERATORS AREA	VARIATION AFTER REDISPATCHING ΔGWh/year DP < 0	VARIATION AFTER REDISPATCHING ΔGWh/year DP > 0	EOH Δh/year
1) 1,750 A on Recreo - Malvinas	NEC	-3	0	0
	NWE	32	0	106
	PAT	0	0	0
	TOTAL	**29**	**0**	**4**
2) 2,000 A on Rio Diamante - Charlone - Junin	NEC	7	0	2
	NWE	26	0	86
	PAT	0	0	0
	TOTAL	**33**	**0**	**5**
3) 1,750 A on Recreo - Malvinas 2,000 A on Rio Diamante - Charlone - Junin	NEC	7	0	2
	NWE	32	0	106
	PAT	0	0	0
	TOTAL	**39**	**0**	**6**

The curtailments on wind production are limited respect to the ones related to PV since the impact of the overloads interesting the lines under analysis is mainly on PV sites.

In the three analysed cases, the need of a lower redispatching and PV production curtailment (as described above) brings to a greater power flow from NWE to NEC compared to the optimal scenario. In

particular, case 3 shows that the power flow before redispatching and after redispatching is almost the same.
Considering that the NTC among the areas remain the same respect optimal scenario, the loading of interconnections is the following:

- Case 1
  - from PAT to NEC: 37%; from NEC to PAT: 0%
  - from NEC to NWE: 33%; from NWE to NEC: 14%.
- Case 2
  - from PAT to NEC: 37%; from NEC to PAT: 0%
  - from NEC to NWE: 33%; from NWE to NEC: 17%.
- Case 3
  - from PAT to NEC: 37%; from NEC to PAT: 0%
  - from NEC to NWE: 33%; from NWE to NEC: 18%.

These results confirms the increase of power flow from NWE to NEC especially if compared with optimal scenario where the loading of the interconnection from NWE to NEC is 13%.

Table 51 - Interconnections - assessment of possible network development

Scenario	AREA A	AREA B	FINAL ENERGY EXCHANGES [GWh/year]		SECTION LIMIT REACHED [h/year]	
			A -> B	A <- B	A -> B	A <- B
0) Optimal scenario	PAT	NEC	13,726	7	0	0
	NEC	NWE	12,540	5,065	2	117
1) 1,750 A on Recreo - Malvinas	PAT	NEC	13,731	7	0	0
	NEC	NWE	12,540	5,324	2	117
2) 2,000 A on Rio Diamante - Charlone - Junin	PAT	NEC	13,769	7	0	0
	NEC	NWE	12,484	6,567	2	118
3) 1,750 A on Recreo - Malvinas 2,000 A on Rio Diamante - Charlone - Junin	PAT	NEC	13,801	6	0	0
	NEC	NWE	12,484	6,642	2	118

Figure 53 provides the main results of the sensitivity in which both lines are improved. The comparison with Figure 50, which is relevant to scenario with optimal VRES amount, highlights the increase of the PV production in NWE, the reduction of needed redispatching and curtailments, and the new energy exchanges between areas.

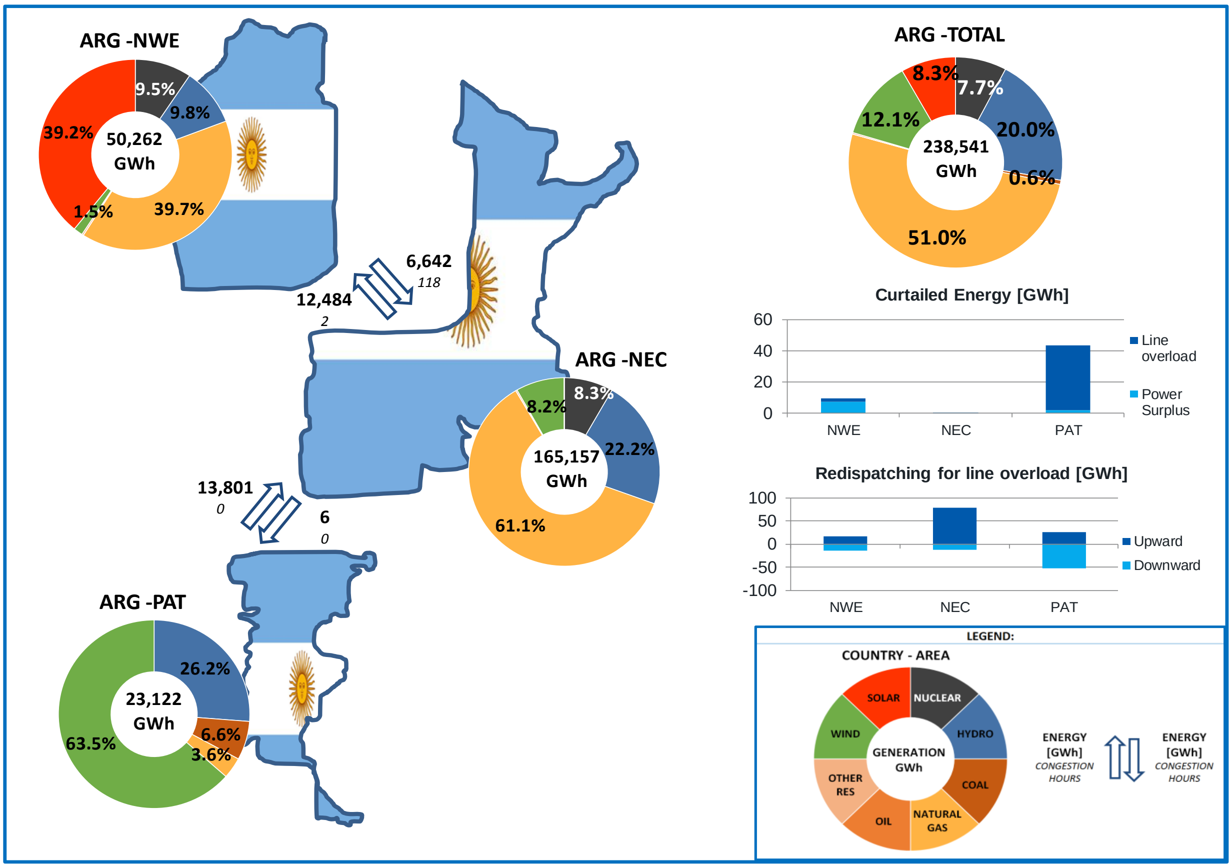


Figure 53 - Total production and energy exchanges – Argentinian scenario with optimal VRES amount and improvement of transmission capacity on Recreo – Malvinas and Rio Diamante - Charlone – Junin lines

Table 52 summarizes the benefit for each sensitivity illustrated in this paragraph, which is mainly due to the savings in redispatching. The costs of the line improvements are not considered here.

Table 52 - Total benefit with respect to optimal scenario - assessment of possible network development

Scenario		ELECTRICAL SYSTEM	ECONOMIC BENEFITS
		GWh/year	MUSD/year
1) 1750 A on Recreo - Malvinas	TOTAL THERMAL GENERATION	-310	+22
	RES CURTAILMENT	-387	-
	TOTAL EENS	0	0
	TOTAL BENEFIT	-	+22
2) 2000 A on Rio Diamante - Charlone - Junin	TOTAL THERMAL GENERATION	-401	+45
	RES CURTAILMENT	-261	-
	TOTAL EENS	0	0
	TOTAL BENEFIT	-	+45
3) 1750 A on Recreo - Malvinas 2000 A on Rio Diamante - Charlone - Junin	TOTAL THERMAL GENERATION	-625	+70
	RES CURTAILMENT	-480	-
	TOTAL EENS	0	0
	TOTAL BENEFIT	-	+70

The savings related to the reinforcements are analysed in order to calculate the investment that can bring advantages to the whole system.
Taking into account a discount rate of 7.7% and a lifetime of the reinforcement project of 40 years [1], the annuity of an investment can be obtained multiplying the investment by 0.0812. An investment in the network development could be considered advantageous from a system point of view if the annualized cost of the investment is lower than the annual saving due to the investment itself.

1. The first case allows a saving of 22 M$/year, and the annualized cost of the investment must be indeed lesser in order to make it cost-effective for the system.
   An investment lower than 22 M$ / 0.0812 = 268 M$ meet this requirement since its annualized cost, taking into account a 7.7% interest rate, is lesser than the expected annual saving.
2. The second case allows a saving of 45 M$/year. This investment is cost-effective provided that it costs less than 45 M$ / 0.0812 = 559 M$.
3. The third case allows an investment of 70 M$/year. The combined investment is indeed cost-effective provided that it costs less than 70 M$ / 0.0812 = 867 M$.

Depending on the required effort needed to improve the transmission capacity of the lines, the investments might be profitable or not.
The costs of these interventions are not publicly available, and should be calculated based on specific data. It is anyway possible to estimate different cases and calculate relative annuities to be compared with the benefits. Based on the information available in [6], the transmission capacity of the Recreo - Malvinas line is limited by some equipment in the substations (for instance the Current Transformers) while the line conductor would be already able to transmit higher power. The cost for the improvement of its transmission capacity is probably very limited, and can be assumed lower than 500 k$ and the corresponding annuity is lower than 50 k$. As a consequence, the investment is strongly recommended, in order to exploit at the best the full capacity of the conductors, and the benefits for the systems would be close to all the ones presented above.
More difficult is the estimation of the costs for the improvement of the transmission capacity of the Rio Diamante – Charlone – Junin line, which is going to be built in the next years. In this case, as a rough estimation, it is possible to consider that the increase of the dimension of the conductor causes an increase of the line costs equal to 150 k€/km, and given the total length close to 750 km, the investment costs becomes more than $ 110 million. The corresponding annuity is about $ 10 million/year, still lower than the generated benefits, meaning that it is advantageous to proceed with this upgrade. It is worth underlining that these are estimations which can vary considerably depending on the actual status of the project, the foreseen solutions and many other factors. It is anyway clear that the performed analysis provided solid criteria for the evaluation of investments in network upgrades.

It is worth underlining that the improvement of the transmission capacity of the lines has no impact on the total amount of installable VRES power plants, as this limit is set by system constraints such as reserve constraints, which are not modified by the upgrade of the transmission network.

3.4.1.4 Replacement of some new PV power plants with wind power plants

A scenario in which part of the additional ***amount of PV installed power*** in NWE (about 830 MW) is replaced by an ***equivalent investment in wind generation*** installed in PAT is simulated. The rationale for the definition of this scenario is the tentative to limit overloads on the lines with a different distribution of the additional VRES plants.
Thanks to the reduction of PV plants in NWE, the overloads on the Recreo – Malvinas line can be reduced, while the movement of generation has no significant impact on the Diamante - Charlone – Junin.
Overall ***EENS*** reduces by 10% to 3.4 GWh, and is more distributed in the areas as some curtailments for line overloads appear also in NEC.
The ***total generation costs*** reduce by 22 M$, obtained thanks to a significant reduction of the costs related to network congestions.
Total ***PV production*** is lower in absolute value (17,700 GWh instead of 19,300 GWh in the optimal scenario), but the EOH are higher thanks to the lower curtailments.
Wind generation increases because of the higher installed power in the areas with highest potential.
As predictable, ***energy exchanges*** between areas increase from PAT to NEC (+900 GWh), while are reduced from NWE to NEC. In particular, the difference of net balance on the NWE-NEC section with respect to the optimal scenario is nearly 1.400 GWh (higher flow towards NWE), while the amount of hours during which the relevant NTC is reached drops down from 120 hours to nearly 0.
It can be noted that the benefits for the system are similar to the ones calculated in the paragraph 3.4.1.3 considering an intervention only on the Recreo – Malvinas line.

On the basis of the results which defined the optimal economic amount of additional VRES (paragraph 3.4.1.2), this further scenario has been analysed in order to evaluate the possible benefits deriving from the installation of a different mix of new VRES power plants, aimed at reducing the congestions on the transmission network which caused the curtailment of some PV production in NWE. Assuming that the total investment in new VRES power plants must remain equal to the one obtained in the previous assessment, 830 MW of new PV plants installed in NWE area, which contributed to the congestions, are replaced with a bit more than 450 MW of new wind power plants installed in PAT and NEC[12]. In particular, the PV plants injecting power in Lavalle, Catamarca and Santiago nodes in NWE (which are among the ones with highest impact on the power flow through the Recreo – Malvinas line) are not considered and the new wind installed power is equally distributed on the predicted wind power plants already considered in the scenario with an optimal economic amount of additional VRES.

The following table shows the EENS, expressed as MWh/year, split by area and reason. Even if EENS due to Line Overload slightly increases with respect to the optimal scenario (Table 35), its total value decreases due to a significant reduction of EENS, due to Lack of Power in NWE (-15%). This is related to the reduction of the amount of variable energy generation in this area, which on one hand reduces the

[12] Given the same total investment, the amount of MW installed per technology is different because of the different installation and operational costs.

possible variations of the production due to the unpredictable changes and on the other requires that more thermal generation remains available, which was shut down in previous simulations. These two effects together increases the capacity of the dispatchable generation to supply the load, avoiding EENS.

Table 53 - Expected Energy Not Supplied - replacement of some new PV with new wind

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	77	366	0	443
TOTAL NWE	2,801	45	21	2,867
TOTAL PAT	0	22	0	22
TOTAL	**2,878**	**433**	**21**	**3,332**

The following table reports the total annual production and the thermal costs.
Respect to scenario with optimal economic amount of additional VRES, energy moved in redispatching phase is reduced from 2,295 GWh/year to 1,775 GWh/year, and the total thermal generation costs by 28 M$.

Table 54 - Total production and fuel costs - replacement of some new PV with new wind

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	166,031	6,535	0	-438	1,726	92
NWE	48,329	1,584	3	-1,149	12	-40
PAT	24,253	135	2	-188	37	-3
TOTAL	**238,613**	**8,254**	**5**	**-1,775**	**1,775**	**49**

In the following table results in term of PV generation are presented. Then Table 56 shows the differences with respect to optimal scenario. As expected, PV production is reduced due to the replacement of about 830 MW of new PV with 455 MW of new wind power plants. The energy curtailed to solve network congestions is approximately 60 GWh/year instead of 440 GWh/year of the scenario with optimal economic amount of additional VRES.
Equivalent operating hours increase by almost 47 hours due to the reduced curtailment during the redispatching phase. This means that in this scenario the PV power plants are better exploited.

Table 55 - Total production of PV plants - replacement of some new PV with new wind

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-9	0	1,932
NWE	17,664	3	-53	0	2,443
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**17,707**	**3**	**-62**	**0**	**2,442**

Table 56 - Difference of total production of PV plants respect to reference scenario

DIFFERENCE RESPECT OPTIMAL SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	0	0	-1	0	-57
NWE	-2,026	-5	382	0	47
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**-2,026**	**-5**	**381**	**0**	**47**

In the following table wind production results are presented. Then Table 58 shows the differences with respect to the optimal scenario. As expected, wind production increases due to the additional wind power plants. The variation in redispatching is negligible. Equivalent operating hours slightly increases due to the higher amount of PV plants in areas with highest potential.

Table 57 - Total production of Wind plants - replacement of some new PV with new wind

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	14,526	0	-8	0	3,929
NWE	773	0	0	0	2,561
PAT	15,737	2	-5	0	4,601
TOTAL WIND GENER.	**31,036**	**2**	**-13**	**0**	**4,183**

Table 58 - Difference of total production of Wind plants respect to reference scenario

DIFFERENCE RESPECT TO OPTIMAL SCENARIO					
WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	1,001	0	-1	0	31
NWE	0	0	32	0	106
PAT	1,050	0	-2	0	0
TOTAL WIND GENER.	**2,051**	**0**	**29**	**0**	**25**

The following table shows energy exchanged among the areas and the saturation of interconnections. Respect to optimal scenario, power flow from PAT to NEC increases and power flow from NWE and NEC decreases (due to the different location of RES generation) The loading of interconnections is:

- from PAT to NEC: 39%; from NEC to PAT: 0%
- from NEC to NWE: 34%; from NWE to NEC: 11%.

Table 59 - Interconnection - replacement of some new PV with new wind

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
PAT	NEC	4,250	4,250	14,823	6	14,660	6	0	0
NEC	NWE	4,300	4,300	12,856	5,123	12,934	4,065	2	5

In this scenario, the main lines which are expected to be constrained are listed in Table 60, ordered from the greatest to the smallest expected duration of the overload.

With respect to the scenario with optimal economic amount of additional VRES, it is worth to underline that, thanks to the different position of the VRES generation, overloads are reduced significantly on the Recreo-Malvinas line, while only slightly on the Rio Diamante – Charlone – Junin one. On the contrary, some line which belongs to the corridor bringing the power from PAT to NEC reaches its limits (line Santa Cruz Norte – Comodoro, close to the PAT-NEC section). This overload is not critical because it can be easily resolved during the redispatching of thermal generation, reducing production in PAT and increasing it in NEC, with a very low cost.

Table 60 - Main overloaded lines - replacement of some new PV with new wind

BUS 1	BUS 2	TOTAL [h/Year]
CHN.RDI	RDA.CHN	1,649
SCN_500	COMODORO	1,098
CHN.JUN	JUNIN	525
RECREO	REC.MALV	423

Figure 54 provides the visual summary of the production and the energy exchanges in the different areas of the Argentinian system. With respect to the optimal scenario, the different generation mix shifted towards the wind production and a more even distribution of the lower VRES curtailments can be observed.

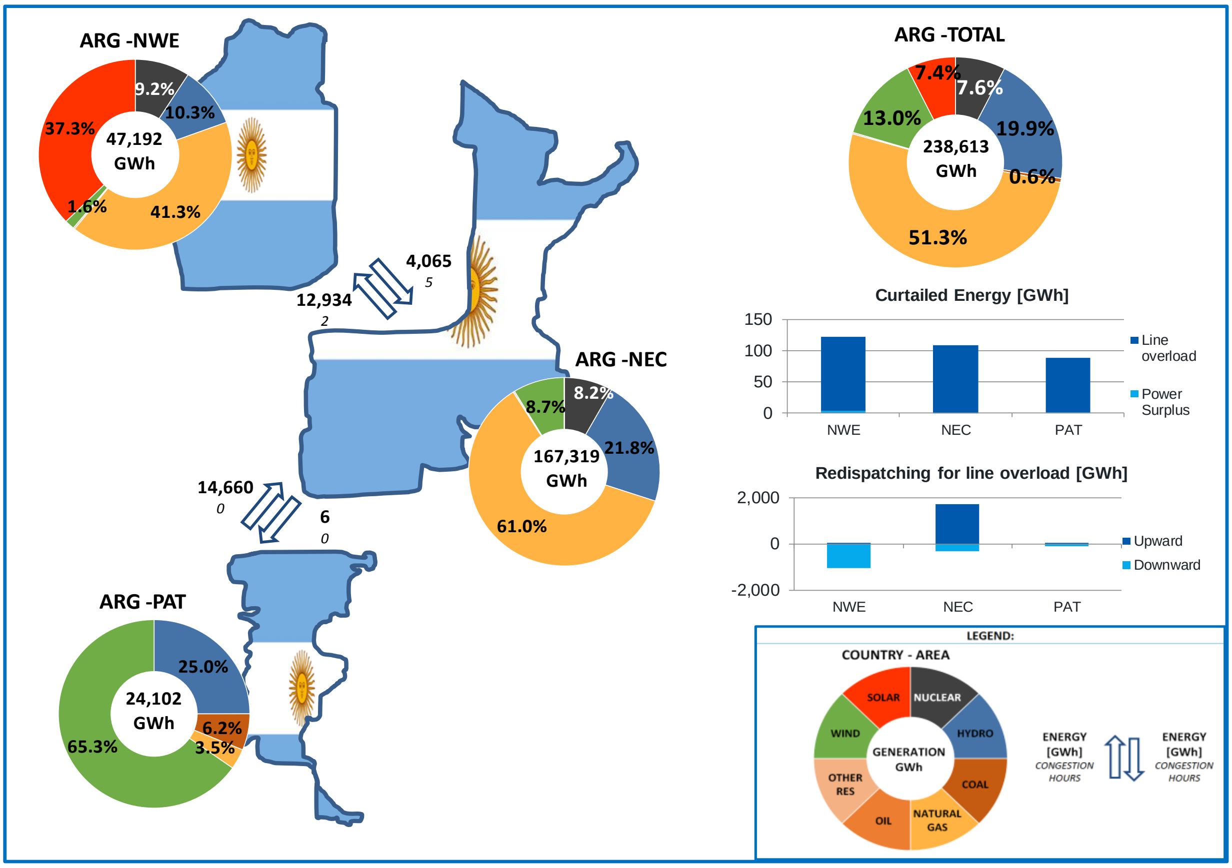


Figure 54 - Total production and energy exchanges – Argentinian scenario with replacement of some PV power plants in NWE with equivalent investment in wind power plants in other areas

Finally, the following table summarizes the total benefit evaluated respect to the optimal scenario. No information are provided about the costs for the plants because the substitution of PV power plants with wind power plants has been defined assuming the same annuity of the investment, without difference in the calculation of the benefits.

Table 61 - Total benefit (respect optimal scenario) - replacement of some new PV with new wind

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-236	+28
RES CURTAILMENT	-415	-
TOTAL EENS	0	+1
TOTAL BENEFIT	**-**	**+29**

It can be observed that this scenario can bring additional benefits to the system thanks to the reduction of the redispatching costs.
It means that with respect to the optimal scenario defined in paragraph 3.4.1.2, a reduction of the network congestions with a slightly different mix of PV and Wind plants, might improve a bit more the overall benefits for the system without additional costs.

3.4.1.5 Relocation of some new PV power plants from NWE to NEC

The decision to ***move some of the new PV plants*** from NWE to NEC in order to reduce overloads on the lines belonging to the NWE-NEC section brings the following results:

- ***EENS*** does not change significantly
- ***Total generation costs*** reduce by 11 M$, resulting from a higher cost to cover the energy not produced by PV due to lower solar irradiation in the new area and a big saving of costs needed to solve network congestions.
- Notwithstanding the fact that the solar irradiation is lower for the relocated PV plants, the ***overall PV generation*** is reduced only by 68 GWh, because the curtailments are also reduced considerably. The net production after redispatching is a bit higher than 19200 GWh.
- ***Wind power*** production also remains constant.
- ***Expected overloads*** are reduced for the Recreo – Malvinas line, while the Diamante - Charlone – Junin one remains in a similar condition. This is due to the selection of the location of the removed and inserted PV plants but also to a lower sensitivity of the nodes.
- ***Energy exchanges*** for PAT to NEC keep constant, while from NWE to NEC reduce, with a the difference of net balance respect to optimal scenario is nearly 1400 GWh.

Starting from the results of the scenario with the optimal economic amount of additional VRES, this further scenario has been analysed in order to evaluate the benefits related to a relocation of the defined RES power plants which have the highest impact on the network constraints.
In particular, the PV plants injecting power in Lavalle, Catamarca and Santiago (nodes belonging to NWE area among the ones with highest impact on the power flow through the Recreo – Malvinas line) are moved to Chaco, Resistencia and Grand Formosa (nodes belonging to NEC area). The total installed PV power transferred from NWE to NEC is about 830 MW. During this analysis, the possible difference in the production has been considered, reducing the expected production profile to consider a lower available irradiation in the new nodes.

The impact on EENS of this relocation is negligible as the total EENS remains almost the same, with an expected reduction of nearly 1%.

The following table reports the total annual production and the thermal costs.
Respect to scenario with optimal economic amount of additional VRES, the cost of the initial dispatching is higher, because some thermal generation must replace the missing PV production in this scenario due to the lower irradiation of the new locations. On the contrary, a lower amount of energy must be redispatched, reducing from 2295 GWh/year to 1783 GWh/year. Considering these opposite effects, the overall savings in fuel costs for the thermal production can be estimated in around 10 M$/year.

Table 62 - Total production and fuel costs - relocation some new PV power plants from NWE to NEC

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	166,818	6,552	0	-472	1,747	90
NWE	48,363	1,587	4	-1,194	14	-41
PAT	23,197	134	2	-117	22	-2
TOTAL	**238,378**	**8,273**	**6**	**-1,783**	**1,783**	**47**

In the following table results in term of PV generation are presented; then Table 64 shows the differences respect to optimal scenario. As expected PV production is reduced in NWE and increases in NEC because of the relocation of about 830 MW of new PV from NWE to NEC. The energy curtailed after redispatching phase reduces to approximately 70 GWh/year from the 440 GWh/year that has been found in scenario with optimal economic amount of additional VRES.
It is worth highlighting that there is a reduction in the equivalent operating hours even if the curtailed energy is reduced: the explanation is that the producibility in NEC is lower than the one in NWE.
The reduction of the PV production because of the lower irradiation in the new nodes in absolute terms is not much higher than the reduction of the curtailed energy, so in some way the effect of this relocation does not change significantly the total energy produced by PV power plants.

Table 63 - Total production of PV plants - relocation some new PV power plants from NWE to NEC

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	1,613	0	-9	0	1,896
NWE	17,662	4	-62	0	2,442
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**19,275**	**4**	**-71**	**0**	**2,384**

Table 64 - Difference of total production of PV plants respect to reference scenario

DIFFERENCE RESPECT TO OPTIMAL SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	1,570	0	-1	0	-93
NWE	-2,028	-4	373	0	46
PAT	0	0	0	0	-
TOTAL PHOTOV. GENER.	**-458**	**-4**	**372**	**0**	**-11**

Wind production is not affected significantly in this scenario, and it can be considered to be the same as in the optimal one.

Table 65 shows energy exchanged among the areas and the saturation of interconnections.
Respect to scenario with optimal economic amount of additional VRES, power flow from NWE and NEC decreases (due to the different location of RES generation). The loading of interconnections is the following:

- from PAT to NEC: 37%; from NEC to PAT: 0%
- from NEC to NWE: 34%; from NWE to NEC: 10%.

It is also possible to note that in this new configuration the power flows across the section NWE-NEC does not reach the NTC limit.

Table 65 - Interconnection - relocation some new PV power plants from NWE to NEC

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
PAT	**NEC**	4,250	4,250	13,855	7	13,747	7	0	0
NEC	**NWE**	4,300	4,300	12,712	5,020	12,798	3,926	2	3

This scenario shows the main overloads reported in the Table 66, ordered from the greatest to the smallest. With respect to the optimal scenario, the overload on the line Recreo-Malvinas is strongly reduced while the others do not change significantly.

Table 66 - Main overloaded lines - relocation some new PV power plants from NWE to NEC

BUS 1	BUS 2	TOTAL [h/Year]
CHN.RDI	**RDA.CHN**	1,666
SCN_500	**COMODORO**	759
RECREO	**REC.MALV**	697
CHN.JUN	**JUNIN**	553
MALVINAS.RE	**REC.MALV**	184

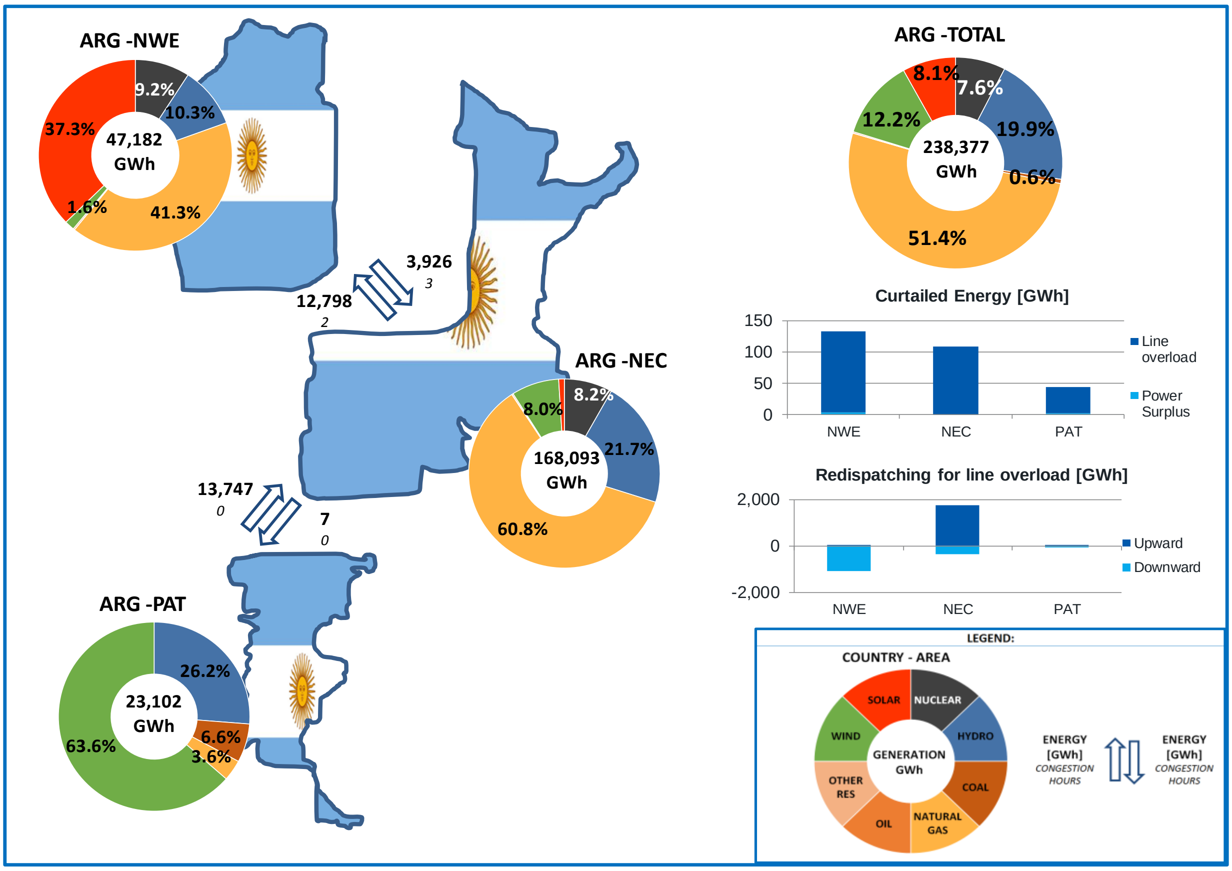


Figure 55 - Total production and energy exchanges – Argentinian scenario with relocation of some PV power plants from NWE to NEC

As already done for the previous sensitivities, a table that summarizes the main benefits (respect to the optimal scenario) is shown.

Table 67 - Total benefit (respect to the optimal scenario) - relocation some new PV power plants from NWE to NEC

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-25	+11
RES CURTAILMENT	-406	-
TOTAL EENS	0	0
TOTAL BENEFIT	-	+11

The information about the investments are not included as only a relocation of the same amount of PV plants has been considered.
Benefits mainly come from the reduction of costs related to redispatching activities to solve overloads.

3.4.1.6 Final considerations on Argentinian isolated system

Following the optimal solution for additional VRES installations defined in 3.4.1.2, different analysis have been performed on the Argentinian system to assess possible solutions of the network congestions close to the NWE-NEC section. They can be considered as the research of a further optimal solution around the one defined in paragraph 3.4.1.2, which determined the best mix of VRES power plants to be installed in the system. The presence of some overloads causes some additional costs for the redispatching, and solutions which might avoid or reduce them can become preferable.

The highest savings can be obtained removing the constraints thanks to improvements of the transmission capacity of the critical lines, but these actions required investments and costs which might be considerable and must be taken into account in the evaluation of the overall benefits for the system. Lower savings can be obtained with a slightly different mix of PV and wind power plants or with different location of the plants, which can reduce the total thermal generation costs. The advantage in this case is the fact that these actions can be considered “cost-free”, and the savings in the fuel cost can become a net benefit for the system.

These solutions must be analyzed and compared during the detailed planning of the system (network and generation), which must consider actual opportunities and constraints in terms of project development.

Real development of projects, especially when a huge quantity of new installations is expected, has in fact some specific requirements, such as availability of terrains with good primary energy resource, permissions and the possibility to get connection to the electrical network. These issues make the actual project development more detailed and “localized” with respect to the general trends depicted in the current study. From this circumstance, some new opportunities or constraints might appear, and the detailed system planning must take them in to account to find the best particular solutions.

3.4.2 Chile

In this paragraph the main results as regard Chile Reference scenario and scenario with optimal economic amount of additional VRES are presented.

3.4.2.1 Reference scenario

The simulation of the Reference scenario shows

- ***Good adequacy*** of the analysed system, with EENS due to lack of power or line overload around 0.5 GWh, equal to around 4×10^{-6} of the total load
- ***Overall generation costs*** are a bit higher than 3,150 M$, with very limited costs related to redispatching to solve network congestions. The average cost of generation is 26.8 $/MWh[13]
- Expected ***generation by PV*** power plants around 10,470 GWh (equivalent to about 2,480 EOH) and nearly no curtailments
- Expected ***generation by wind*** power plants close to 9,750 GWh (equivalent to about 2,450 EOH) and nearly no curtailments
- Only few cases show the need to reduce the VRES production due to overgeneration in low load cases
- No lines are significantly expected to be overloaded before redispatching
- The NTC of section between SIC and SING is reached for about 275 h from SING to SIC and only 11 hours from SIC to SING

The detailed results obtained simulating the operation of the Chilean system in the Reference scenario are presented.

The following table shows the EENS divided for area and reason. The system has a good generation adequacy. EENS is equally distributed among SIC and SING (taking into account the different load). EENS in SING is mainly due to line overload while the main reason of EENS in SIC is lack of power.

Table 68 - Expected Energy Not Supplied - Chilean Reference scenario

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL SIC	183	94	94	371
TOTAL SING	10	112	0	122
TOTAL	**193**	**206**	**94**	**493**

In Table 69 the total energy produced in each area and the related costs are shown. The cost is associated only with the thermal production. The cost of all thermal generator is 3,156 M$. A very limited need of redispatching to solve overloads can be observed because no lines are significantly expected to be overloaded. Only few ones have an expectation to be overloaded 30 hours per year or less.

[13] This value does not represent the average price at which the energy is sold. See also footnote [11] at pg. 79.

Table 69 - Total production and fuel costs - Chilean Reference scenario

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
TOTAL SIC	83,908	1,783	0	-10	14	1
TOTAL SING	33,829	1,373	0	-6	1	0
TOTAL	**117,737**	**3,156**	**0**	**-16**	**15**	**1**

The following tables show the results of the Reference scenario for the Wind and PV production. PV installed power plants (4,220 MW) produce 10,470 MWh of energy – mainly produced in SIC area. Wind farms (3,990 MW) produce 9,747 MWh, also in this case mainly generated in SIC area. It can be underlined that for both PV and wind the equivalent operating hours are approximately 2,400/2,500.
No significant need of VRES production curtailments is required.

Table 70 - Total production of PV plants - Chilean Reference scenario

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
TOTAL SIC	9,305	0	0	0	2,460
TOTAL SING	1,165	0	0	0	2,642
TOTAL PHOTOV. GENER.	**10,470**	**0**	**0**	**0**	**2,479**

Table 71 - Total production of Wind plants - Chilean Reference scenario

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
TOTAL SIC	8,317	0	0	0	2,407
TOTAL SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**9,747**	**0**	**0**	**0**	**2,443**

Table 72 sums up the information about the interconnection between SIC and SING.
The energy that annually flows from SING to SIC is 5,180 GWh, corresponding to a loading factor of 39%. The loading factor northward is only 5%.

Table 72 - Interconnections - Chilean Reference scenario

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	5,180	618	5,176	618	278	11

Figure 56 provides a visual summary of the generation mix and the energy exchanges in the areas of the Chilean system.

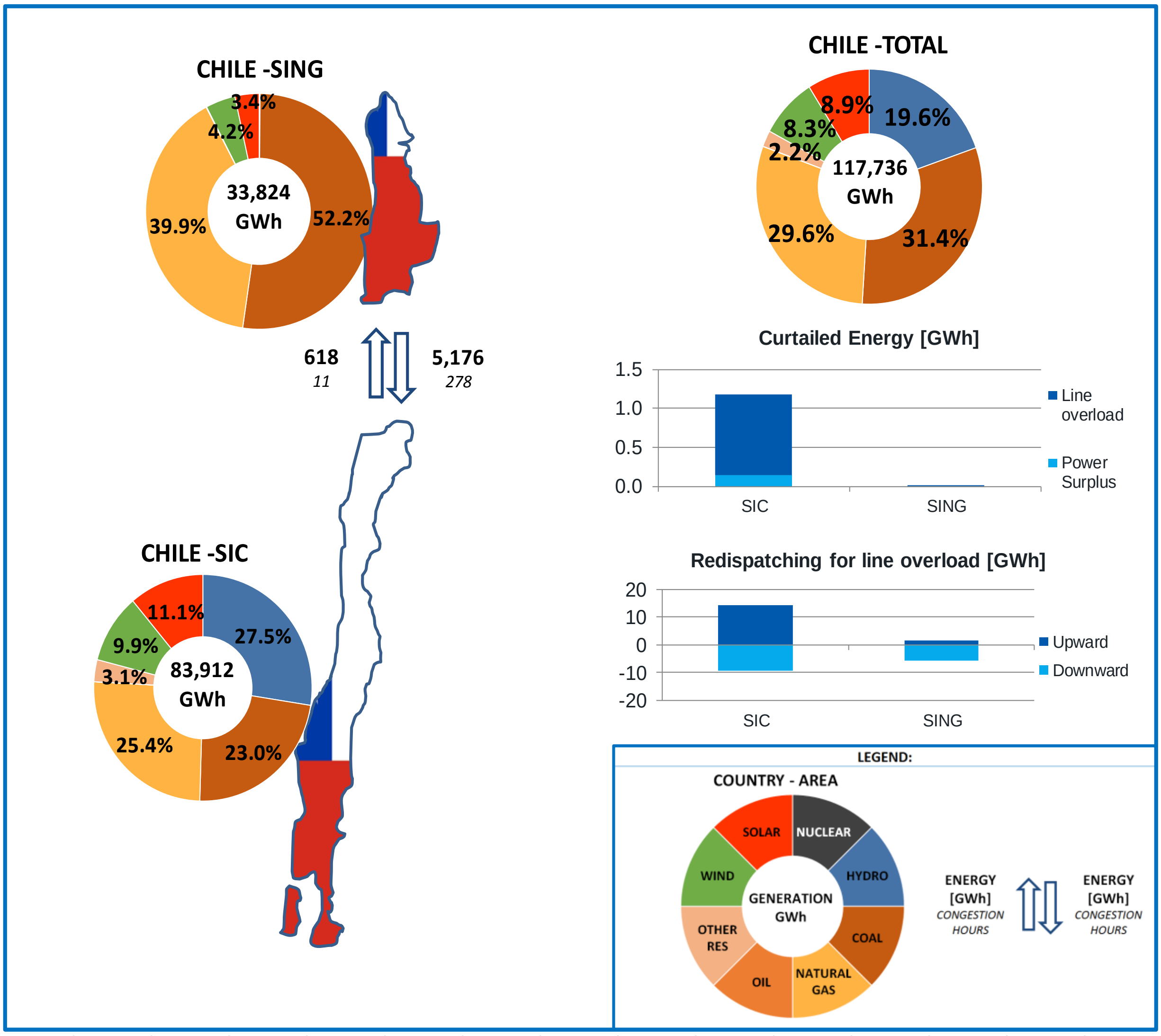


Figure 56 - Total production and energy exchanges – Chilean Reference scenario

3.4.2.2 Scenario with optimal economic amount of additional VRES

At the end of the computational process depicted in Figure 43, ***the optimal amount of additional VRES*** with respect to the installed power already considered in the reference scenarios is about 170 MW of PV and 30 MW of wind power plants.

The ***expected LCOE*** for PV is 27.3 $/MWh, while for wind 68.4 $/MWh. The gap is mainly due to the difference in installation and operational costs: the annuity of the investment in PV plants is lower than half of the relevant one for wind plants.

For this reason the amount of additional VRES is highly shifted towards PV plants.

By the target year 2030 the installation of 4,400 MW PV and about 4,000 MW wind, for a total VRES installed power equal to 8,400 MW, turns out to be technical and economic feasible. The amount of installed power considered divided by area is reported in the following table.

Table 73 - Total VRES installed power in the Scenario with optimal economic amount [MW]

AREA	PV installed power	Wind installed power
SIC	3,917	3,486
SING	475	535

It is worth underlining that these values are close to the ones of the Reference scenario because at the end of the Chapter 2 it was found out that it is possible to install only 200 MW additional VRES due to system constraints under the BAT scenario assumptions. As the transmission network and the rest of the generation fleet is the same considered in the Reference scenario, similar results have to be expected. They are listed below:

- The ***EENS*** due to lack of power or line overload remains around 0.5 GWh
- ***Overall generation costs*** decrease to 3,132 M$ because part of the thermal generation is replaced by the new VRES plants. No significant variation of the costs related to network congestions. The average cost of generation is 26.6 $/MWh[14]
- Expected ***generation by PV*** power plants increases up to 10,890 GWh, the EOH remains 2,480h and nearly no curtailments
- Expected ***generation by wind*** power plants close to 9,820 GWh (equivalent to about 2,450 EOH) nearly no curtailments
- ***VRES curtailments*** due to overgeneration do not change with respect to the Reference scenario
- There is a slight increase of the ***energy exchanges*** from SIC to SING

The analysis performed following the procedure described in Figure 43 provides an optimal amount of additional VRES installations in Chile equal to about 170 MW in PV and 30 MW in wind power plants.

The numbers are limited due to the system constraints considered during the calculation of the upper bond limit for VRES installed power (see par. 2.3.2). this amount is not high enough to replace some of the new CCGTs needed to meet peak and load increase. During the evaluation of the benefits this issue should be anyway kept in mind.

[14] This value does not represent the average price at which the energy is sold. See also footnote [11] at pg. 79.

Table 34 provides the detail of the added PV and wind installed power in each area with respect to the Reference scenario and the final resulting values.

Table 74 - Additional and total VRES installed power in the Scenario with optimal economic amount [MW]

AREA	PV installed power		Wind installed power	
	Added to reference scenario	Total	Added to reference scenario	Total
SING	34	441	0	535
SIC	135	3,782	31	3,455

The results of the simulation of one year of operation of the system with this new amount of VRES installed power are shown in detail below.

In general it can be stated that the installation of additional 165 MW of PV and 35 MW of wind power plants with respect to the Reference scenario does not modify the operation of the system and the power flows significantly.

The addition of the new VRES power plants makes available some new power which can contribute to the reduction of the EENS due to lack of power, especially in the SIC system. In fact, the results of the simulations show a slight decrease of this value (around -20 MWh/year, 10%) with respect to the Reference scenario.

In the following table the total energy produced in each area and the related costs are shown. As expected, there is a reduction in the thermal production costs thanks to the additional renewable production which replaces the energy produced by thermal power plants. The total saving is about 25 M$, which is anyway lower that 1% of the total costs.

A very slight increase of the redispatched energy can be observed, caused by the presence of higher amount of VRES.

Table 75 - Total production and fuel costs - Chilean optimal scenario

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
SIC	83,997	1,766	0	-12	17	1
SING	33,748	1,365	0	-6	1	0
TOTAL	**117,745**	**3,131**	**0**	**-18**	**18**	**1**

The following tables show the results in term of PV and wind produced energy and the differences respect to optimal scenario results. PV production increases by 420 GWh/year that corresponds to a growth of about 4%. The small additional wind installation brings to 70 GWh/year more than the Reference scenario (a growth less than 1%). No curtailments are expected to solve the limited network congestions.

Table 76 - Total production of PV plants - Chilean optimal scenario

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
SIC	9,637	0	0	0	2,460
SING	1,254	0	0	0	2,642
TOTAL PHOTOV. GENER.	**10,891**	**0**	**0**	**0**	**2,480**

Table 77 - Difference of total production of PV plants between Chilean optimal scenario and the Reference one

DIFFERENCE RESPECT REFERENCE SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
SIC	332	0	0	0	0
SING	89	0	0	0	0
TOTAL PHOTOV. GENER.	**421**	**0**	**0**	**0**	**1**

Table 78 - Total production of Wind plants - Chilean optimal scenario

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
SIC	8,390	0	0	0	2,407
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**9,820**	**0**	**0**	**0**	**2,442**

Table 79 - Difference of total production of Wind plants between Chilean optimal scenario and the Reference one

DIFFERENCE RESPECT TO REFERENCE SCENARIO					
WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
SIC	73	0	0	0	0
SING	0	0	0	0	0
TOTAL WIND GENER.	**73**	**0**	**0**	**0**	**-1**

Table 80 sums up the information regarding the SIC - SING interconnection. Differences with respect to Reference scenario are negligible.

Table 80 - Interconnections - Chilean optimal scenario

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	5,131	647	5,127	648	278	13

Also for this scenario, a visual summary of the generation mix and the energy exchanges in the areas of the Chilean system is provided (Figure 57). As explained, no significant changes with respect to the Reference scenario can be observed.

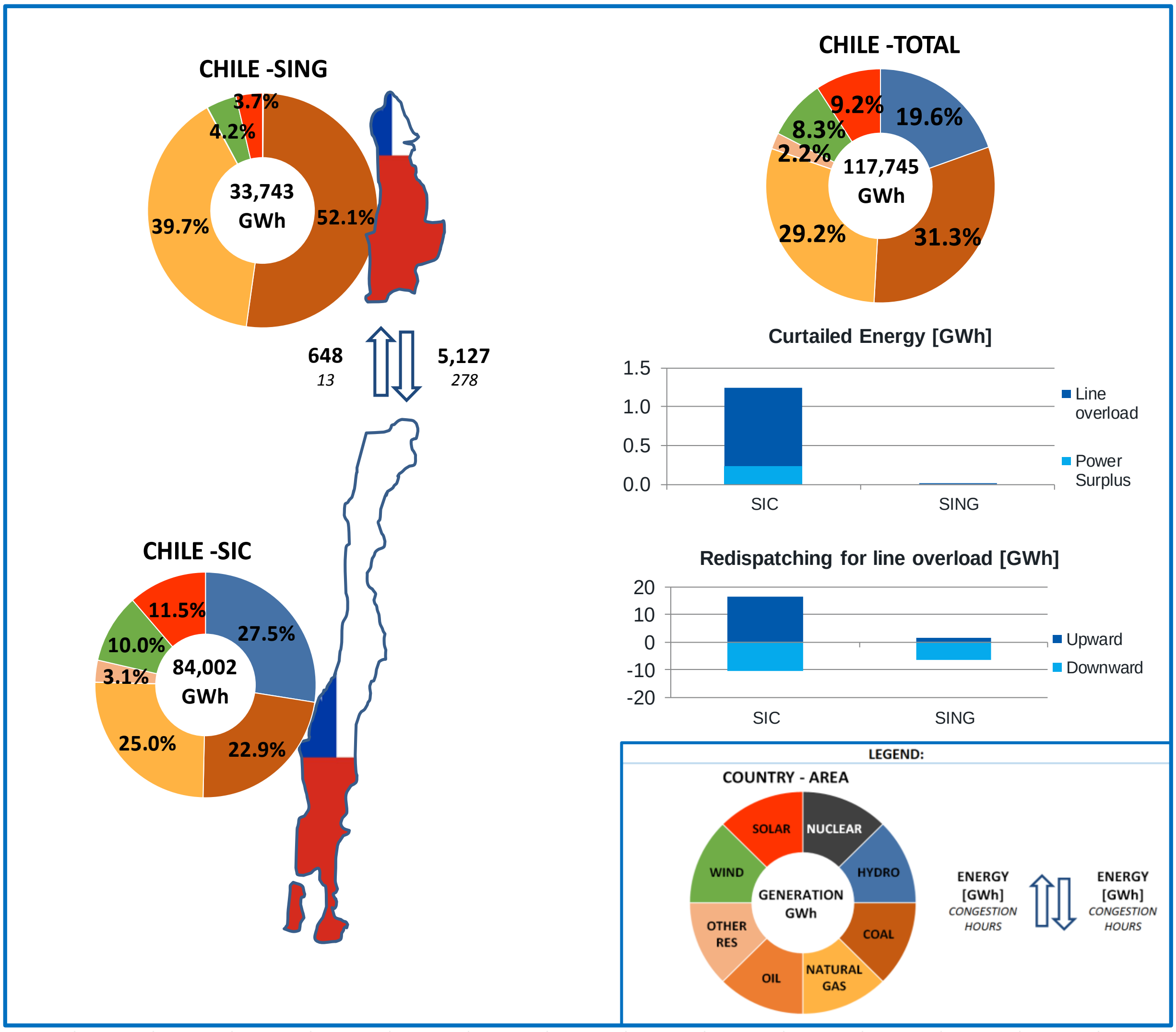


Figure 57 - Total production and energy exchanges – Chilean scenario with optimal amount of additional VRES

The analysis of the results obtained by the simulation of the operation of the system with the additional 200 MW of VRES power plants is completed with a table that summarizes the total benefit evaluated respect to Reference scenario, so expressed as a difference between optimal scenario and the reference one.

As for the Argentinian case, the table shows the difference of the installed VRES power and the variation of CCGT power (equal to 0 MW in this case). Moreover, the table reports the main differences in terms of:

- total thermal generation variation, already considering the needed redispatching
- RES curtailment variation;
- EENS variation.

These values are expressed in GWh/year.

For each of the previous information, economic benefits are presented.

Benefit has been evaluated for each MW of additional VRES too.

Table 81 - Total benefit (respect to reference scenario) - Chilean optimal scenario

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	200	-17
NEW CCGT AVOIDED	0	0
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-485	+25
RES CURTAILMENT	0	-
TOTAL EENS	0	0
TOTAL BENEFIT	-	+8

BENEFIT/MW VRES [kUSD/year]	+42

The benefits are mainly related to the reduction of the thermal costs, which is higher, in absolute value, than the annuity of the costs of the additional VRES plants.

Finally, based on the results presented above, it is possible to calculate the expected LCOE for the PV and wind power plants in Chile.

Considering the CAPEX and OPEX reported in Table 10, the resulting values are:

- LCOE for PV power plants: 27.3 $/MWh
- LCOE for wind power plants: 68.4 $/MWh

In this case, contrary to what happened for the Argentinian case, there is a big difference between the LCOE of the two technologies. The reasons are mainly two:

- LCOE for PV plants is very low due to the lower assumption on CAPEX and to the availability of the highest solar irradiation

- LCOE for wind is higher because of the lower availability of wind resource in Chile compared to the conditions available in Patagonia and on the costs of the central region in Argentina. In the regions considered in the study, Chile is characterized by the presence of some specific locations with high potential, but an average producibility not as high as the one available in Argentina, causing the increase of the specific cost per produced MWh

Figure 58 show the results of the sensitivities performed to assess the variation of the LCOE depending on CAPEX and interest rate. It can be seen that PV remains in any case more competitive than wind.

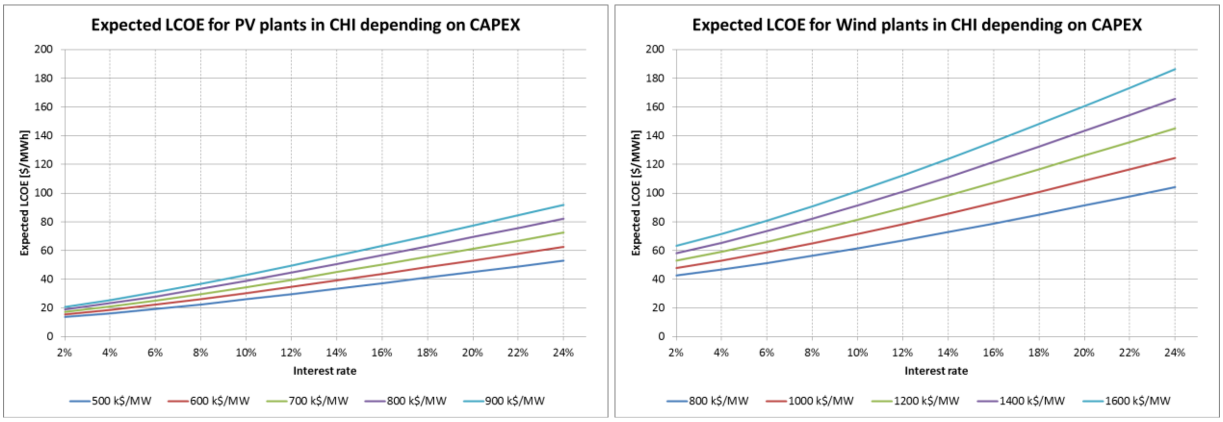


Figure 58 - Expected LCOE variations in Chile depending on CAPEX and interest rate

3.4.2.3 Final considerations on Chilean isolated system

Some important improvements of the Chilean generation fleet and transmission system foreseen at 2030 have been deemed necessary to carry out the required analysis, in order to mitigate the risk of Lack of Power and the overloads in the system which are not caused by the introduction of the additional VRES power plants that are the focus of this study.

Once the Reference scenario has been adjusted to allow the execution of the calculations focusing on the impact of the penetration of additional PV and wind plants, the analysis performed on the Chilean isolated system showed that it is able to absorb the additional optimal amount of VRES power plants defined in 3.4.2.2.

No main variations can be noted in the system operation when the optimal amount of new VRES generation is introduced.

Thanks to very low CAPEX and high producibility, PV plants can provide high benefits to the system.

However, it is important to underline that when real projects are developed and executed, some specific opportunities and constraints may arise, which can modify the assumptions on the needed investments. In particular, the difficulty to get connections to the transmission network might increase the cost of the projects.

3.4.3 Interconnected countries

Following the analysis of the Argentinian and Chilean systems considered as isolated, in which the optimal economic amount of VRES power plants that each country individually can accept without jeopardizing the security of the power system has been evaluated, in this paragraph the results of the analysis of the two systems interconnected are presented.

The evaluation of the operation of the two systems together and the assessment of the benefits that an additional amount of VRES plants can bring to the whole system is carried out starting from the configurations obtained at the end of the analysis of the isolated systems, i.e. including the VRES plants resulting at the end of the previous optimizations.

At first, a new simulation of the two systems not interconnected is carried out, to become the reference for the assessment presented in this paragraph. This new run, which replicates the two conditions evaluated in paragraphs 3.4.1.2 and 3.4.2.2 in one single case, is necessary because of the simulation method, which, based on Montecarlo approach, analyses thousands of different configuration of the system extracted randomly according their likelihood to happen. When the configuration of the system changes (from two single countries to one single scenario), new sets of system configurations are extracted, and small differences can appear with respect to the ones utilized during the analysis of the isolated cases. For this reason, a new reference scenario is necessary, which contains both the systems and that can become the starting point for the comparison when the interconnections are introduced, ensuring that the results obtained for the scenarios with the interconnections are based exactly on the same sets of configurations used as reference. Because of the change of the system conditions considered during the probabilistic analysis, this new simulation can show some minor variations with respect to the results presented for the single isolated countries. However, a very good alignment can be seen between the results presented at the end of the analysis of the isolated countries and the ones presented in this first simulation of the countries together, and this confirms that the analysis presented in advance had reached a good level of convergence.

Once the new reference scenario with the two isolated countries is ready, a simulation to assess the effects of the interconnection and the possibility to exchange energy between the countries is run: the operation of the two systems together, with exactly the same generation fleet, is evaluated to quantify the amount of energy flowing through the interconnections and the possible fuel costs savings.

Finally, the simulation with the additional VRES power plants, which becomes acceptable by the systems thanks to the interconnection, is performed, and the benefits provided by the new plants are also assessed.

3.4.3.1 Reference scenario (Argentina and Chile together without interconnection)

A new Reference scenario has been analysed including both the Argentinian and the Chilean systems, without considering any interconnection between the countries. As regard PV and wind installed power, the values established in the previous simulations, corresponding to the optimal amount of VRES installations, have been considered. The installed capacity in the different areas is reported in the following table.

Table 82 - Total VRES installed capacity in Reference scenario for the two countries together [MW]

AREA	PV installed power	Wind installed power
NEC	18	3,467
NWE	8,034	302
PAT	0	3,191
SIC	3,917	3,486
SING	475	535

The simulation of this scenario, which becomes the reference for the evaluation of the benefits introduced by the interconnection, shows results in line with the sum of the results obtained for the two isolated countries independently:

- ***EENS*** is around 4.1 GWh; it is about $1.2x10^{-5}$ of the total load
- ***Overall generation costs*** are close to 11,450 M$; of which 70 M$ due to presence of network congestions. The average cost of generation is 32.1 $/MWh
- Expected ***generation by PV*** power plants around 30,200 GWh (2,426 EOH) considering a curtailment of 426 GWh, corresponding to less than 1.5% of the total PV production
- Expected ***generation by wind*** power plants close to 38,800 GWh (about 3,529 EOH) and a curtailment of 51 GWh, corresponding to 0.1% of the total PV production
- The NTC of section between SING and SIC is reached for about 270 h from SING to SIC and only 11 hours from SIC to SING. The interconnection PAT – NEC is saturated for about 60 h in the direction from PAT to NEC while the saturation hours from NWE to NEC are around 120 h.

These values become the reference for the quantitative evaluation of the benefits generated by the interconnection between the countries.

The detailed results of the simulations of Argentinian and Chilean systems together but not interconnected are reported below. The system configuration and the generation fleet are the ones resulting from the evaluation of the optimal amount of additional VRES carried out on the isolated countries (par. 3.4.1.2 and 3.4.2.2).
Results are aligned with the ones obtained with the simulations of single countries, but some small differences can appear due to different probabilistic simulations applied to both countries together. The new Reference scenario for the evaluation of the benefits resulting from the interconnection is then briefly presented.

The following table shows the EENS, expressed as MWh/year, split by area and reason. The greatest part of EENS is concentrated in Argentina, in NWE area, and it is mainly due to lack of interconnection. This lack of interconnection mostly correspond to the lack of power found in the simulations of the single country, which are now counted as interconnection problems because some power would be available in the other country if there were an interconnection available. Line overloads that are not solved after redispatching produces 545 MWh/year of EENS, mainly concentrated in NEC (Argentina).

Table 83 - Expected Energy Not Supplied – Interconnected countries Reference scenario (NTC=0)

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	9	342	2	353
TOTAL NWE	135	44	3,164	3,343
TOTAL PAT	0	0	0	0
TOTAL SIC	4	102	256	362
TOTAL SING	0	57	10	67
TOTAL	**148**	**545**	**3,432**	**4,125**

Table 84 shows the total energy produced in each area and the related costs. These costs are only due to thermal power plants. In reference scenario overall generation costs including redispatching are around 11,450 M$/year in the entire system (Argentina and Chile).

Table 84 - Total production and fuel costs - Interconnected countries Reference scenario (NTC=0)

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	165,023	6,538	0	-293	1,961	113
NWE	50,258	1,580	7	-1,686	132	-41
PAT	23,197	134	2	-134	21	-3
SIC	84,025	1,768	0	-18	26	1
SING	33,721	1,364	0	-10	2	0
TOTAL	**356,224**	**11,384**	**9**	**-2,141**	**2,142**	**70**

The following table shows PV generation before redispatching and PV curtailments after redispatching for each area of the system. Total production is around 30,200 GWh/year; 65% of the production is concentrated in Argentina while the remaining part is produced in Chile. Considering that the total installed capacity is 8 GW in Argentina (mainly in NWE) and 4.4 in Chile (mainly in SIC), the equivalent operating hours similar in the two countries. The energy curtailed after the redispatching phase is 426 GWh/year that is less than 1.5% of total production, concentrated in NWE as expected.

Table 85 - Total production of PV plants - Interconnected countries Reference scenario (NTC=0)

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-7	0	2,045
NWE	19,692	7	-418	0	2,398
PAT	0	0	0	0	-
SIC	9,639	0	-1	0	2,461
SING	1,253	0	0	0	2,640
TOTAL PHOTOV. GENER.	**30,627**	**7**	**-426**	**0**	**2,426**

As regard wind generation, total production is around 38,800 GWh/year, as illustrated in Table 86. The production is mainly concentrated in Argentina (75%) where it is almost equally divided between NEC and PAT. The energy curtailed after redispatching phase is negligible (only 51 GWh/year that is less than 0.5% of total production).

Table 86 - Total production of Wind plants - Interconnected countries reference scenario (NTC=0)

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	13,526	0	-6	0	3,899
NWE	773	0	-35	0	2,445
PAT	14,685	2	-10	0	4,599
SIC	8,389	0	0	0	2,407
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**38,803**	**2**	**-51**	**0**	**3,529**

As shown in Table 87, there are no exchanges between Argentina and Chile (SIC-NWE, SING-NWE) as expected (Reference scenario has been modelled without any interconnection between these countries). In Argentina power flow is mainly from PAT to NEC and from NEC to NWE. The saturation of the interconnections is negligible (61 hours/year from PAT to NEC and 122 hours/year from NWE to NEC). The loading of interconnections, evaluated as energy/limit is the following:

- from PAT to NEC: 40%; from NEC to PAT: 0%
- from NEC to NWE: 33%; from NWE to NEC: 14%.

As regard Chile, main power flow is from SING to SIC: the annual energy that flows from SING to SIC is 5,180 MWh, corresponding to a loading factor of 39%. The loading factor northward is only 5%.

Table 87 - Interconnections - Interconnected countries reference scenario (NTC=0)

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	5,111	654	5,104	655	273	13
PAT	NEC	4,250	4,250	14,860	7	14,945	6	61	0
NEC	NWE	4,300	4,300	12,514	6,664	12,559	5,156	1	122
SIC	NWE	0	0	0	0	0	0	0	0
SING	NWE	0	0	0	0	0	0	0	0

The following figure provides a visual summary of the operation of the Argentinian and Chilean systems in the Reference scenario, highlighting the generation mix per areas, the energy exchanges between areas and the curtailed VRES production and thermal redispatching needed to solve network congestions.

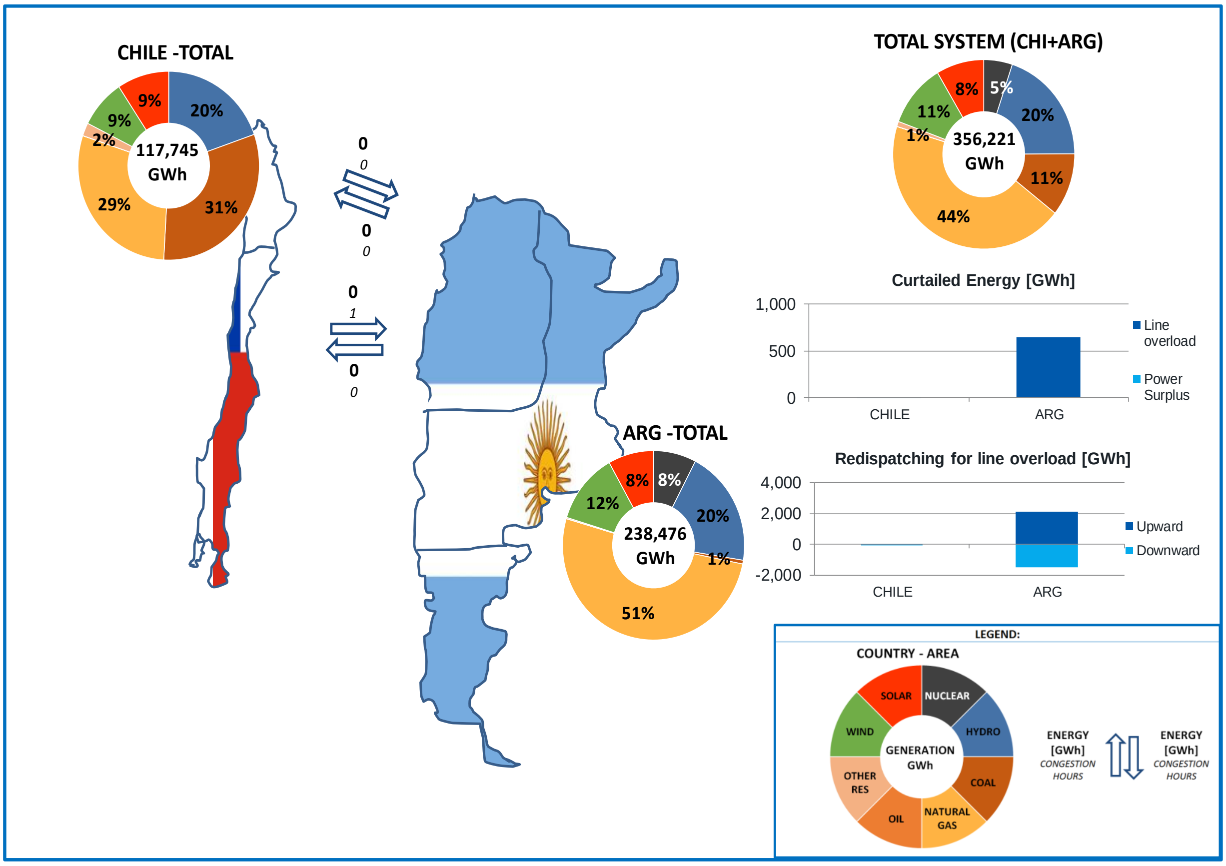


Figure 59 - Total production and energy exchanges – Reference scenario interconnected countries without energy exchanges

3.4.3.2 Scenario with the interconnection (NTC=1,200 MW)

This scenario represents the ***Argentinian and Chilean systems interconnected*** with the possibility to ***exchange up to 1,200 MW*** through the sections SIC - NWE and SING - NWE together.
As regard PV and wind installed power, it is equal to reference scenario.

The presence of the interconnection provides the following main variations with respect to the reference scenario:

- A ***reduction of the EENS*** form more than 4 GWh to 1.2 GWh (-70%). The final EENS corresponds to about 3.5×10^{-6} of the total load
- ***Overall generation costs*** are reduced by more than 35 M$ (-0.3%)
- Expected ***generation by PV*** in line with the Reference scenario; PV curtailment of 88 GWh with a reduction of nearly 350 GWh (-80%) with respect to the Reference scenario
- Expected ***generation by wind*** does not change respect to Reference scenario; wind curtailment remains negligible
- ***Energy exchanges between the countries*** equal to 3.6 TWh from Chile to Argentina and 2.6 TWh form Argentina to Chile.
  As regard the two sections between Argentina and Chile, the section SIC-NWE is quite balanced while power flow on the other section is mainly from SING to NWE. These are the saturation hours during the year:
    - From SIC to NWE: 1,041 h; from NWE to SIC: 978 h.
    - From SING to NWE: 1,292 h; from NWE to SING: 165 h.

  The sections in Argentina e Chile are less saturated respect to Reference scenario.

The presence of the interconnection provides ***benefits for the whole system*** evaluated equal to 43 M$, divided in a quite balanced way between the countries.

In this paragraph, the results of the simulations carried out on the Argentinian and Chilean interconnected systems are presented. The comparison with the outcomes reported in paragraph 3.4.3.1, which describe the key information of the operation of the two systems considered isolated, allows the evaluation of the impact that the possibility to exchange energy between the two countries has on the whole system and the relevant possible benefits.

When the two systems are interconnected, it is necessary to define the maximum power that can be exchanged between them. Based on the information included in [1], a first simulation with a Net Transfer Capacity (NTC) equal to 1,600 MW has been carried out and it turns out that with this limit, that is equal to the sum of the maximum capacity of the two lines connecting the countries, and because of the fact that the distribution of the real power flow determined by the transmission system is not even between the two lines, for many hours the Gran Mendoza – Polpaico line between NWE and SIC is overloaded, requiring a reduction of the exchange.
A lower NTC limit has been then defined, to reduce to less than 10% of the time the situations in which the balance of the two systems must be adjusted to avoid overloads on the interconnection.

The new NTC value considered in the simulations is then 1,200 MW.

The following tables shows the results of the simulations performed on the two interconnected systems with the defined NTC.
A positive impact can be noted concerning EENS, that is reported in Table 88.
Thanks to the interconnection and to the possibility to exchange energy between the countries, the EENS due to lack of power/lack of interconnection reduces nearly by 85% (reaching 600 MWh) compared to the Reference scenario.
On the contrary, EENS due to line overloads that are not solved after thermal generation redispatching has a slight increase (+10%) to about 600 MWh/year, mainly concentrated in NEC (Argentina).

Table 88 - Expected Energy Not Supplied – Scenario with the interconnection (NTC=1,200)

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	20	329	0	349
TOTAL NWE	140	106	431	677
TOTAL PAT	0	3	0	3
TOTAL SIC	7	99	3	109
TOTAL SING	0	58	0	58
TOTAL	**167**	**595**	**434**	**1,196**

Table 89 shows the total energy produced in each area and the related costs.
Total costs slightly reduce because the interconnection makes cheaper generation available from one country to the other and increases the flexibility of the system to solve network congestions. It is worth noting that the overall amount of produced energy increases with respect to the Reference scenario (+255 GWh, corresponding to a bit less than 0.1% of the overall demand) because power flows along greater distances also from one country to the other, and this causes higher system losses.

Table 89 - Total production and fuel costs - Scenario with the interconnection (NTC=1,200)

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	163,331	6,427	0	-195	1,492	82
NWE	50,006	1,557	1	-774	559	6
PAT	23,202	134	1	-107	20	-1
SIC	85,196	1,825	0	-934	233	-15
SING	34,744	1,412	0	-338	45	-10
TOTAL	**356,479**	**11,355**	**2**	**-2,348**	**2,349**	**62**

In Table 90 the results related to PV generation are presented; Table 91 shows the difference of total PV production respect to Reference scenario. Since the total PV installed capacity remains the same, PV production does not change significantly. However, PV curtailments are strongly reduced, since the

1,200 MW interconnection between Chile and Argentina allows to export the energy that was curtailed for overgeneration or overloads in NWE when Argentina was isolated. This allows to save about 340 GWh of PV production, which is more than 1% of the overall PV production. The equivalent operating hours are 2,455 h/year, so there is an increase in the EOH respect reference scenario (almost 30 hours) due to the reduced curtailment.

Table 90 - Total production of PV plants - Scenario with the interconnection (NTC=1,200)

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	0	0	2,443
NWE	19,698	1	-87	0	2,441
PAT	0	0	0	0	-
SIC	9,639	0	-1	0	2,461
SING	1,253	0	0	0	2,640
TOTAL PHOTOV. GENER.	**30,633**	**1**	**-88**	**0**	**2,455**

Table 91 - Difference of total production of PV plants between scenario with the interconnection and the Reference one

DIFFERENCE RESPECT TO REFERENCE (NTC=0) SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	0	0	7	0	398
NWE	6	-6	331	0	43
PAT	0	0	0	0	-
SIC	0	0	0	0	0
SING	0	0	0	0	0
TOTAL PHOTOV. GENER.	**6**	**-6**	**338**	**0**	**29**

In Table 92 wind production results are presented; Table 93 shows the difference of total wind production with respect to the Reference scenario.

The annual wind production does not change since the total wind installed power remains the same. Curtailed energy is lower than in the reference scenario, remaining negligible with respect to the total generation.

Table 92 - Total production of Wind plants - Scenario with the interconnection (NTC=1,200)

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	13,526	0	0	0	3,901
NWE	773	0	-15	0	2,512
PAT	14,687	1	-10	0	4,600
SIC	8,389	0	0	0	2,407
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**38,805**	**1**	**-25**	**0**	**3,531**

Table 93 - Difference of total production of Wind plants between scenario with the interconnection and the Reference one

DIFFERENCE RESPECT TO REFERENCE (NTC=0) SCENARIO					
WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	0	0	6	0	2
NWE	0	0	20	0	67
PAT	2	-1	0	0	1
SIC	0	0	0	0	0
SING	0	0	0	0	0
TOTAL WIND. GENER.	**2**	**-1**	**26**	**0**	**2**

Table 41 gathers information on the energy exchanges across the sections between countries and areas in the interconnected scenario.

The energy exchange between Argentina and Chile, allowed by the interconnection, is significant: in total, more than 6.2 TWh flow between the countries in the two directions. This is mainly related to the usage of the available cheap thermal generation from one country to the other depending on the situations. Looking at the final energy exchanges on the two sections between the countries, the flow on the SIC-NWE is quite balanced while the exchange between SING and NWE is mainly from Chile to Argentina.

The loading of these interconnections is the following:

- from SIC to NWE: 31%; from NWE to SIC: 29%
- from SING to NWE: 46%; from NWE to SING: 11%

Looking at the internal areas and the energy exchanges between them, in Argentina the energy exchange on the section PAT-NEC increases in the direction from PAT to NEC, while on the other cutset, there is a reduction of the export from NEC to NWE even if main power flow remains from NEC to NWE. The loading of these internal interconnections is the following:

- from PAT to NEC: 41%; from NEC to PAT: 0%
- from NEC to NWE: 28%; from NWE to NEC: 14%

As regard Chile, the exchanges from SING to SIC are reduced even if main power flow remains in the same direction (from SING to SIC); the loading factor in this direction is reduced from 39% to 34% while the loading factor northward is only 3%.

Table 94 - Interconnections - Scenario with the interconnection (NTC=1,200)

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year] BEFORE RE-DISPATCHING		ENERGY EXCHANGES [GWh/year] AFTER RE-DISPATCHING		SECTION LIMIT REACHED [h/year]	
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	4,681	357	4,515	330	69	0
PAT	NEC	4,250	4,250	14,991	7	15,247	6	62	0
NEC	NWE	4,300	4,300	10,619	6,414	10,637	5,222	34	92
SIC	NWE	900	900	3,042	2,055	2,448	2,301	1,041	978
SING	NWE	300	300	1337	286	1,197	300	1,292	165

Figure 60 provides a visual summary of the operation of the two interconnected systems.
From the comparison with the Reference scenario (Figure 59), it can be noted that the fact that the two systems are interconnected causes some downward redispatching to move from Argentina to Chile, because the power flow on the congested lines can be reduced also by decreasing the export from Chile.

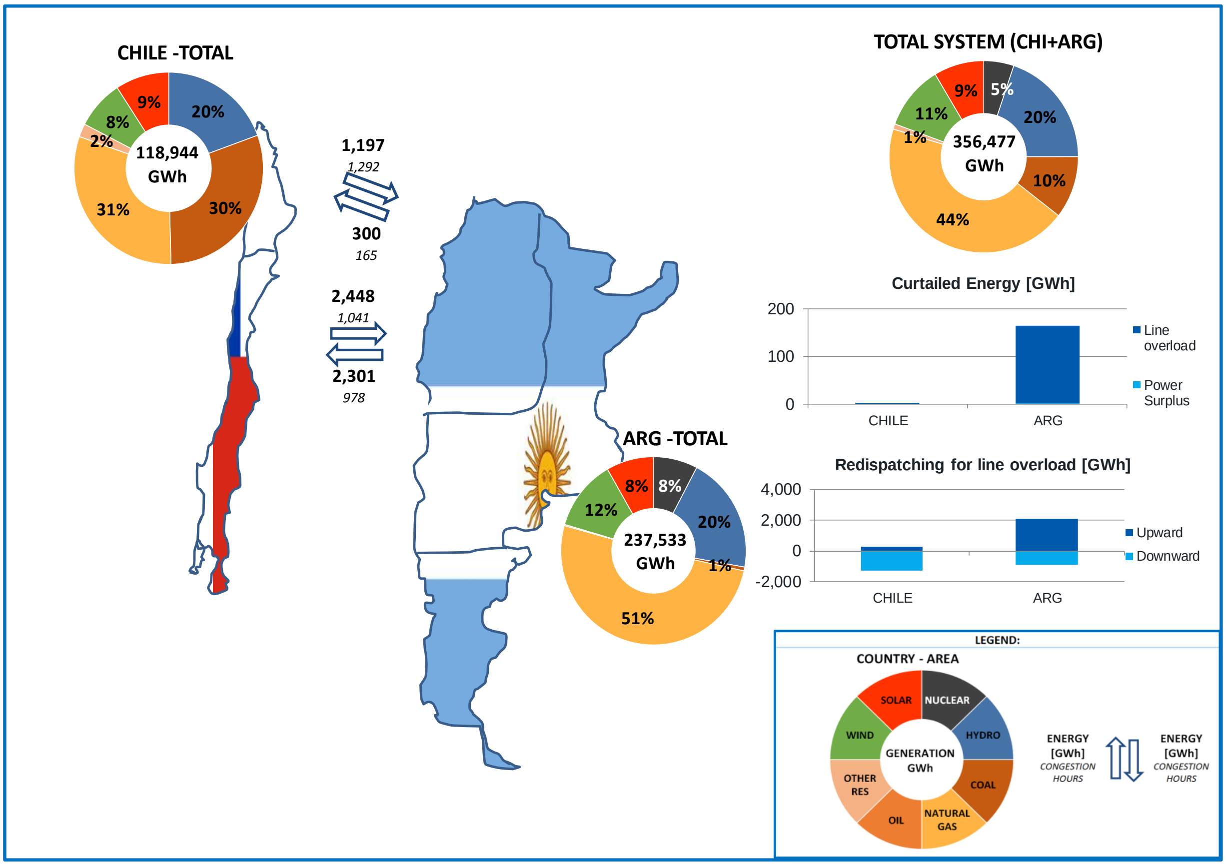


Figure 60 - Total production and energy exchanges – interconnected scenario

Table 95 illustrates the summary of the benefits introduced for the whole systems by the interconnection, not considering the cost of the new line. The savings are equal to 43 M$ and the main advantage is due to the lower generation costs, and a small part is related to the strong reduction of the EENS.

Table 95 - Total benefit (respect to reference scenario) - Scenario with the interconnection (NTC=1200)

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-227	+37
RES CURTAILMENT	-364	-
TOTAL EENS	-3	+6
TOTAL BENEFIT	**-**	**+43**

The reduction of the EENS is mostly concentrated in Argentina, so it is possible to say that the relevant benefit should be allocated mainly to this country.
Concerning the generation costs, in Chile they increase with respect to the reference scenario (+79 M$, equal to 2.5% of the overall costs), due to the fact that the net balance between import and export results in more than 1 TWh exported to Argentina, which corresponds to a higher generation in Chile. For the same reason, in Argentina the generation costs reduce (-116 M$, equal to 1.5% of the overall costs) due to the net import of energy.
Despite the uneven variation of the generation costs, which is principally due to the net energy exchange between the countries, the overall benefits are quite similar and positive for the two systems. It is in fact worth underlining that the good balance of the energy exchanges across the interconnections (3.6 TWh from Chile to Argentina and 2.6 TWh from Argentina to Chile) indicates that both the countries have several conditions in which import energy from the other one and many in which they export energy. When a country imports energy, the energy price is lower than the one that would be present with no interconnection, and this constitutes a benefit for the consumers, which have cheaper energy available. This benefit for the consumers is present and positive in both the systems. Moreover, the fact that some VRES production is not curtailed and can be used in Argentina and Chile thanks to the interconnection, constitutes an additional source of benefit, being energy available with no cost.
It can be concluded then the interconnection introduces a benefit that can be evaluated in 43 M$ per year and that the benefits are positively distributed in both countries. This saving should be compared to the annuity of the investment needed to build and operate the interconnection to evaluate the economic convenience.

3.4.3.3 Scenario with optimal economic amount of additional VRES

The interconnection of the Argentinian and Chilean systems allows the ***introduction of further VRES plants***. A scenario with additional 1,500 MW of VRES per country has been analysed.
850 MW of new dispatchable generators have been replaced (500 MW in Argentina and 350 MW in Chile) by 3,000 MW VRES, divided in 2,170 MW of PV (42% in Argentina and 58% in Chile) and about 830 MW of wind (73% in Argentina and 27% in Chile).
The final total amount of installed power considered divided by area is reported in the following table.

Table 96 - Total VRES installed power in interconnected optimal scenario [MW]

AREA	PV installed power	Wind installed power
NEC	18	3,767
NWE	8,936	302
PAT	0	3,490
SIC	4,932	3,717
SING	729	535

The simulation of the interconnected scenario shows:

- ***EENS*** is around 2.2 GWh that is about $6.5x10^{-6}$ of the total load.
- A sensible ***reduction of the generation costs*** down to 11,060 M$ which include an increase of the redispatching costs by about 20 M$.
- Expected ***generation by PV*** is 35,700 GWh (there is an increase of almost 5,200 GWh/year in the annual production, +17.5%), considering PV curtailment risk equal to 273 GWh, increased with respect to the interconnected scenario but still lower than 1% of the total PV production. Due to the higher curtailments, the LCOE of the additional VRES plants increases in Argentina (45.9 $/MWh vs. 44.3 $/MWh), while remains constant in Chile around 27.3 $/MWh.
- Expected ***generation by wind*** is 42,000 GWh (there is an increase of almost 3,243 GWh/year in the annual production, +8%). Wind curtailments increase but remain negligible. LCOE of the added plants remains in line with previous values, and is equal to 42.1 $/MWh in Argentina and 68.3 $/MWh in Chile.
- Concerning the ***interconnections between Argentina and Chile***, power flow is quite similar to the one of interconnected scenario: the section SIC-NWE is balanced while the exchange on the other section is mainly from SING to NWE.

The ***total benefits for the whole system*** are evaluated equal to 100 M$, thanks to the reduction of fuel costs but mostly to the possibility to avoid the construction of two dispatchable generators. This value can be intended also as the possible loss of benefit in case the growth of VRES power plants penetration in the system will not be as high as required to reach the optimal amount of installed capacity.

A scenario with additional amount VRES has been analysed starting from interconnected one presented in paragraph 3.4.3.2 and introducing VRES power plants which become acceptable for the systems due to the possibility to export the generated power in case of low load and high generation.
The analysis performed in Chapter 2 defined a limit of 3,000 MW of additional plants for the whole system when interconnected, with respect to the optimal values found for the two isolated countries (results have been presented in paragraph 2.3.3). Moreover, in case of a 1,600 MW interconnection, every country was able to accept up to 2,000 MW of new plants.
Since the NTC has been reduced to 1,200 MW to take into account operational limitations, this limit should be reduced almost linearly resulting in a new maximum acceptable value per country equal to 1,500 MW. This new value perfectly fits with the limit defined for the whole system, and suggests the analysis of a scenario based on the previous one plus the addition of 1,500 MW of VRES power plants per country. In each country, the allocation of these 1,500 MW to PV or wind projects is made on the basis of the results obtained by the isolated countries. In fact, the convenience of one technology or the other depends on the producibility and on the investment cost (CAPEX, OPEX and interest rate), which are all data which are defined per country and per area, and are not subject to variations when the systems are interconnected.
The introduction of additional VRES power plants allows the possibility to shut down (or avoid the construction) of thermal power plants, increasing the benefits for the system. As a final configuration, 850 MW of CCGTs have been replaced (500 MW in Argentina and 350 MW in Chile) with 2170 MW of PV (42% in Argentina and 58% in Chile) and about 830 MW of wind (73% in Argentina and 27% in Chile).

The following table shows the EENS, expressed as MWh/year, split by area and reason. As expected, the EENS increases: greater values for lack of power and lack of interconnection are present especially in NWE area. Some increase of EENS due to line overloads (from 595 MW/year to 1146 MW/year) is also present, because the absence of CCGTs reduces the possibility to solve network congestions with redispatching of thermal generation. However, the values remain acceptable and the EENS is about 6.5×10^{-6} of the total demand.

Table 97 - Expected Energy Not Supplied – Interconnected optimal scenario

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	54	755	6	815
TOTAL NWE	332	219	648	1,199
TOTAL PAT	0	9	0	9
TOTAL SIC	14	108	5	127
TOTAL SING	0	55	0	55
TOTAL	**400**	**1,146**	**659**	**2,205**

Table 98 shows the total energy produced in each area and the related costs. The most important result regards the decrease in total thermal costs: it is equal to 11,060 M$ (so nearly 360 M$ less than the cost in the interconnected scenario). In this general reduction, it can be seen that the costs due to network congestions increase from 62 M$ to 91 M$.

Moreover, it can be seen that a slight increase of the curtailments due to the operational constraints of the generators increases, confirming that with the total amount of VRES is reaching the limit of the system, which in some load conditions cannot accept more VRES production.

Table 98 - Total production and fuel costs - Interconnected optimal scenario

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	160,791	6,243	0	-240	2,228	124
NWE	51,916	1,550	8	-1,035	494	0
PAT	24,502	130	6	-209	33	-2
SIC	86,939	1,765	3	-1,276	323	-21
SING	32,758	1,280	0	-384	66	-10
TOTAL	**356,906**	**10,968**	**17**	**-3,144**	**3,144**	**91**

In Table 99 the results of the PV generation are presented; Table 100 shows the difference of total PV production respect to interconnected scenario.
In the analysed scenario, the 58% of additional PV plants are deployed in Chile (distributed principally in SIC; only a small part is located in SING); the residual part, so 42%, is deployed in Argentina (exclusively in NWE area), so the main variations can be seen in these areas.
There is an increase of almost 5,200 GWh/year in the annual production (+17.5%). The energy curtailed to avoid network congestions is approximately 270 GWh/year (remaining lower than 1% of the total energy produced). These curtailments area higher than in the interconnected scenario and are located in NWE area. The reduction in the equivalent operating hours (11 hours/year) is due to the greater curtailment needed in order to fulfil all the network constraints.

Table 99 - Total production of PV plants - Interconnected optimal scenario

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-2	0	2,330
NWE	21,900	8	-269	0	2,420
PAT	0	0	0	0	-
SIC	12,136	1	-2	0	2,460
SING	1,922	0	0	0	2,638
TOTAL PHOTOV. GENER.	**36,001**	**9**	**-273**	**0**	**2,444**

Table 100 - Difference of total production of PV plants between interconnected optimal scenario and scenario with the interconnection and without the amount of additional VRES

DIFFERENCE RESPECT TO INTERCONNECTED SCENARIO					
PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	0	0	-2	0	-113
NWE	2,202	7	-182	0	-21
PAT	0	0	0	0	-
SIC	2,497	1	-1	0	-1
SING	669	0	0	0	-2
TOTAL PHOTOV. GENER.	**5,368**	**8**	**-185**	**0**	**-11**

In Table 101 wind production results of this last optimal scenario analyzed are presented; Table 102 shows the difference of total wind production respect to interconnected scenario.
The 73% of additional wind plants are deployed in Argentina (equally distributed in Patagonia and in NEC areas); the residual part, so 27%, is deployed in Chile (exclusively in SIC area).
The annual wind production reaches almost 42,000 GWh/year, with an increase of about 3,250 GWh/year with respect to the interconnected scenario (+8%). There is a relative increase in the curtailed energy, but it remains still negligible with respect to the total generation. The EOH remains almost the same (3,555 h/year; the increase is equal to 24 h/year).

Table 101 - Total production of Wind plants - Interconnected optimal scenario

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	14,840	0	-2	0	3,939
NWE	773	0	-28	0	2,469
PAT	16,060	6	-25	0	4,593
SIC	8,945	0	0	0	2,407
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**42,048**	**6**	**-55**	**0**	**3,555**

Table 102 - Difference of total production of Wind plants between interconnected optimal scenario and scenario with the interconnection and without the amount of additional VRES

DIFFERENCE RESPECTINTERCONNECTED SCENARIO					
WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	ΔGWh/year	Reduction Min.Tec.Gen. ΔGWh/year	ΔGWh/year DP < 0	ΔGWh/year DP > 0	Δh/year
NEC	1,314	0	-2	0	38
NWE	0	0	-13	0	-43
PAT	1,373	5	-15	0	-7
SIC	556	0	0	0	0
SING	0	0	0	0	0
TOTAL WIND. GENER.	**3,243**	**5**	**-30**	**0**	**24**

Table 103 gathers information on the interconnections in the optimal scenario.
Looking at the exchanges between Argentina and Chile, there is a reduction of 500 GWh in the net export from Chile to Argentina (which reduces from almost 1,050 GWh to 550 GWh). This is due to the fact that and equal amount of VRES power plants has been introduced in the two countries, but the producibility of the wind plants in Argentina is much higher than PV or wind in Chile. It means that the added plants produce more energy in Argentina compared to the ones in Chile, reducing the need of import in Argentina.
It is also worth underlining that in Argentina there is a small increase of the number of hours during which the energy flowing to NEC reaches the NTC limit, both from PAT than from NWE.
In Chile there is a reduction of the energy flowing from SING to SIC, due to the higher generation of VRES plants in this last area.

Table 103 - Interconnections - Interconnected optimal scenario

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	3,257	667	3,097	640	33	0
PAT	NEC	4,250	4,250	16,536	6	16,635	5	157	0
NEC	NWE	4,300	4,300	10,696	8,163	10,698	6,353	40	417
SIC	NWE	900	900	3,094	2,098	2,383	2,473	1,171	998
SING	NWE	300	300	1185	364	1040	403	1,027	244

Figure 61 provides a visual summary of the operation of the Argentinian system in the interconnected scenario, highlighting the generation mix per areas, the energy exchanges between areas and the curtailed VRES production and thermal redispatching needed to solve network congestions.
Form the comparison with the interconnected scenario without the additional VRES power plants (Figure 60), the increase of the share of PV and wind production can be seen, together with the increase of the curtailed energy (concentrated in Argentina) and the amount of GWh to be redispatched to solve network congestions.

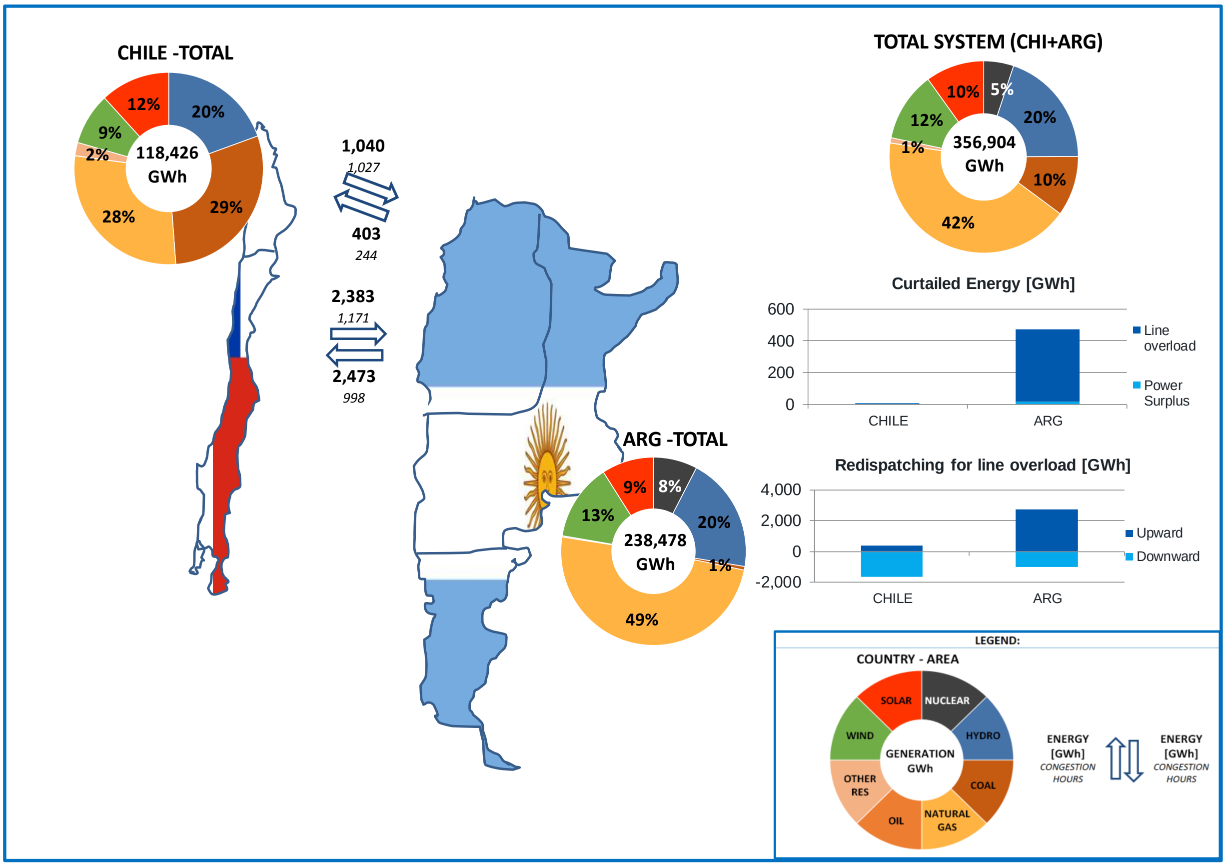


Figure 61 - Total production and energy exchanges –-interconnected optimal scenario

This paragraph is completed with a table that summarizes the total benefit evaluated with respect to interconnected scenario, expressed as a difference between this last optimal scenario and the interconnected one presented in 3.4.3.2.

The main benefit introduced by the additional VRES is due to total thermal generation costs reduction (358 M$/year); the avoided costs due to new CCGT are equal to 74 M$/year. The additional cost due to EENS increase is very limited (2 M$/year). Considering that the annuity of the investment for the additional VRES is 330 M$/year, total cost savings are around 100 M$/year that corresponds to 33 k$/(MW*year). This value can be intended also as the possible loss of benefit in case the growth of VRES power plants penetration in the system will not be as high as required to reach the optimal amount of installed capacity. In other words, the benefit resulting from the installation of additional 3,000 MW PV and wind plants in the system can be seen as an opportunity which is lost in case the plants will not be installed. It means that in the analysed countries a special focus on the development of the VRES generation fleet should be put in place to ensure the maximum benefit for the system.

Table 104 - Total benefit (respect interconnected scenario) - Interconnected optimal scenario

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	3,000	-330
NEW CCGT AVOIDED	850	+74
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-7,888	+358
RES CURTAILMENT	215	-
TOTAL EENS	1	-2
TOTAL BENEFIT	-	+100

BENEFIT/MW VRES [kUSD/(MW*year)]	+33

3.5 Sensitivities

Three further simulations have been carried out on the configuration of the Argentinean and Chilean power systems resulting from the last analysis on the interconnected countries with additional VRES generation. These three sensitivities want to provide information about the operation of the system in conditions that are slightly different from the ones analysed in paragraph 3.4. Only one element is modified in each sensitivity, in order to allow a clear understanding of the impact that the variation of the considered variable can have on the overall system.
The analysis has been focused on three main aspects which affect the generation fleet in the countries. In the first case, a possible delay in the development of dispatchable generation in Argentina has been assessed. In the other two cases, variations of the expected production by hydropower plants has been evaluated. In fact, the optimal amount of PV and wind power plants defined in paragraph 3.4.3.3, under the assumption of the BAT scenario, considered average hydrological conditions, but the operation of the system is strongly affected by high variations of the hydro resource availability, given the high percentage of electricity produced with hydroelectric power plants. In particular, dry conditions can be critical because can jeopardize the security of supply due to the increasing risk of lack of power in case other resources are not available to compensate the hydro power reduction, and because of the lower amount of redispatchable resources needed to fulfil the operational constraints.

Hence, the three sensitivities analysed in the following paragraphs can be summarized as follows:

- Possible delays in the development of dispatchable generation in Argentina, which has been modelled with a reduced installed power of future dispatchable plants
- Dry year, with a lower generation by hydro power plants
- Wet year, with a higher generation of hydro power plants

3.5.1 Possible delays in the development of dispatchable generation in Argentina

The analysis presented so far showed that in the next years a massive development of the generation fleet, concentrated on VRES plants and on some other dispatchable ones, will be possible and required especially in Argentina, to fulfil the expected demand increase in the countries.
To highlight how a possible slower development of the generation fleet in Argentina can impact the operation of the power system, its costs and the security of supply, a simulation of the expected operation in absence of 2,000 MW of dispatchable power plants (modelled reducing the power of the CCGTs included in the Reference scenario and still in operation in the final optimal configuration) has been carried out.

It's worth recalling here that the dispatchable power plants (CCGTs) was introduced in the Reference scenario aimed at ensuring generation adequacy. In particular, Argentinean system suffered too high risk of not being able to supply the load, due to the strong peak load and demand increase foreseen from 2025 to 2030 which was not associated to a corresponding increase of the generation fleet. For this reason, it is expected that reducing the installed capacity will bring the system back to a situation with more lack of generation, which can be only partially compensated by an increased import from Chile to Argentina, and higher EENS
The simulations confirmed what was expected. The main results are summarized in the following.

Reduced generation adequacy

Table 105 shows the values of EENS in the analyses sensitivity. From the comparison with Table 97 referred to the optimal solution of the BAT scenario, it is possible to state that, in absence of 2,000 MW dispatchable generation, the Argentinean system is subject to a strong reduction of the generation adequacy, as the EENS in this country increases nearly ten times, attaining almost 19 GWh (close to $1x10^{-4}$ of the total load). All the main causes (lack of available power in the system, lack of interconnections between areas, network constraints) increase considerably with respect to the original case. In Chile also a slight increase of EENS is present, which is caused by a general lack of power in the overall system due to missing production capacity and by line overloads not resolvable with the available generation resources.

Table 105 - EENS – Sensitivity with delays in the development of dispatchable generation in Argentina

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	808	5,469	437	6,714
TOTAL NWE	2,204	2,025	7,586	11,815
TOTAL PAT	0	194	0	194
TOTAL SIC	49	360	36	445
TOTAL SING	1	62	0	63
TOTAL	**3,062**	**8,110**	**8,059**	**19,231**

Increase energy export from Chile to Argentina

In this sensitivity, the net energy exchange from Chile to Argentina increases considerably, reaching nearly 1.9 TWh. Also the overall utilization of the interconnection increases, with the total exchanges in the two directions attaining 6.6 TWh, against previous 6.3 TWh. In conditions when the generation resource is less available, more energy exchanges are required because more often production in one country is required to support meeting the demand also in the other.

Table 106 contains the detailed information referred to the energy exchanged between areas.

Table 106 - Interconnections - Sensitivity with delays in the development of dispatchable generation in Argentina

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	3,393	610	3,262	576	40	0
PAT	NEC	4,250	4,250	16,662	5	16,768	4	162	0
NEC	NWE	4,300	4,300	10,113	8,560	10,213	6,568	22	508
SIC	NWE	900	900	4,021	1,501	3,128	1,986	1,991	647
SING	NWE	300	300	1279	321	1,107	385	1,035	222

Higher fuel costs

The fuel costs (reported in Table 107) increase by $ 82 million for the whole system, as more expensive generation must be used. At country level, in Argentina these costs remain comparable to the BAT

scenario (Table 98) because the usage of more expensive generation is compensated by an overall lower production, and the load is supplied thanks to a much higher import from Chile. This import increase causes the overall expense to fulfil the demand in the Argentinean system to be higher than the one in the BAT scenario. The difference would be even greater if the countries were isolated, because more expensive generation in Argentina should be used instead of importing energy from Chile.
On the other side, the growth of fuel costs in Chile will be covered by higher earnings obtained by selling more energy to Argentina. For the Chilean system there is an overall positive benefit because the producers can obtain higher revenues which exceed the higher costs the Chilean consumers have to bear due to a general energy price increase.

Table 107 - Total production and fuel costs -
Sensitivity with delays in the development of dispatchable generation in Argentina

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	159,678	6,222	0	-166	2,438	141
NWE	51,219	1,543	5	-993	515	1
PAT	24,605	138	5	-218	38	-2
SIC	88,307	1,844	3	-1,538	256	-33
SING	33,096	1,298	0	-399	66	-11
TOTAL	**356,905**	**11,045**	**13**	**-3,314**	**3,313**	**96**

PV curtailment risk

The risk of PV generation curtailments in NWE area reduces by -20%, corresponding to 50 GWh higher production absorbed by the grid.

This first sensitivity case, focused on possible delays in developing the generation fleet in Argentina, highlights that the security of supply is strongly affected by the quantity of dispatchable generation available in the country. The absence of 2,000 MW causes a strong increase of the EENS which gets multiplied nearly by ten, reaching values which should be considered not acceptable in a long term planning.
From these results it appears that the implementation of development plans concerning the power system in Argentina is crucial, to ensure that the generation development is well aligned with the growth of the power peak and load demand and that the load can be supplied in a reliable and economic way.

3.5.2 Dry conditions

In many South American countries a considerable part of the electricity is generated thanks to hydropower plants. For this reason, the operation of the system is strongly affected by different hydrological conditions.
The analysis presented so far considered a contribution by the hydropower plants which can be assumed as an average value that can be expected over several years. This approach is consistent with the fact

that the assessment aimed at the definition of an optimal amount of VRES power plants, which operate in the system for 20 years or even more. During their lifetime they will face years with different hydrological conditions and the economic evaluation must be done on average values. It is anyway essential to verify that the planned power system does not suffer critical conditions especially during dry years, and that in this condition generation resources are available to supply the load compensating the lower energy available from hydroelectric plants.

The analysis of the system adequacy during dry years is of particular importance for Chile because great variations of the hydro resource have been registered in the past in this country.

Based on available historical data series, the simulation of the system operation in such condition has been performed assuming that in Chile the energy which can be produced from hydro resource is reduced by 30% with respect to the BAT scenario, while in Argentina the reduction is assumed equal to 10%.

The main results are summarized below.

Generation adequacy

The lower availability of power and energy from hydropower plants, especially in Chile, causes the EENS to increase. In the whole system it reaches 3.7 GWh against 2.2 GWh in the BAT scenario (65% growth), but remains still within acceptable ranges. In Chile, where a more severe condition has been considered, the value becomes nearly three times than before (attaining 0.5 GWh) while in Argentina the variation is about +50% (reaching 3.2 GWh).

Table 108 - Expected Energy Not Supplied – Dry year sensitivity

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	134	1,003	15	1,152
TOTAL NWE	1,049	287	677	2,013
TOTAL PAT	0	9	0	9
TOTAL SIC	112	200	96	408
TOTAL SING	1	59	9	69
TOTAL	**1,296**	**1,558**	**797**	**3,651**

Higher production by dispatchable generators

Table 109 shows the overall production costs. To compensate the lower energy from hydropower plants, dispatchable thermal generators have to produce 11.5 TWh more than in the BAT scenario (+5.6%), and the corresponding cost increases to $ 636 million.

Table 109 - Total production and fuel costs - Dry year sensitivity

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	159,678	6,222	0	-166	2,438	141
NWE	51,219	1,543	5	-993	515	1
PAT	24,605	138	5	-218	38	-2
SIC	88,307	1,844	3	-1,538	256	-33
SING	33,096	1,298	0	-399	66	-11
TOTAL	**356,905**	**11,045**	**13**	**-3,314**	**3,313**	**96**

Energy exchanges between Chile and Argentina

Given the variation of the hydro generation, the energy exchanges between the countries are also affected. As can be derived from the detailed results of the energy exchanged through the interconnections reported in Table 110, Argentina becomes a net exporter towards Chile for an amount around 0.7 TWh. This fact highlights the important role of the interconnections in terms of mutual support between the countries, which allows the whole system to withstand also critical hydrological conditions with the other available resources.

Table 110 - Interconnections - Dry year sensitivity

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	4,265	348	3910	350	66	0
PAT	NEC	4,250	4,250	15,760	11	15,946	9	123	0
NEC	NWE	4,300	4,300	11,891	7,956	11,628	6,775	82	394
SIC	NWE	900	900	2,174	3,130	1,728	3,100	599	1,766
SING	NWE	300	300	1,083	335	987	339	982	137

PV curtailment risk

The risk of PV generation curtailments in NWE area reduces by 80 GWh, corresponding to a reduction by -30% of the expected cut energy.

These results show that the amount of VRES and dispatchable generation identified at the end of the analysis of the BAT scenario (paragraph 3.4.3.3) allows a proper operation of the system also in dry conditions though with non-negligible additional dispatching costs. In fact inevitably, higher fuel costs are required in case lower hydro production is available, and a small growth of the EENS is expected, but there is no risk of an unacceptable decrease of the system adequacy.

3.5.3 Wet conditions

The behaviour of the system in a wet year has been also simulated. This condition is expected to be not critical for the system adequacy, because of the higher availability of energy by hydropower plants, which can be used to supply the load and partially to optimize the power flows in case of transmission network congestions. Only overgeneration problems might become more critical, but the presence of some hydropower plants with reservoir allows a different allocation of the additional available energy in periods with low overgeneration risks, thus minimising the possible disadvantages.
It has been assumed that 10% more energy is available from hydropower plants in both countries.

The main results are listed below:

EENS reduction

Thanks to the availability of more energy from the hydro source, the EENS is reduced by -30%, reaching 1.5 GWh against 2.2 GWh of the BAT scenario. The reduction is distributed quite similarly in all the areas, with the highest effect visible in NWE (-35%).
Table 111 shows the values of EENS for each area.

Table 111 - Expected Energy Not Supplied – Wet year sensitivity

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	28	592	0	620
TOTAL NWE	161	158	443	762
TOTAL PAT	0	6	0	6
TOTAL SIC	6	92	2	100
TOTAL SING	0	54	0	54
TOTAL	**195**	**902**	**445**	**1,542**

Fuel savings

Dispatchable thermal generators have to produce 6.6 TWh less (-3%), which are provided by the additional production by the hydropower plants. The corresponding cost saving is about $ 360 million.
Table 112 shows the detailed values for each area. The amount of thermal energy to be redispatched to solve network congestions is aligned to the one resulting for the dry year.

Table 112 - Total production and fuel costs - Wet year sensitivity

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	160,723	6,046	0	-246	2,502	140
NWE	51,630	1,502	17	-1,084	433	-3
PAT	25,036	126	12	-259	42	-2
SIC	87,585	1,676	7	-1,466	313	-29
SING	32,138	1,250	0	-324	90	-7
TOTAL	**357,112**	**10,600**	**36**	**-3,379**	**3,380**	**99**

Energy exchanges between Chile and Argentina

Given the fact that the hydrological conditions are modified in a similar way in both countries, the impact on the total energy exchanges between the countries is limited. As presented in Table 113, the usage of the interconnections and the net balance are aligned with the results of the BAT scenario. Argentina remains a net importer for an amount around 0.5 TWh.

Table 113 - Interconnections - Wet year sensitivity

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	2,926	836	2,824	781	24	1
PAT	NEC	4,250	4,250	17,240	4	17,299	3	215	0
NEC	NWE	4,300	4,300	10,850	8,086	10,907	6,103	42	410
SIC	NWE	900	900	3,234	2,081	2,432	2,480	1,384	995
SING	NWE	300	300	1,129	415	983	456	899	322

VRES curtailment risk

As expected, the higher production available due to hydropower plants causes a slight increase of the VRES curtailment risk. In fact, the higher production by run-of-river plants, which cannot be modulated, increases the overgeneration in the periods which were critical also in the BAT scenario, requiring more reduction of VRES plants. However, the increase remains limited to acceptable values (+60 GWh possible cuts of PV production).

As a general result it can be stated that in a wet year the system can operate with lower fuel costs and lower EENS. The only slightly negative effect is the increase of overgeneration risk.

4 VARIANTS

In this chapter the results of the different scenarios, called Variants, as defined in [1] are presented. They have the aim to evaluate the behaviour of the system in case some major changes take place with respect to the assumptions at the basis of the Reference scenario analysed in the previous Chapter 3.
By comparing the outcomes of the Variants with those of the optimal configurations resulting from the performed assessments, it is possible to appraise to what extent they fit against possible different evolutions of the power systems: the more flexible are the solutions, the better is for the potential investors.
The main key parameters that are modified with respect to the Reference scenario are:

- Electric demand
- Generation evolution
- Possibility to have electrical storage systems

To clearly identify the relationships between the assumptions adopted in the Variants and the relevant outcomes, a reduced set of changes in the parameters with respect to the Reference Scenario is introduced in each Variant. In fact, if many parameters are modified together, it becomes hard to identify the main reasons of a change in the system operation. In some cases, changes in the assumptions can have opposite effects on the results, so there is the risk to miss some important effects on the operation of the system that may be netted by another change in the parameters having an opposite impact.
Thus, basically two key criteria are used to build Variants:

1) selection of a reduced set of key parameters to be modified;
2) definition of clearly distinct scenarios.

Both the variants have been investigated on the system with interconnected countries, as described in 3.4.3. A first simulation is carried out to analyse the operation of the systems with the PV and wind plants defined at the end of the analysis of the Reference Scenario, and evaluate the impact that the changes of the key parameters have on the results. This simulation becomes also the Base Case for the Variants, used for the comparison of the results of further simulations performed to assess the possible benefits related to the introduction of some specific change (such as the addition or removal of some generators or change of some operational parameters).
In this way, even for the Variants it is possible to evaluate the impact that some decisions can have on the systems and the trends which the operation is subject to in case some investments are performed or not. The comparison of the possible benefits obtained with different actions can indicate which the best direction to be taken to improve the overall benefits is.

4.1 First Variant: Accelerated decarbonization in a strong economic development

In the first Variant a higher demand scenario has been evaluated. Also an important change in the generation fleet has been taken into account, since it has been evaluated a transition to a carbon-free condition of the system.
The key parameters that are modified with respect to the Reference Scenario are described in the following.

Demand

In this Variant a strong increase of the demand is analysed. The main drivers which can contribute to a demand higher than the one in the Reference Scenario are:

- Stronger economic growth of the countries
- Increase of population
- Higher electricity penetration, with particular reference to transport sector and residential use

The annual energy consumption is 8% higher than the Reference Scenario (in both Argentina and Chile). The increase of the load is assumed to be mainly due to a stronger economic growth and partially to the impact of the e-mobility, concentrated in the biggest cities.
The additional demand due to e-mobility is estimated in 0.75 TWh in Argentina (4% of the total increase) and 0.35 TWh in Chile (4% of the total increase). This demand is considered to be concentrated in the metropolitan areas of Grand Buenos Aires and Santiago, during the night hours (between 11pm and 07am). The rest of the demand increase (the part caused by a general higher economic growth of the countries) is applied in a flat way in all the regions.
The energy increase is sum up in the following table.

Table 114 - First Variant - Energy Increase

COUNTRY	Energy increase due to e-mobility [GWh]	Energy increase due to population and economic growth [GWh]
Argentina	750	17,630
Chile	350	8,585

Generation

The generation fleet assumed in the first Variant is the same as the one considered in the last analysis of the Reference Scenario, with interconnected systems and maximum VRES installation (paragraph 3.4.3.3).
The transition towards a "carbon-free" generation has been simulated to minimize GHG emission. The coal power plants[15] have been considered to be replaced by equivalent VRES power plants or with Combined Cycle Natural Gas power plants of the same size in case the increase of VRES plants is not sufficient to substitute all of them keeping a suitable level of generation adequacy.
The amount of coal plants to be replaced is 4,650 MW in Chile and 240 MW in Argentina.

[15] With the exception of the Bocamina coal power plant, due to the fact that it is still at the initial phase of operation, and in 2030 it will not be close to the end of its lifetime.

Transmission

In a scenario with higher load, the transmission system is in general more stressed, showing more bottlenecks and risk of curtailments due to overloads. In this condition, investments in transmission system are necessary to keep it adequate to the more demanding operation. In order to focus the analysis of the cases in Variant 1 on the impact of additional VRES plants on the systems, without obtaining results conditioned by local congestions, some reinforcements of lines have been introduced:

- The 500 kV lines Recreo-Malvinas and Rio Diamante-Charlone-Junin have been considered with the improved capacity already analyzed in 3.4.1.3, as their benefits have been already analyzed for the Reference Scenario
- The transmission capacity of the 500 KV line Santa Cruz Norte-Comodoro in Patagonia has been considered improved from 1,000 A to 1,800 A, as the limit of 1,000 A is lower than the limit of the conductor, probably due to a limitation of current transformers that can be upgraded with a minor investment
- The 220 kV line El Tesoro-Esperanza in SING has been reinforced because caused a local congestion for many hours during the year. Also in this case, the investments for the improvement of the transmission capacity if required would remain limited due to the short length of the line

Analyzed Scenarios

At first, a scenario in which the coal plants are switched off and their generation is replaced with VRES has been simulated: 4,890 MW of coal power is replaced with 14,700 MW of RES (which means a substitution ratio of approximately 1:3). The additional VRES is distributed proportionally to the replaced traditional power: 95% in Chile and 5% in Argentina. In Chile this further VRES is equally installed as PV and Wind.

The results show a dramatic increase in the EENS that reaches a value close to 500 GWh (in Chile the EENS corresponds to about 0.4% of the annual requested energy). This EENS is due to lack of power and lack of interconnection between Chile and Argentina and it is indeed an indicator of a generation inadequacy of the Chilean system: the traditional generation fleet is inadequate to cope with the switching off of the coal plants, even if these plants are replaced with VRES with a total capacity 3 times bigger.

The Base Case for the Variant 1 is then defined starting from the final configuration analysed in 3.4.3.3, considering the load demand increase and the switch of the coal power plants excluded Bocamina plant) to Natural Gas. The VRES installed power is reported in Table 96. This scenario becomes the one used as reference when comparing the results of different ones, and allows the calculation of the benefits to assess the maximum installable amount of VRES power plants.

Some different scenarios have been analysed to evaluate technical and economic performances of the systems in presence of further VRES power plants. The increase of the load in fact allows the system to accept additional 2,900 MW because the limit defined in Chapter 2 can be exceeded as the minimum load is greater. Moreover, in some cases the presence of new pumped storage plants has been considered, which can increase further the load in the minimum conditions, enabling the system to accept other VRES without affecting the reserve requirement.

In particular, the following variations of the Base Case of Variant 1 have been defined:

- Scenario V1a, with installation of 1,600 MW of pumped storage plants and addition of 4,900 MW of further VRES (2,900 MW added thanks to the load increase, 2,000 MW thanks to the pumped storage plants)
- Scenario V1b, like the V1a, with the removal of 2 CCGTs (one per country) to check whether VRES might allow a reduction of the investments in other technologies
- Scenario V1c, in which only 2,900 MW of VRES are added to the Base Case for Variant 1 (made possible thanks to the load increase) without the new pumped storage plants. Form the comparison with V1a it is possible to evaluate whether investments in storage plants to support VRES penetration can bring positive feedbacks to the system.

In the scenarios where the presence of 1,600 MW of pumped-storage has been simulated in the system (V1a and V1b), three plants have been introduced. The main data of the pumped-storage considered in these conditions are shown in the following Table 115. In addition, an efficiency (ratio between the produced energy with respect to the absorbed one) equal to 75% has been simulated.
In order to analyse the economic viability of the investment in pumped-storage plants, i.e. whether their presence contributes to positive benefits for the whole system, it is necessary to define a CAPEX and a lifetime. To this aim, an investment cost of 2,000 k$/MW has been considered with a lifetime of 40 years. The actual cost of a pumped storage plant is very dependent on the environmental and topological conditions, so the evaluation of real possible opportunities should be performed based on more accurate cost estimations during feasibility analysis.

Table 115 - First Variant - Pumped-Storage main data

AREA	Pmax [MW]	Pmin [MW]	Pumping equivalent hours	Connection node	Unit cost [k$/MW]	Lifetime [years]
Argentinean plant	1,000	-1,000	8	Gran Mendoza 500kV	2,000	40
Chilean plant n°1	300	-300	8	Polpaico 500kV		
Chilean plant n°2	300	-300	8	Domeyko 220kV		

4.1.1 *Base Case Scenario for Variant 1*

Base Case for Variant 1 is defined starting from the Scenario with optimal economic amount of additional VRES with the interconnected countries (paragraph 3.4.3.3).
The ***total amount of VRES*** installed power is indeed:

Table 116 - Total VRES installed power in Base Case for Variant 1 Scenario [MW]

AREA	PV installed power	Wind installed power
NEC	18	3,767
NWE	8,936	302
PAT	0	3,490
SIC	4,932	3,717
SING	729	535

In the Base Case for Variant 1 ***load is increased of 8%*** taking into account ***high electric vehicles penetration*** (increased load during the night in Buenos Aires and Santiago metropolitan areas).
Coal plants (except Bocamina) have been ***replaced with CCGT*** technology, increasing the cost accordingly.

The simulation of this Base Case scenario for Variant 1, which becomes the reference for the comparison of results of other simulations, brings to the following results:

- ***EENS*** is around 4.9 GWh; it is about $1.3x10^{-5}$ of the total load
- ***Overall generation costs*** are close to 13,285 M$; there is an increase of the costs of about 35%. This increase is due to both increased load (which alone would increase the generation costs by 15%) and higher cost of CCGT in respect to coal (which causes the additional 20% increase). The average generation costs is then equal to 34.5 $/MWh
- Expected ***generation by PV*** power plants is around 36,000 GWh (equal to the production in the Reference Scenario reported in paragraph 3.4.3.3) and the curtailments are practically zero thanks to the higher load.
- Expected ***generation by wind*** power plants is close to 42,000 GWh (equal to Reference Scenario in 3.4.3.3) with no curtailments thanks to the higher load

A Base Case scenario for Variant 1 has been analysed starting from the scenario with interconnected countries and optimal economic amount of additional VRES (paragraph 3.4.3.3).
The load demand is increased by 8%; furthermore the load trends are modified in the metropolitan areas of Santiago and Gran Buenos Aires in order to take into account high electric vehicles penetration which is considered to increase the load during the night.
All the coal plants are replaced with CCGT plants of the same size (with the exception of Bocamina plant), increasing the relevant generation cost.

The following table shows the EENS, expressed as MWh/year, split by area and reason. As expected, the higher load implicate an increase in the EENS compared to the scenario with the same generation fleet and the reference load, but the system maintains an acceptable level of adequacy.
Compared to the values shown in Table 97, it can be noted that EENS due to line overloaded increases more than for the other reasons, and this is understandable in a system that is generally more overloaded due to the growth of the demand. It is worth recalling here that few network improvements are considered in this Base Case scenario (as described in 4.1) to limit the impact of some local congestions on the overall operation of the system.
EENS due to lack of power or lack of interconnection also increases because with a higher load there are more conditions in which the generation available in the system or in a specific area is not sufficient to cover the power peak.

Table 117 - Base Case for Variant 1 - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	27	1,971	12	2,010
TOTAL NWE	531	111	678	1,320
TOTAL PAT	0	312	0	312
TOTAL SIC	67	513	351	931
TOTAL SING	10	236	51	297
TOTAL	**635**	**3,143**	**1,092**	**4,870**

Table 118 shows the total energy produced in each area and the related costs. In reference scenario of the first variant overall generation costs are around 13,285 M$/year in the whole system (Argentina and Chile), with a growth of 35% with respect to the scenario with standard load. This is due to the higher load (which causes an increase of the generation cost equal to 15%) and to the replacement of the coal plants with the CCGTs which are more expensive (which is responsible of the remaining 20%).

Table 118 - Base Case for Variant 1 - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	179,832	7,328	0	-569	145	-2
NWE	55,993	1,825	4	-204	140	4
PAT	24,450	135	3	-62	3	-1
SIC	92,161	2,395	4	-117	666	39
SING	32,519	1,562	0	-69	68	1
TOTAL	**384,955**	**13,245**	**11**	**-1,021**	**1,022**	**41**

The following table shows PV generation and curtailments for each area of the system. Total production is around 36,000 GWh/year; 61% of the production is concentrated in Argentina while the remaining part is produced in Chile. The curtailed energy, which in the scenario with standard load was about

280 GWh, drops down to negligible values thanks to the considered improvement of the transmission capacity of the critical lines and to the fact that with a higher load more generators are in service and also less constrained to the minimum when the PV production is high, providing more flexibility to the overall system. The equivalent operating hours are indeed equal to the theoretical value: around 2,450 in Argentina and 2,480 in Chile.

In this condition, the total PV plants have an average LCOE equal to 41.9 $/MWh in Argentina and to 27.5 $/MWh in Chile, calculated assuming the investment costs considered in this study.

Table 119 - Base Case for Variant 1 - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	0	0	2,452
NWE	21,901	4	-5	0	2,450
PAT	0	0	0	0	-
SIC	12,125	2	-2	0	2,458
SING	1,921	0	0	0	2,637
TOTAL PHOTOV. GENER.	**35,990**	**6**	**-6**	**0**	**2,462**

In Table 86 wind production results of the optimal scenario are presented.

The annual wind production reaches more than 42,000 GWh/year and the amount of curtailed energy is negligible.

The results are similar to the ones with standard load condition (Table 101) since in both scenarios the wind plants can almost reach a level close to their theoretical producibility.

In this condition, the total wind plants have an average LCOE equal to 44.6 $/MWh in Argentina and to 67.4 $/MWh in Chile, calculated assuming the investment costs considered in this study. These values can be different from the ones analysed so far during the study, as they refer to the whole amount of wind power plants, and not only the additional ones which are supposed to be in more windy regions.

Table 120 - Base Case for Variant 1 - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	14,857	0	-5	0	3,939
NWE	773	0	0	0	2,562
PAT	16,081	3	-17	0	4,597
SIC	8,945	1	0	0	2,406
SING	1,430	0	-2	0	2,669
TOTAL WIND GENER.	**42,086**	**4**	**-24**	**0**	**3,559**

Table 87 gathers information about the interconnections.

The amount of energy exchanged between the two countries through the interconnections slightly increases from 6.3 TWh to nearly 6.5 TWh, and it is interesting to note that the main direction changes, because in this condition Argentina has a net export of 1.8 TWh towards Chile. This can be explained by the fact that generation in Chile has become more expensive due to the change from coal to CCGT.
As far as the energy exchanges internally to the countries are concerned, the increase of the load causes more energy to flow to the SIC area (from SING or from Argentina) because of the high demand in the region, and from NEC to NWE because of the higher export towards Chile and the increase of the load in an area which already had problems of lack of power. The interconnection from NWE to SIC reaches its limit for a high number of hours during the year (2,300h).

Table 121 - Base Case for Variant 1 - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	**SIC**	1,500	1,500	1,811	799	1,734	805	7	0
PAT	**NEC**	4,250	4,250	15,062	16	15,106	17	92	0
NEC	**NWE**	4,300	4,300	13,453	6,533	13,150	6,714	84	123
SIC	**NWE**	900	900	1,721	3,984	1,652	3,450	681	2,299
SING	**NWE**	300	300	699	780	686	684	488	558

Figure 62 provides a visual summary of the operation of the system in the Variant 1 reference scenario, highlighting the generation mix per areas, the energy exchanges between areas, the curtailed VRES production and thermal redispatching needed to solve network congestions.
The comparison with Figure 61 highlights the different energy mix (coal production drops to nearly zero, replaced by natural gas), the higher exchanges from Argentina to Chile and the change of the redispatched energy (Argentina is required to reduce the production because the economic export is limited by the interconnections).

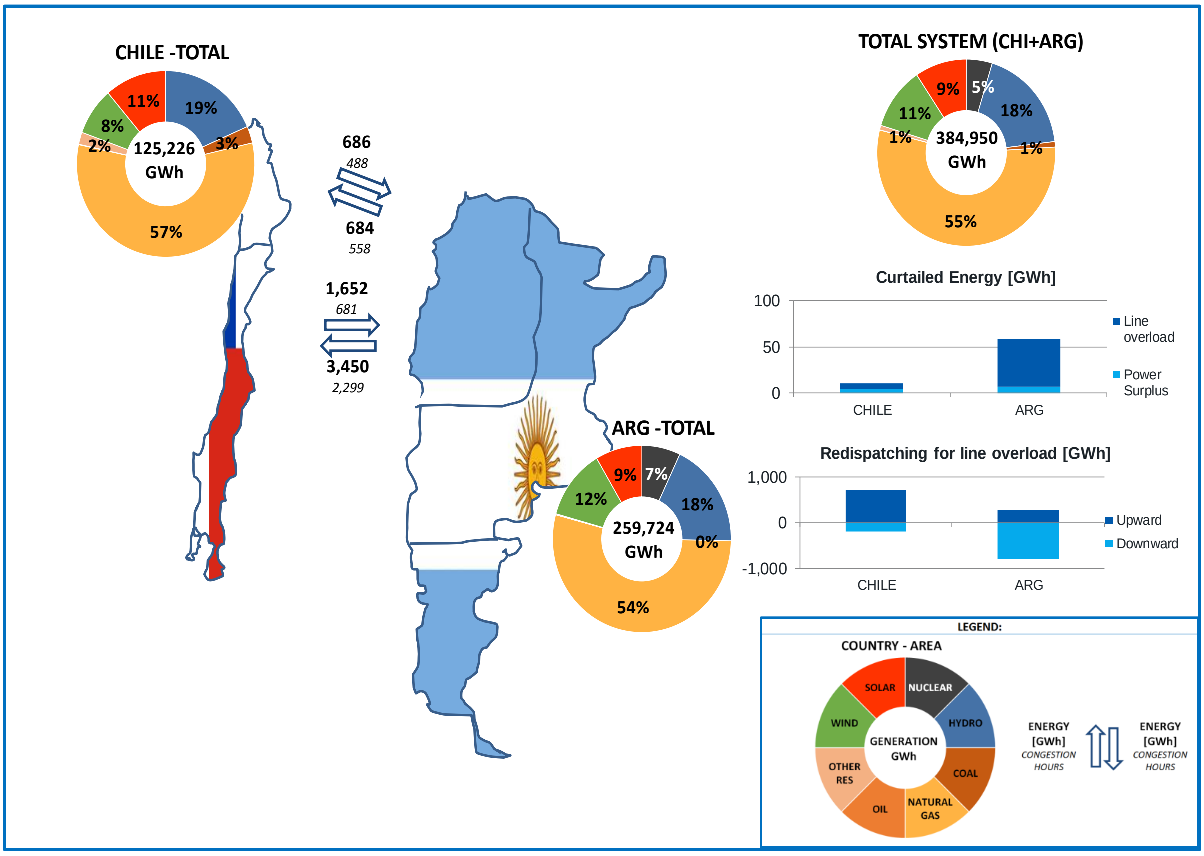


Figure 62 - Base Case for Variant 1 - Total production and energy exchanges

4.1.2 Scenario V1a: additional VRES - pumped-storage plants

A scenario with ***additional VRES plants*** has been simulated.
2,900 MW of PV and wind generators are added because the higher load in Variant 1 creates the conditions to have more VRES without affecting the reserve margin.
Moreover, ***three pumped storage plants*** are installed (1,000 MW in Argentina and 600 MW in Chile) to support the balance of the system, and allow the installation of further 2,000 MW of VRES, reaching the total of 4,900 MW more than the Base Case of Variant 1. They are divided between the countries proportionally to the load increase and to the power of the installed pumped storage systems, and between the technologies based on the ratios defined in previous analysis.
The Table 122 sums up the VRES installed capacity in this scenario.

Table 122 - Scenario V1a - Total VRES installed capacity [MW]

AREA	PV installed capacity	Wind installed capacity
NEC	18	4,425
NWE	10,892	302
PAT	0	4,149
SIC	6,037	3,968
SING	1,005	535

Same load and generation fleet as the Base Case for Variant 1 (coal replaced with CCGT).

The simulation of this scenario, leads to the following results:

- ***EENS*** is around 3.2 GWh; it is about 0.9×10^{-5} of the total load.
- ***Overall generation costs*** are close to 12,580 M$; the thermal costs decrease by 708 M$ (-5.3%) thanks to the higher VRES generation.
- Expected ***generation by PV*** power plants is close to 43,840 GWh: 7,800 GWh more than the one in Base Case scenario (+22%). The production curtailments are 400 GWh (less than 1% of theoretical production).
- Expected ***generation by wind*** power plants is close to 48,270 GWh: 6,200 GWh more than the one in Base Case scenario (+15%). The production curtailments are 300 GWh (less than 1% of theoretical production).
- The ***high cost of investment in pumped-storage*** implies that this scenario is not economically viable if compared to Base Case for Variant 1, when only the benefits deriving from the energy shift are considered. If other benefits more related to the realtime operation of the system, such as the contribution to fast frequency control, are taken in to account, the conclusions might become different, in particular in case some project specific conditions require investments lower than the considered ones.

The increase of the load with respect to the Reference Scenario allows the systems to accept additional VRES production without affecting the reserve requirements. In fact, it implicates a less limiting low load condition: the 10th minimum load during the hours with high solar irradiation is 2,300 MW (+6.6%) higher

compared to the reference load scenario. It allows to install 2,900 MW additional VRES in the system (divided between the countries proportionally to the load increase, i.e. 69% in Argentina and 31% in Chile).
In this scenario V1a three pumped storage plants are installed (1,000 MW in Argentina and 600 MW in Chile) to support the system to supply higher peak load and to reduce the variations between minimum and maximum load the thermal generation has to deal with. The presence of 1,600 MW of pumped-storage installed power, which can further increase the minimum load, allows to install additional 2,000 MW of VRES in the system (with the same distribution of the pumped-storage plants: 1,250 MW in Argentina and 750 MW in Chile).
Load and the rest of generation fleet are the same as the Base Case for Variant 1.

The hydro pumped-storage plants exploitation is shown in Table 123. Since the pumping/production cycle is a non-ideal process (it has an efficiency of 75%), in the pumped-storage the energy used for pumping is more than the production. The plants are used for a limited time aimed at increasing the flatness of the residual load which must be supplied by thermal generation.

Table 123 - Scenario V1a - Pumped-storage plants productions

[GWh]	Argentinean plant	Chilean plant n°1	Chilean plant n°2	Total
Produced Energy	339	84	117	540
Pumped Energy	-452	-113	-156	-721
Total	-113	-29	-39	-181

In the following table the detailed results concerning EENS are presented. The presence of additional generation (4,900 MW of PV and wind plants) and of pumped storage plants improves the adequacy of the whole system, strongly reducing the lack of power and lack of interconnection. EENS due to line overloads remain almost the same in the two countries, as the generation which can be dispatched to solve network congestions does not change.

Table 124 - Scenario V1a - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	0	1,143	7	1,150
TOTAL NWE	19	903	67	989
TOTAL PAT	0	162	0	162
TOTAL SIC	3	495	135	633
TOTAL SING	1	235	28	264
TOTAL	**24**	**2,938**	**237**	3,199

Table 125 reports the overall generation costs, close to 12,580 M$. There is a significant reduction by more than 5% with respect to the Base Case for Variant 1, due to the replacement of thermal generation with PV and wind. The 66% cost reduction is in Argentina (465 M$) and the 34% in Chile (241 M$), in line with the location of the new plants. Moreover, also the pumped storage plants contribute to a better exploitation of the rest of the generation fleet. As already seen in other cases, the introduction of big quantity of VRES plants increases the amount of energy which must be redispatched to solve network congestions, increasing the relevant part of the generation costs. Finally, some curtailments due to the minimum production constraint of thermal generator appears, indicating that the defined amount of VRES reached the operational limit due to the reserve and the low load conditions.

Table 125 - Scenario V1a - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	176,355	6,971	0	-682	457	13
NWE	58,644	1,718	173	-678	378	3
PAT	27,251	123	44	-462	4	-5
SIC	91,834	2,197	70	-152	1,274	71
SING	31,980	1,493	1	-252	113	-6
TOTAL	**386,064**	**12,502**	**288**	**-2,226**	**2,226**	**76**

The following Table 126 and Table 127 show the production of PV and wind power plants respectively. Thanks to the additional installed capacity, compared to the Base Case for Variant 1 a strong increase of the amount of energy injected in the grid can be noted (+22% for PV and +15% for wind), but it is important to highlight also the increase in the energy curtailments both due to overgeneration ("Reduction Min.Tec.Gen") and for network congestions. PV is curtailed about 400 GWh, while wind about 300 GWh, which in both cases correspond nearly to 5% of the additional production for each technology. These curtailments have an impact on the expected LCOE of these new plants, especially in Argentina where most of the curtailments are located.

The additional PV plants in Argentina have an expected LCOE equal to 45.1 $/MWh, while in Chile it is equal to 27.7 $/MWh. Concerning wind plants, the added ones in Argentina have an expected LCOE equal to 43.5 $/MWh, and in Chile equal to 69.5 $/MWh.

Table 126 - Scenario V1a - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	0	0	2,452
NWE	26,531	171	-174	0	2,420
PAT	0	0	0	0	
SIC	14,804	39	-8	0	2,451
SING	2,649	1	0	0	2,636
TOTAL PHOTOV. GENER.	**44,027**	**211**	**-182**	**0**	**2,442**

Table 127 - Scenario V1a - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	17,729	0	-13	0	4,003
NWE	771	2	0	0	2,556
PAT	19,051	44	-239	0	4,535
SIC	9,540	11	-1	0	2,404
SING	1,429	0	-1	0	2,669
TOTAL WIND GENER.	**48,521**	**57**	**-254**	**0**	**3,608**

The following Table 128 shows the results of the inter-area interconnections.
In Argentina, more new installed power is introduced (both in terms of hydro pumped storage and VRES), and the added VRES power have a higher capacity factor thanks to the excellent wind resource in PAT and NEC. This means that more cheap energy becomes available in Argentina with respect to Chile, with the effect to further boost the energy exchange from East to West. The overall energy exchanged through the line remains stable, around 6.4 TWh, but Argentina reaches a net export of 2.4 TWh towards Chile.

Table 128 - Scenario V1a - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	**SIC**	1,500	1,500	1,649	985	1,442	1,067	4	1
PAT	**NEC**	4,250	4,250	18,461	15	17,699	16	532	0
NEC	**NWE**	4,300	4,300	14,103	8,723	13,639	8,941	138	866
SIC	**NWE**	900	900	1,384	4497	1,358	3,637	498	2,748
SING	**NWE**	300	300	628	886	627	736	498	645

The following Figure 63 provides a visual summary of the main information related to the operation of the system in the V1a scenario.
The growth of curtailed energy, both for overgeneration and for line overload, can be seen, together with the increase of the energy flow from Argentina to Chile.

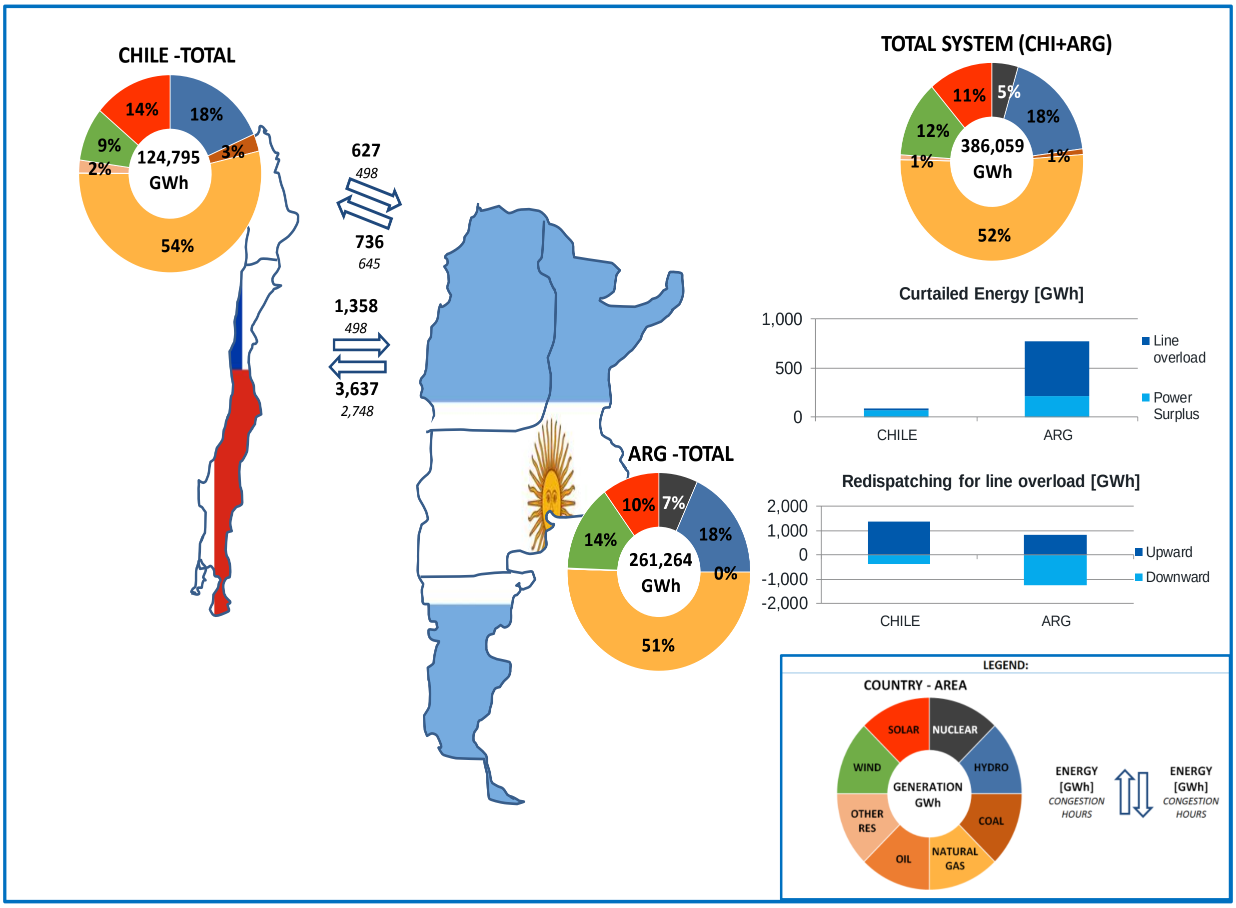


Figure 63 - Scenario V1a - Total production and energy exchanges

Finally, the analysis of the economic viability of this scenario is performed, evaluating costs and savings with respect to the Base Case for Variant 1. The main data to be taken into account are:

- The investment cost of pumped-storage plants, considering 1,600 MW with an investment cost of 2,000 k$/MW and a lifetime of 40 years, leads to an annualised cost of 300 M$
- The investment in the additional VRES plants, which, taking into account the different technology and interest rates in Argentina and Chile, sums up to an annualised cost of 581 M$
- The slight reduction in the EENS, corresponding to a saving of about 3 M$
- The reduction of total thermal cost of the system thanks to the replacement of traditional generation with VRES, equal to 708 M$

The previous data lead to a total cost that is 170 M$/year higher than the high load Base Case scenario. This means that the scenario analysed in this paragraph is not economically viable. Looking at the following table it can be noticed that the main reason is the high cost of the investment in pumped-storage plants, which is not compensated adequately. It is worth underlining here that the benefits that a pumped-storage system introduces in an electrical system can be wider than the ones considered in the present analysis, mainly focused on minimization of energy cost in the long term scenario. In fact, this type of power plants are often utilized for fast frequency control, thanks to their ability to quickly modify high amount of power. The benefits deriving from this service cannot be evaluated in long term planning phase, but might be considerable and support the decision to build similar projects in the system.

Moreover, the considerations about the non-viability strongly depend on the cost of the hydro pumped-storage plant considered in this evaluation. In case project specific conditions can reduce the needed investment for the construction of a plant of the technology, it is possible to reach different conclusions. In summary, the introduction of hydro pumped-storage system only to foster VRES penetration in the electrical systems seems not feasible, and should be evaluated in a more detailed manner, based on project specific information and on an assessment of the benefits that such plants can introduce in the real time operation, thanks to the possibility to have a fast control of significant amount of power.

Table 129 - Scenario V1a - Total Benefit

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	4,900	-581
NEW CCGT AVOIDED	0	0
ADDITIONAL PUMPED STORAGE	1,600	-300
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-12,648	+708
RES CURTAILMENT	663	-
TOTAL EENS	-2	+3
TOTAL BENEFIT	**-**	**-170**

Two further scenarios are analysed in the next paragraphs to evaluate, on one hand, whether the additional VRES plants can avoid investments in other technologies (such as CCGTs) to cover the load, and, on the other, which would be the benefit for the system in case additional VRES are installed without the pumped storage plants.

4.1.3 *Scenario V1b: pumped-storage plants - additional VRES - Reduced CCGT*

Starting from the scenario V1a, which includes pumped storage and additional 4,900 MW of VRES plants, the ***removal of two CCGTs*** among the ones introduced in the Reference Scenario to cover the load increase is simulated, to assess the possibility to avoid investment costs in different technologies thanks to the additional VRES generators. One 500 MW CCGT is shut down in Argentina and a 350 MW one in Chile.

The simulation of this scenario, brings to the following results:

- ***EENS*** is around 3.6 GWh (about $1x10^{-5}$ of the total load), lower than the values obtained in Base Case for Variant 1 and slightly higher than Scenario V1a. The system maintains a good generation adequacy also without two CCGTs.
- ***Overall generation costs*** are close to 12,610 M$; the thermal costs decrease by 675 M$ compared to Base Case for Variant 1, but increase by 33 M$ (+0.3%) compared to Scenario V1a.
- Expected ***generation by PV*** power plants remains equal to the one in Scenario V1a (more than 43,860 GWh with curtailments of 400 GWh).
- Expected ***generation by wind*** power plants remains equal to the one in Scenario V1a (close to 48,270 GWh with curtailments for 300 GWh).

The scenario is ***not economically viable*** compared to the Base Case for Variant 1 due to the high investment cost required for pumped-storage plants. On the other hand, it is confirmed that some investments in other power plants can be avoided, bringing a positive benefit with respect to the Scenario V1a.

In this scenario the possibility to reduce the CCGT fleet has been investigated in order to understand if the additional VRES could replace traditional generation with a further benefits for the system.
The scenario is based on the system configuration analysed in the Scenario V1a, which includes:

- 3 pumped storage are installed (1,000 MW in Argentina and 600 MW in Chile);
- There is additional 4,900 MW of VRES installed power.

850 MW of CCGT installed power is shut down with respect to the fleet considered in the Base Case for Variant 1 and Scenario V1a (500 MW in Argentina and 350 MW in Chile). The rest of the generation fleet is the same, i.e. the coal plants are replaced by CCGT.

The hydro pumped-storage plants exploitation is shown in Table 130. There is a slight reduction (-3%) of their total exploitation compared to the Scenario V1a in which the 850 MW CCGT are still in service.

Table 130 - Scenario V1b - Pumped-storage plants productions

[GWh]	Argentinean plant	Chilean plant n°1	Chilean plant n°2	Total
Produced Energy	326	75	121	522
Pumped Energy	-436	-100	-161	-697
Total	-110	-25	-40	-175

Table 131 shows that the reduction in CCGT capacity leads to a slight increase in EENS, mainly due to a lack of power or interconnection. However this increase is not significant and the systems still has a good generation adequacy being the EENS about $1x10^{-5}$ of the overall load.

Table 131 - Scenario V1b - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	3	962	25	990
TOTAL NWE	71	874	179	1,124
TOTAL PAT	0	214	0	214
TOTAL SIC	11	507	346	864
TOTAL SING	4	236	205	445
TOTAL	**89**	**2,793**	**755**	**3,637**

In the following table it can be seen the small increase of thermal generation costs with respect to the Scenario V1a (+33 M$, less than 0.2% of the overall costs), with positive or negative variations in the different areas. The amount of curtailed energy slightly reduces because the removal of two CCGTs reduces the minimum power constraint, limiting the situations with overgeneration.

Table 132 - Scenario V1b - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	175,678	6,956	0	-556	420	15
NWE	59,250	1,763	166	-680	349	0
PAT	27,335	129	43	-469	5	-5
SIC	93,208	2,279	62	-157	1,148	64
SING	30,417	1,412	1	-195	135	-2
TOTAL	**385,888**	**12,539**	**272**	**-2,057**	**2,057**	**72**

The reduction of CCGT installed power has a minimal effect on the overall PV and wind production with respect to Scenario V1a. Curtailments are reduced in a negligible manner because of the limitation of the overgeneration and reduction of network congestions.
For the same reason, there is no significant change in the expected LCOE for the two technologies.

Table 133 reports the main information about the energy exchanges through the interconnections between areas and between countries. The exchanges vary because of the different generation fleet available in the system. The main changes on the international exchanges are focused on the interconnection between NWE and SIC, where Argentina exports 200 GWh more than in the Scenario V1a even if a bigger plant is removed from there. Other variations are present within the countries, but not really significant as dependant on the location of the CCGTs.

Table 133 - Scenario V1b - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	906	1,596	783	1,692	1	1
PAT	NEC	4,250	4,250	18,501	15	17,725	15	539	0
NEC	NWE	4,300	4,300	13,787	8,896	13,372	9,081	118	903
SIC	NWE	900	900	1,412	4433	1,386	3,634	566	2,595
SING	NWE	300	300	504	995	504	837	312	854

Figure 64 provides a visual summary of the operation of the system in Scenario V1b, and there are no big differences with respect to Scenario V1a (Figure 63).

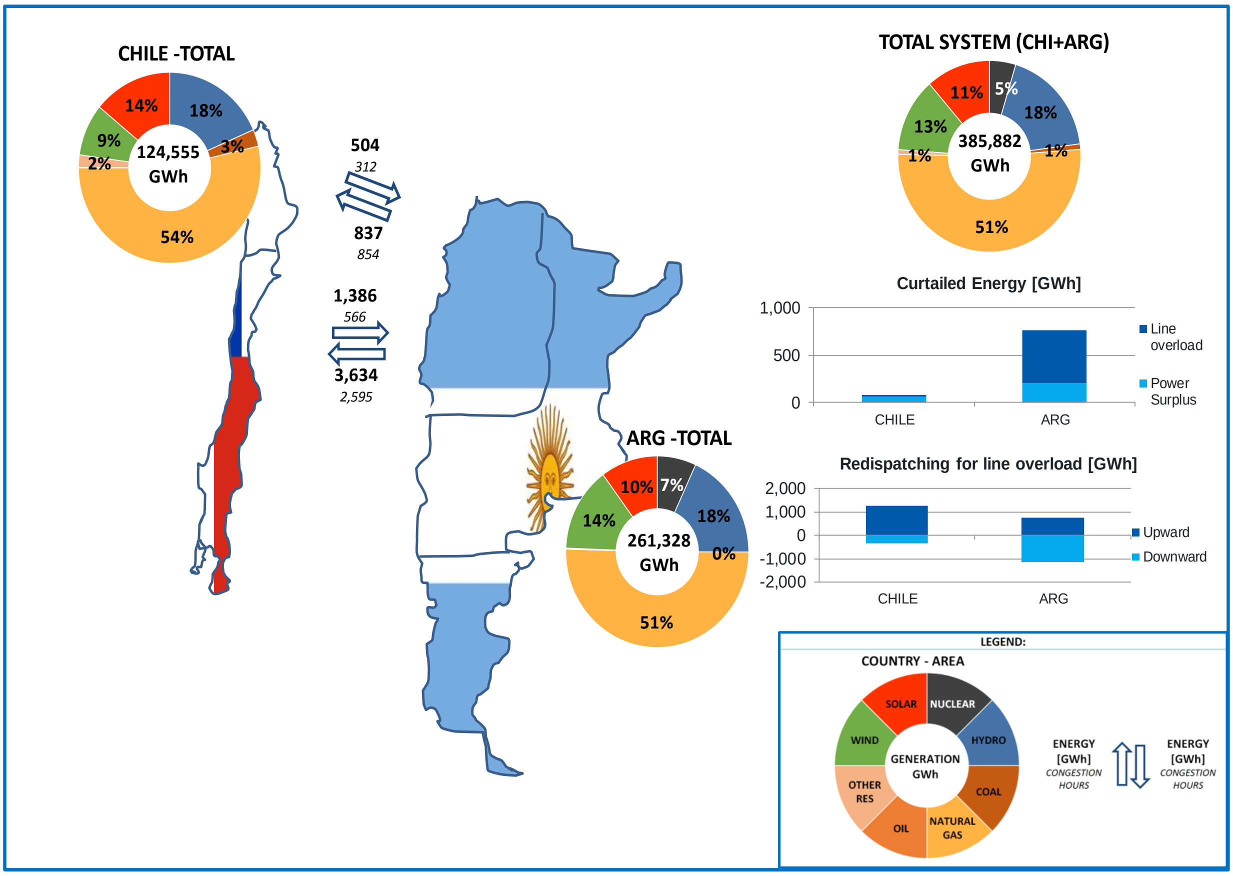


Figure 64 - Scenario V1b - Total production and energy exchanges

Table 134 provides the results of the assessment of the benefits for the system in Scenario V1b compared to Base Case for Variant 1. The difference between these values and the ones reported in Table 129 allows also the evaluation of the benefits obtained in V1b with respect to V1a scenario.

Also in this case, the high investment costs required by the pumped storage plants bring to an overall negative benefit, i.e. the non-viability of the scenario. Considerations done for V1b, concerning the fact that the costs highly depend on project specific conditions and may vary considerably and that a big part of the advantages for the electrical system introduced by pumped storage plants is related to more operational issues, not considered in this analysis, remain still valid.

It is worth noting that the removal of CCGTs brings a positive benefit of 40 M$ with respect to the Scenario V1a thanks to the high amount of avoided investment costs in CCGTs, only partially reduced by the increase of the generation costs.

Table 134 - Scenario V1b - Total Benefit

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	4,898	-581
NEW CCGT AVOIDED	850	+74
ADDITIONAL PUMPED STORAGE	1,600	-300
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-12,856	+675
RES CURTAILMENT	640	-
TOTAL EENS	-1	+2
TOTAL BENEFIT	**-**	**-130**

4.1.4 Scenario V1c: 2,900 MW Additional VRES - Reduced CCGT - No pumped storage plants

In this ***Scenario V1c***, the ***pumped storage plants have been removed*** with respect to the Scenario V1b, as they are the most expensive cost in the benefit analysis. Due to absence of pumped storage system, ***2,900 MW VRES have been introduced*** with respect to the Base Case for Variant 1 (i.e. 3,000MW less have been considered with respect to Scenario V1b).
850 MW of CCGTs are switched off (500 MW in Argentina and 350 MW in Chile).

The simulation of this scenario, brings to the following results:

- ***EENS*** increases to around 6.5 GWh (about $1.7x10^{-5}$ of the total load), higher than Base Case
- Overall ***generation costs*** are close to 12,900 M$; the thermal costs increase of 287 M$ (+2.3%) compared to the Scenario V1b, because of the lower VRES installed capacity. The increase should be compared to the saving related to not investing in 1,600 MW of pumped-storage plants.
- Expected ***generation by PV*** power plants is more than 43,860 GWh: The production curtailments are 400 GWh (less than 1% of theoretical production).
- Expected ***generation by wind*** power plants is close to 48,270 GWh. The production curtailments are 300 GWh (less than 1% of theoretical production).

This scenario is ***more cost-effective*** than the scenarios with the pumped-storage plants. It is also more economical than the Base Case for Variant 1. This leads to confirm that the pumped-storage plants are not convenient due to their high investment costs, even if they allow a greater VRES penetration. Evaluation of such kind of plants should be done considering other advantages they can bring to the system in the short term and real time operation, for example fast frequency regulation.

In this scenario the effects of the presence or absence of pumped-storage plants have been investigated. Starting from Scenario V1b, the pumped-storage plants has been switched off in order to understand the actual effect that they have on the operation and the benefits of the overall system.
Since the pumped-storage are not present, the limit of the maximum amount of VRES is lower than in previous Scenario V1a and V1b, as there is only the increased load and not the pumping power which creates the conditions for additional VRES plants.
For this reason, with respect to the Base Case for Variant 1 in this scenario there are:

- additional 2,900 MW of VRES installed power ;
- 850 MW of CCGT switched off ;

The rest of the generation fleet is the same as the Base Case for Variant 1 (the coal plants are replaced by CCGT).

The simulations provided the results presented in the following tables.
Table 135 shows the values of EENS which in this Scenario V1c is equal to 6.5 GWh, corresponding to $1.7x10^{-5}$ of the overall supplied load. Compared to the Scenario V1b, in which both pumped-storage plants and additional 2,000 MW of VRES were present, EENS for lack of power or lack of interconnection show the highest growth as predictable, due to lower installed capacity.

Table 135 - Scenario V1c - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	71	1,662	25	1,758
TOTAL NWE	1,314	119	721	2,154
TOTAL PAT	0	524	0	524
TOTAL SIC	137	554	720	1,411
TOTAL SING	64	236	301	601
TOTAL	**1,585**	**3,095**	**1,768**	**6,448**

The following table shows that the increase of thermal cost is located mainly in NEC and SIC areas. The overall generation costs are 290 M$ higher than Scenario V1b due to a lower VRES production which must be compensated by the thermal one (the saving of nearly 20 M$ in costs due to network constraints is already considered). The reduction of generation due to situation of power surplus is reduced to less than half the previous value.

Compared to the Base Case for Variant 1, the introduction of 2,900 MW of VRES plants brings a saving of nearly 390 M$, but in the initial case there was nearly no curtailed energy due to overgeneration.

Table 136 - Scenario V1c - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	176,873	7,093	0	-537	266	6
NWE	58,484	1,814	73	-492	235	-2
PAT	26,268	134	20	-261	5	-4
SIC	93,238	2,364	31	-126	888	52
SING	30,571	1,439	1	-75	98	2
TOTAL	**385,434**	**12,844**	**125**	**-1,491**	**1,492**	**54**

Table 137 and Table 138 sum up the results of the expected PV and wind production which is lower than in the previous Scenario because of the lesser installed capacity. It is interesting to note that also curtailments are reduced, being 130 GWh against previous 400 GWh for PV and about 160 GWh against previous 300 GWh for wind plants. The reduction of the curtailments even if pumped storage plants are not active underlines that the amount of overall VRES in the system has a greater influence on the energy which cannot be injected in the grid than the presence of big storage plants.

Table 137 - Scenario V1c - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	0	0	2,452
NWE	24,798	73	-37	0	2,441
PAT	0	0	0	0	
SIC	13,586	16	-2	0	2,455
SING	2,316	0	0	0	2,637
TOTAL PHOTOV. GENER.	**40,743**	**89**	**-40**	**0**	**2,456**

Table 138 - Scenario V1c - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	16,622	0	-8	0	3,981
NWE	772	1	0	0	2,559
PAT	17,914	20	-130	0	4,564
SIC	9,269	5	0	0	2,405
SING	1,430	0	-1	0	2,670
TOTAL WIND GENER.	**46,007**	**26**	**-140**	**0**	**3,595**

Looking at the energy exchanges reported in Table 139, it can be noted that negligible variations are present concerning the interconnections between the two countries, while some slight difference happens in the inter-area exchanges within a country, depending on the position of the power plants. The changes are however not significant.

Table 139 - Scenario V1c - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	933	1,505	856	1,546	1	0
PAT	NEC	4,250	4,250	17,194	15	16,829	15	341	0
NEC	NWE	4,300	4,300	13,653	8,304	13,278	8,457	109	606
SIC	NWE	900	900	1,506	4,292	1,465	3,607	630	2,449
SING	NWE	300	300	504	961	503	818	269	816

Figure 65 provides a visual summary of the operation of the system in the Scenario V1c: comparing it with Figure 64 relevant to Scenario V1b, it can be noted in particular the decrease of the curtailed energy.

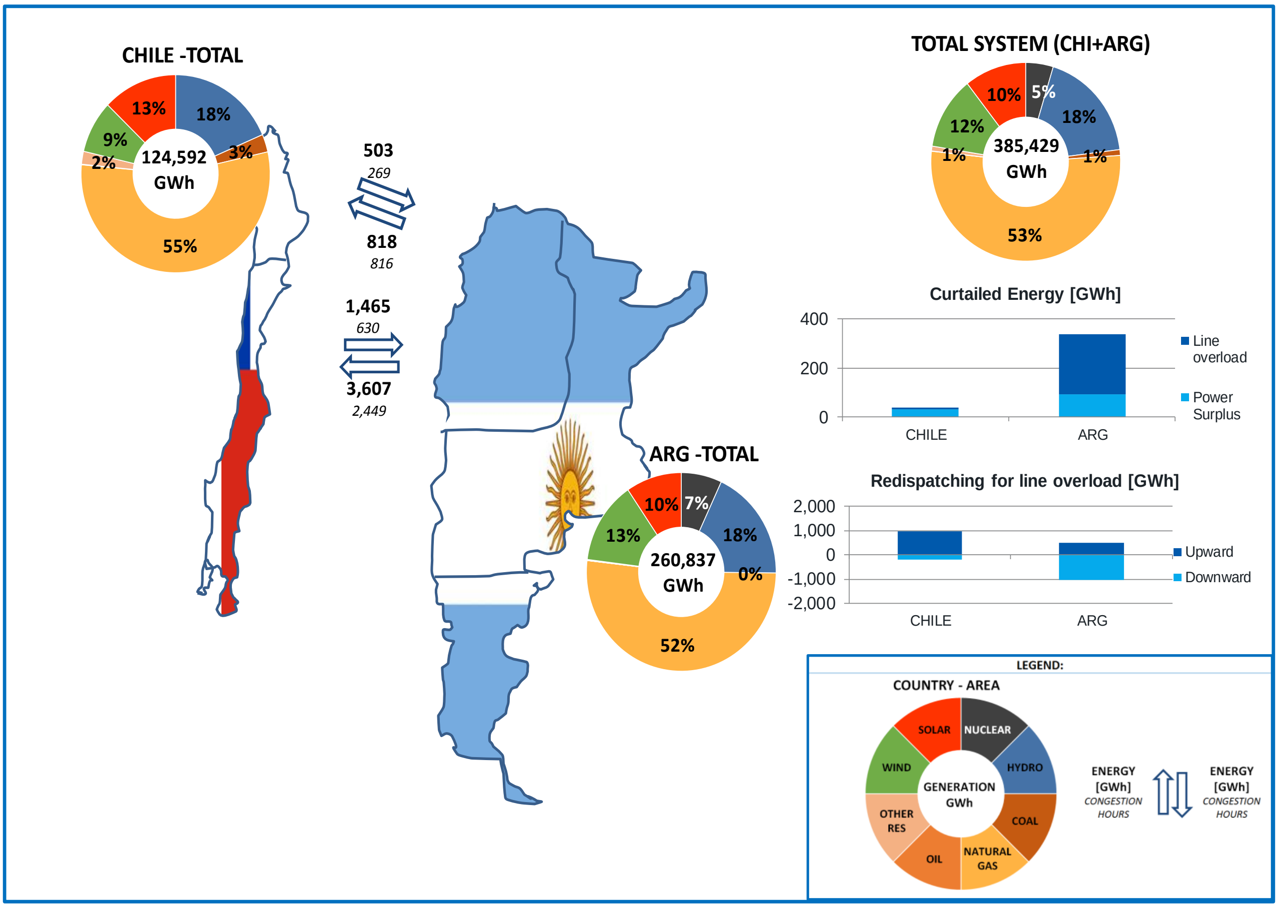


Figure 65 - Scenario V1c - Total production and energy exchanges

From an economical point of view, this Scenario V1c can be compared to the previous Scenario V1b since the only difference between them is the presence of the pumped-storage plants (and the part of the additional VRES related to the presence of these plants). The data that must be taken into account in the comparison between Scenario V1c and V1b are sum up in the following Table 140:

Table 140 - Scenario V1c - Total benefit compared to scenario with pumped-storage

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	-2,000	+233
NEW CCGT AVOIDED	0	0
ADDITIONAL PUMPED STORAGE	-1,600	+300
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	4,862	-287
RES CURTAILMENT	-388	-
TOTAL EENS	3	-6
TOTAL BENEFIT	**-**	**+241**

A big amount of avoided costs can be related to the absence of pumped-storage plants and another part to the additional VRES. The system has an overall higher thermal cost and higher EENS, but the sum of these two drawbacks is lesser than the avoided cost. It can be then said that this scenario is more cost-effective than the scenario with the pumped-storage plants. As already underlined in the previous analysis, the main reason for this result is the high cost of the pumped storage system, which are not paid back by the only benefit introduced in terms of dispatch of renewable energy. The advantages for the electrical system introduced by this type of plants should be analysed also taking into account their short term and real time performances, which provides a great contribution to the frequency regulation which is not considered in the present long term planning analysis.

It is possible to compare the results of this Scenario V1c also with the Base Case for Variant 1. The difference between the two scenarios are the 2,900 MW of additional VRES and 850 MW of CCGT lesser. The main economic data useful for the comparison are listed in the following Table 141.

Table 141 - Scenario V1c - Total benefit compared to reference scenario

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	2,900	-348
NEW CCGT AVOIDED	850	+74
ADDITIONAL PUMPED STORAGE	0	0
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-7,994	+388
RES CURTAILMENT	252	-
TOTAL EENS	2	-3
TOTAL BENEFIT	**-**	**+111**

This Scenario V1c is indeed more convenient than the Base Case for Variant 1: the savings in the total thermal costs and the avoided investment costs in CCGT exceed the investment cost in the VRES.

4.2 Second Variant: enhanced energy efficiency

In the second variant a lower demand scenario has been considered. According to the load reduction also the generation fleet has been modified compared to the Reference Scenario, in particular no new conventional generation has been added because the generation considered in the targets of each country was enough to guarantee the system adequacy. Furthermore, 1,600 MW of pumped storage has been included in the Variant 2 in order to reduce the risk of energy curtailments which becomes more challenging in this low load scenario.

The key parameters that are modified with respect to the Reference Scenario are described below.

Demand

In this Variant 2 a scenario with lower demand is analysed. The main drivers which can contribute to a demand lower than the one in the Reference Scenario is a possible lower economic growth of the country and improvement of energy efficiency. According to what defined in [1], the load is reduced 15% in Argentina and 10% in Chile, as for this country energy efficiency has been already partially considered in the definition of the load applied in Reference Scenario. The demand reduction, caused by a general impact of energy efficiency is distributed proportionally in all the regions.

The changes of the demand considered in this Variant 2 are summarized in the following table.

Table 142 - Second Variant - Energy reduction

COUNTRY	Energy reduction [GWh]
Argentina	-34,454
Chile	-16,753

Generation

The generation fleet assumed in Variant 2 is the same as the one described in paragraph 3.4.3.3, i.e. with the optimal amount of VRES plants defined for the interconnected system in the Reference scenario. The new conventional power plants (CCGTs) added by CESI in the Reference scenario are not considered anymore because no needed anymore as the lack of power is limited also without them thanks to the reduction of the energy demand and power demand peak.

As for the Variant 1, three pumped storage has been introduced in the system with a total installed capacity equal to 1,600 MW. The main data of the pumped-storage are shown in the following table.

Table 143 - Second Variant - Pumped-Storage main data

AREA	Pmax [MW]	Pmin [MW]	Pumping equivalent hours	Connection node	Unit cost [k$/MW]	Lifetime [years]
Argentinean plant	1,000	-1,000	8	Gran Mendoza 500kV	2,000	40
Chilean plant n°1	300	-300	8	Polpaico 500kV		
Chilean plant n°2	300	-300	8	Domeyko 220kV		

In order to understand the economic viability of investment, for these plants it has been considered an investment cost of 2,000 k$/MW and a lifetime equal to 40 years.

The VRES installed capacity is reported in Table 96. A reduction of VRES installed power has been assessed in this second variant in order to estimate the impact on the energy curtailment and system costs variation.

Transmission
Variant 1 considers the same transmission system as in the Reference Scenario, because the lower overall demand should in general reduce the power flow on the lines, not requiring any reinforcement.

Analyzed Scenarios
The Base Case for Variant 2 is defined starting from the final configuration analysed with Argentina and Chile interconnected (paragraph 3.4.3.3). Due to lower load, high curtailments are expected, even if pumped-storage plants are introduced.
Then, some further scenario are simulated defined as follow:

- Scenario V2a: the amount of VRES installed power in the system is reduced by 3,000 MW with respect to the Base Case, to reduce high VRES energy curtailments.
- Scenario V2b: in the last scenario, the reduction of the minimum power constraints of the thermal dispatchable generators is simulated. In a low load Variant, a greater flexibility of the generators towards low power can provide positive benefits.

4.2.1 *Base Case Scenario for Variant 2*

A ***Base Case for Variant 2*** has been defined and analysed starting from the Reference Scenario with optimal economic amount of additional VRES with the interconnected countries (3.4.3.3). The total amount of VRES installed power is recalled in the following table.

Table 144 - Base Case for Variant 2 - Total VRES installed capacity in High Load Reference Scenario [MW]

AREA	PV installed power	Wind installed power
NEC	18	3,767
NWE	8,936	302
PAT	0	3,490
SIC	4,932	3,717
SING	729	535

The ***load is reduced*** by 15% in Argentina and 10% in Chile, simulating the impact of energy efficiency on the power system.
The ***generation fleet is the same*** considered in the targets published by Argentinian and Chilean authorities. Three new pumped-storage plants are added in the system, one in Argentina with 1,000 MW installed capacity and two 300 MW ones in Chile.

The simulation of this scenario, which becomes the reference for further tests, brings to the following results:

- ***EENS*** is around 0.3 GWh; it is about 0.9×10^{-6} of the total load.
- ***Overall generation costs*** are close to 8,400 M$, corresponding to an average generation cost equal to 27.7 $/MWh; there is a reduction of the costs of about 25% compared to the Reference Scenario due to both decreased load and the presence of storage technologies which support an effective operation of the generation fleet.
- Expected ***generation by PV*** power plants is around 35,200 GWh; curtailments reach the considerable amount of 800 GWh (2.3% of the production), more than 500 GWh higher than the value obtained in the Reference Scenario (paragraph 3.4.3.3).
- Expected ***generation by wind*** power plants is close to 41,900 GWh; curtailments are higher than 250 GWh, 200 GWh more than in the Reference Scenario (paragraph 3.4.3.3).

The following Table 145 shows the EENS, expressed as MWh/year, split by area and reason. As can be seen, the lower demand implicates a decrease in the EENS compared to the Reference Scenario, although in this Second Variant the new CCGTs added by CESI in the Reference Scenario are not present. Most of EENS is due to line overloads (243 MWh), a very low value compared to the total demand (0.9×10^{-6}), mainly because no lack of power is present and the transmission line is in general not loaded, and the demand curtailment happen just in very rare operational conditions.

Table 145 - Base Case for Variant 2 - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	0	143	0	143
TOTAL NWE	0	74	4	78
TOTAL PAT	0	12	0	12
TOTAL SIC	0	3	19	22
TOTAL SING	0	11	2	13
TOTAL	**0**	**243**	**25**	**268**

Table 146 shows the total energy produced in each area and the related costs. Overall generation costs are close to 8,400 M$/year in the whole system which means a reduction of the costs of about 25% compared to Reference scenario in which the load was higher. The lower load and the presence of storage technologies which support an effective operation of the generation fleet allows to minimize the usage of expensive plants, and also increases the conditions in which only very cheap generation is used. Network constraints are responsible for about 80 M$, which is 15% less than the value obtained in the Reference scenario.

Table 146 - Base Case for Variant 2 - Total production and fuel costs

	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	134,630	4,935	0	-289	1,408	80
NWE	44,612	1,207	362	-829	467	11
PAT	23,987	111	163	-199	42	0
SIC	72,194	1,023	143	-863	223	-14
SING	27,592	1,035	1	-141	182	2
TOTAL	**303,015**	**8,311**	**669**	**-2,321**	**2,322**	**79**

The following table shows PV generation and curtailments for each area of the system. The final production is around 35,200 GWh/year; 60% of the production is concentrated in Argentina while the remaining part is produced in Chile. The energy curtailed is significant (more than 800 GWh, nearly 2.5% of the overall PV generation) and, in similar part, is due to both power surplus and line overload, mainly as a consequence of the demand reduction. The high value of curtailments due to overgeneration, which is the highest presented so far, indicates that too often there are conditions in which the system is operating with all the dispatchable generators at the minimum power, and the overall production including the non-dipatchable plants is still higher than the load. Such conditions are critical for the system because there is very low flexibility being all the plants at the minimum, and in addition cheap energy is wasted. This is the situation which should be avoided or at least minimized defining the limits of maximum installable VRES capacity calculated in Chapter 2. In this Base Case for Variant 2 we are in fact considering the VRES power installed in presence of the higher load analysed in the Reference scenario, which becomes too much leading to many overgeneration conditions when the load is lower.

The average LCOE for the PV plants considered in this Base Case for Variant 1 is 42.6 $/MWh in Argentina and 27.7 $/MWh in Chile.

Table 147 - Base Case for Variant 2 - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-2	0	2,278
NWE	21,549	357	-357	0	2,332
PAT	0	0	0	0	-
SIC	12,041	85	-3	0	2,424
SING	1,920	1	0	0	2,632
TOTAL PHOTOV. GENER.	**35,553**	**443**	**-362**	**0**	**2,378**

In Table 148 wind production results of the Base Case for Variant 2 are presented.
The final annual wind production reaches more than 41,800 GWh/year, while the curtailed energy is higher than 250 GWh, mainly for power surplus. Also in this case this value is the highest obtained so far, highlighting the critical operating condition faced by the system with high VRES installed capacity and low load. However, it can be noted that wind production is less affected by curtailments than PV because the areas where wind plants are installed are less congestioned.

Table 148 - Base Case for Variant 2 - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	14,857	0	-2	0	3,943
NWE	768	5	-33	0	2,417
PAT	15,920	163	-33	0	4,505
SIC	8,919	27	0	0	2,392
SING	1,429	0	0	0	2,671
TOTAL WIND GENER.	**41,893**	**195**	**-68**	**0**	**3,525**

Table 149 gathers information on the interconnections.
The amount of energy exchanged through the lines remains similar (6.2 TWh). The loading of the international interconnections is the following:

- from SIC to NWE: 26%; from NWE to SIC: 36%
- from SING to NWE: 25%; from NWE to SING: 26%

A general increase of the energy flow from Argentina to Chile can be observed, as the net energy exchange is about 0.8 TWh from East to West, while in the Reference scenario Chile exported more than 0.5 TWh.

Concerning the connections between areas within the countries, there is more energy exchanged between SING and SIC and between NEC and NWE.

Table 149 - Base Case for Variant 2 - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year] BEFORE RE-DISPATCHING		ENERGY EXCHANGES [GWh/year] AFTER RE-DISPATCHING		SECTION LIMIT REACHED [h/year]	
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	3,793	1,051	3,766	938	61	1
PAT	NEC	4,250	4,250	17,453	2	17,592	1	205	0
NEC	NWE	4,300	4,300	11,216	7,942	11,189	6,953	19	333
SIC	NWE	900	900	2,500	2,754	2,037	2,846	1,165	1,171
SING	NWE	300	300	743	723	664	689	454	710

Figure 66 provides a visual summary of the operation of the system in the Base Case for Variant 2 Compared to the situation presented in Figure 61 relevant to the Reference Case, it is possible to note the inversion of the energy exchanges between the countries and the presence of a big amount of curtailed energy due to overgeneration in the system.

Moreover, the energy mix in the overall system and in the countries shows the strong reduction of the share covered by Natural Gas and the increase of the VRES penetration, which reaches more than 25% of the overall demand.

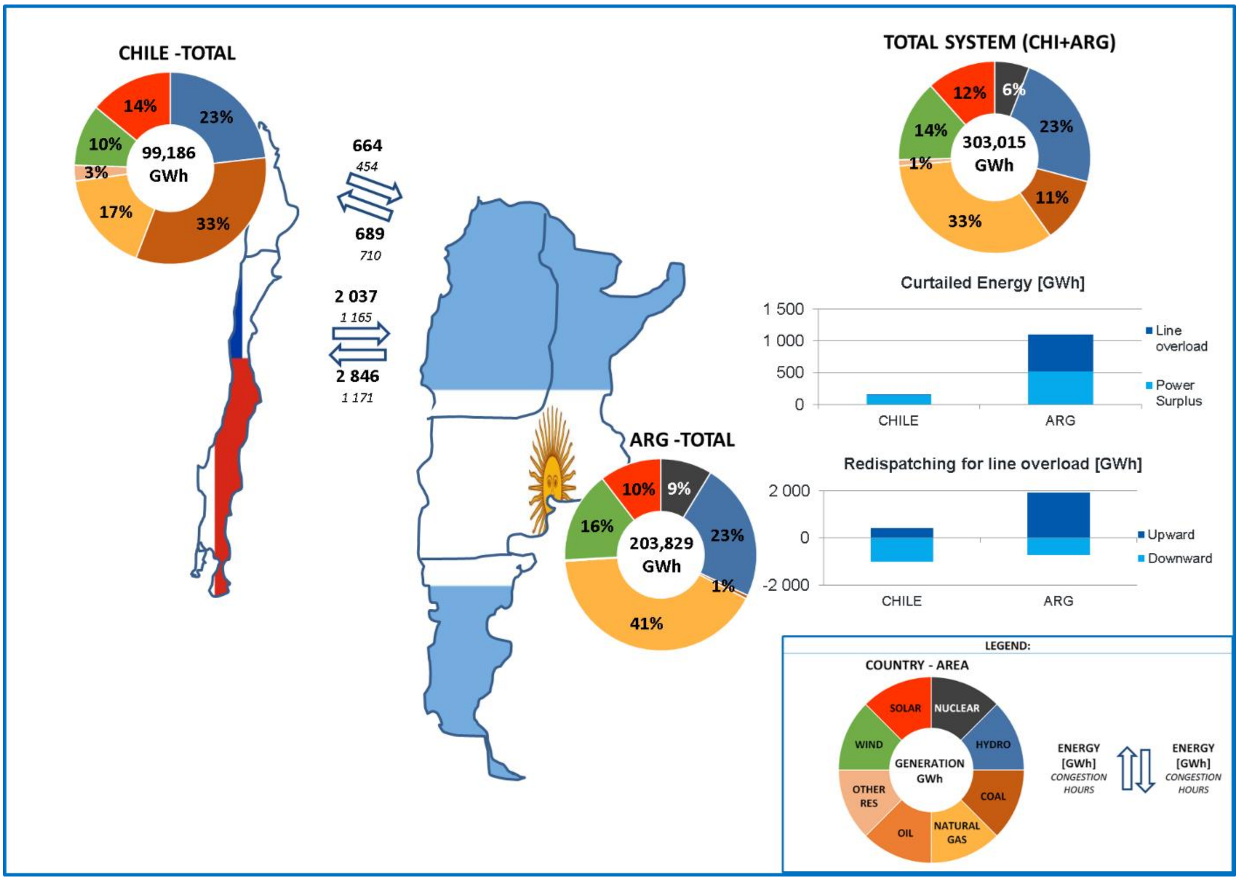


Figure 66 - Base Case for Variant 2 - Total production and energy exchanges

4.2.2 *Scenario V2a: removal of 3,000 MW of VRES*

The Base Case for Variant 2 showed a huge VRES energy curtailment (more than 1,200 GWh). This amount of overgeneration suggests performing a further simulation with a ***reduced VRES installed capacity***. The scenario described in this paragraph does not consider 3,000 MW of additional VRES introduced in the optimal scenario of the Reference Case.
The Table 150 sums up the VRES installed capacity in this scenario.

Table 150 – Scenario V2a - Total VRES installed capacity [MW]

AREA	PV installed capacity	Wind installed capacity
NEC	18	3,468
NWE	8,035	302
PAT	0	3,191
SIC	3,917	3,486
SING	475	535

Load and conventional generation fleet are the same as in the Base Case for Variant 2: low load and new pumped storage are considered.

The simulation of this scenario, brings to the following results:

- ***EENS*** is around 0.3 GWh; it is about 1.1×10^{-6} of the total load
- ***Overall generation costs*** are close to 8,730 M$, of which 59 M$ due to network constraints; the thermal costs increase more than 4% with respect to the Base Case for Variant 2 because of the lower VRES generation.
- Expected ***generation by PV*** power plants is close to 30,280 GWh: 4,900 GWh less than the Base Case for Variant 2 (-14%). The curtailments are 338 GWh (about 1% of theoretical production) respect to more than 800 GWh.
- Expected ***generation by wind*** power plants is close to 38,690 GWh, with a reduction of 3,100 GWh (-7%) respect to the Base Case for Variant 2. The production curtailments are 111 GWh (less than 1% of theoretical production and half than the values in the Base Case).

The operational cost increase when 3,000 MW VRES plants are removed is greater than the investment cost in those plants, highlighting that even in a lower demand scenario it might be convenient to consider the same optimum economic VRES installed power identified in paragraph 3.4.3.3. This solution remains a stable reference value even when a significant reduction of the load is considered.

The Scenario V2a described in this paragraph considers a reduction of 3,000 MW VRES compared to the Base Case for Variant 2. This last one in fact highlighted a significant amount of energy curtailment (1,200 GWh), mainly due to situations with overgeneration caused by the reduced load in the system. For this reason, the changes in operational conditions suggest to investigate the cost opportunity of the optimal amount of VRES estimated with another demand level.

The following table shows the EENS, expressed as MWh/year, split by area and type. As can be seen, less installed generation determines a 25% of EENS increase compared to the Base Case for Variant 2 but its value remains acceptable as a percentage of the total load (1.1×10^{-6} of the total load). As expected, the lack of power component is still null, because of the reduced peak load which characterize this variant.

Table 151 - Scenario V2a - Expected Energy Not Supplied

EENS [MWh/Year]	Lack of Power	Line overload	Lack of interconnection	TOTAL
TOTAL NEC	0	164	0	164
TOTAL NWE	0	95	12	107
TOTAL PAT	0	9	0	9
TOTAL SIC	0	12	33	45
TOTAL SING	0	11	2	13
TOTAL	**0**	**291**	**47**	**338**

Table 152 shows the total energy produced in each area and the related costs. In the Base Case for Variant 2, overall generation costs were close to 8,400 M$/year (of which 79 M$ due to network constraints). The values reported for Scenario V2a highlight an overall cost of 8,728 M$/year given by the sum of the dispatching cost (8,669 M$/year) and costs due to the network congestions (59 M$/year). The dispatching cost increases by more than 4% because the 3,000 MW of VRES with zero variable cost have to be replaced by conventional generation, while the redispatched energy and the relevant cost decreases (with a saving of 20 M$/year) because of the lower variable generation in the critical areas.
It is important also to underline the reduction of curtailed energy in the situation of overproduction, which passes from 669 GWh to 226 GWh.

Table 152 - Scenario V2a - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	136,710	5,093	0	-290	1,007	56
NWE	43,404	1,245	137	-685	471	9
PAT	22,789	116	67	-105	27	0
SIC	71,349	1,118	22	-704	195	-10
SING	28,326	1,097	0	-111	195	4
TOTAL	**302,578**	**8,669**	**226**	**-1,895**	**1,895**	**59**

The following table shows PV generation and curtailments for each area of the system. Total production is around 30,280 GWh/year and the energy curtailment is reduced to less than half of the value found in the Base Case for Variant 2 (338 GWh against more than 800 GWh), thanks to the lower share of VRES.
From the difference between this Scenario V2a and the Base Case for Variant 2, it is possible to calculate the LCOE that the PV plants not considered in this scenario would have had: in Scenario V2a PV plants in Argentina would have had a LCOE equal to 45.3 $/MWh, while PV plants in Chile a LCOE equal to 28.3 $/MWh. These values are higher than the average calculated in Base Case for Variant 2 because the

curtailments caused by the presence of these additional plants would be in percentage higher than the average value, reducing the expected producibility of the plants and increasing their LCOE.

Table 153 - Scenario V2a - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-1	0	2,386
NWE	19,561	135	-192	0	2,394
PAT	0	0	0	0	-
SIC	9,620	10	0	0	2,453
SING	1,252	0	0	0	2,638
TOTAL PHOTOV. GENER.	**30,476**	**145**	**-193**	**0**	**2,422**

Table 154 shows generation and curtailments of wind farms for each area of the system. Total production is around 38,700 GWh/year and, and expected curtailment about 100 GWh, respect to more than 250 GWh in the Base Case for Variant 2.

Also in this case, it is possible to estimate that the LCOE for wind plants in Argentina would have been equal to 42.5 $/MWh, while in Chile 72.6 $/MWh.

Table 154 - Scenario V2a - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	13,525	0	-1	0	3,900
NWE	771	2	-22	0	2,475
PAT	14,620	67	-15	0	4,556
SIC	8,385	4	0	0	2,404
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**38,731**	**73**	**-38**	**0**	**3,517**

Table 155 gathers information about the interconnections.

Not significant changes happen between the countries, while it is possible to see an increase of the energy flows from SING to SIC and from NEC to NWE, because of the reduction of the PV installed capacity in the importing areas.

Table 155 - Scenario V2a - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	4,308	852	4,281	727	75	0
PAT	NEC	4,250	4,250	15,978	2	16,279	1	84	0
NEC	NWE	4,300	4,300	10,946	6,430	10,953	5,799	11	83
SIC	NWE	900	900	2,492	2,815	2,101	2,834	1,179	1,234
SING	NWE	300	300	734	710	665	656	381	720

Figure 67 provides a visual summary of the operation of the system in the Scenario V2a with 3,000 MW reduction of VRES, highlighting the generation mix per areas, the energy exchanges between areas, the curtailed VRES production and thermal redispatching needed to solve network congestions. Compared to the Base Case for Variant 2, a strong reduction of the curtailed energy can be observed, even if the amount due to overgeneration is still higher than the values observed in Reference Scenario.

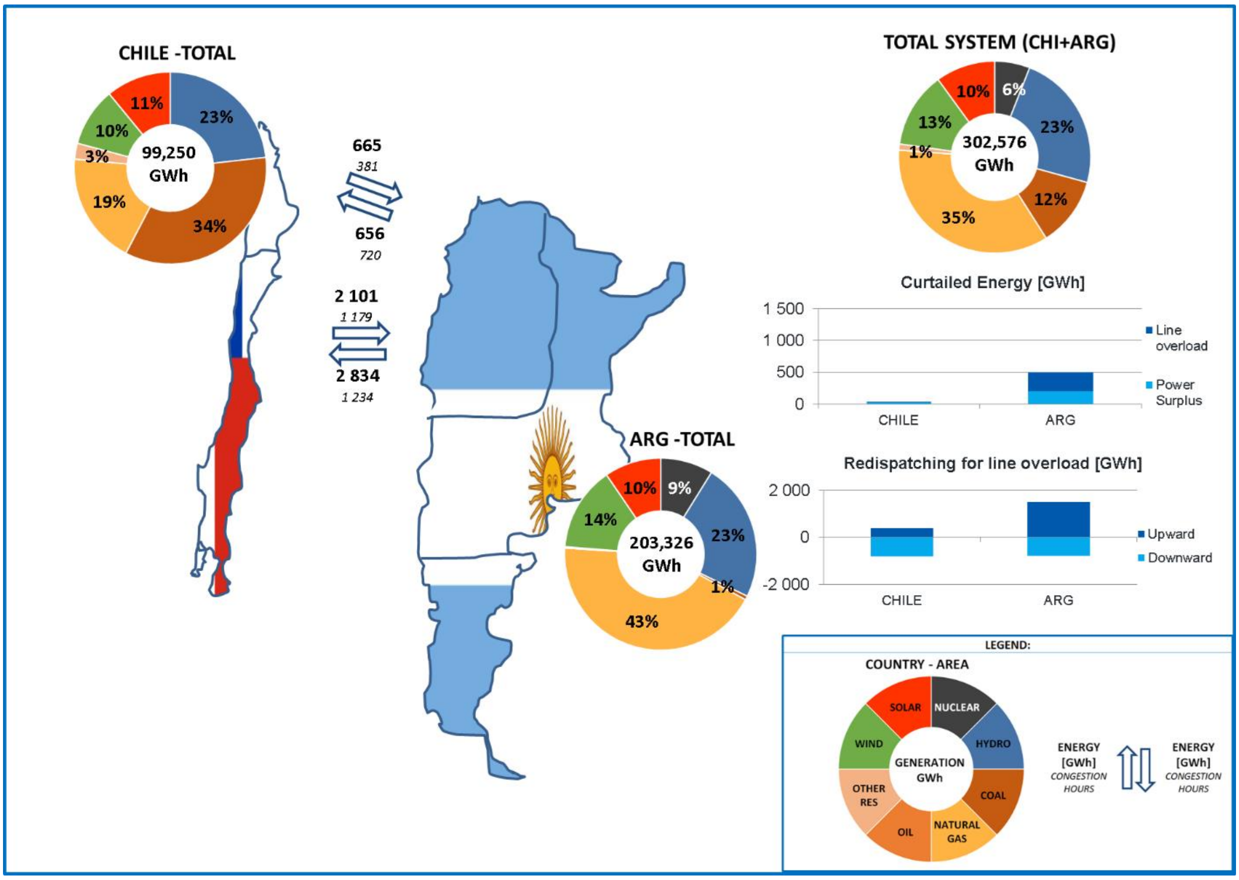


Figure 67 - Scenario V2a - Total production and energy exchanges

Comparing the economic viability of Scenario V2a with the Base Case for Variant 2, it should be taken into account the cost increase of thermal generation (338 M$) and the savings due to avoided investment cost in new VRES generation (329 M$). The two values are similar and as can be seen in Table 156, the total benefit of reducing installed VRES by 3,000 MW is slightly negative (-9 M$), which would indicate the opportunity to invest in VRES even in this scenario with a significant load reduction. But the benefit is very low compared to the big investments needed for the VRES plants which probably constitutes a risk. With the high amount of VRES plants many constraints are introduced in the system, forcing the thermal generators to often work at their minimum power with no flexibility during operation needed to follow the load and the VRES variations. The operation of the system in this condition, if one hand theoretically can provide a slightly lower energy price, on the other hand can cause a big increase of the costs for the real time operation, leading to a non-optimal situation. Moreover, there are big uncertainties in the planning phase and some variables can be actually very different from the supposed ones: a situation with a very limited benefit could easily become negative if some parameter change, and this risk would be difficult to accept.

Table 156 - Scenario V2a - Total Benefit

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	-3,000	+329
NEW CCGT AVOIDED	0	0
NEW PUMPED STORAGE AVOIDED	0	0
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	7,440	-338
RES CURTAILMENT	-619	-
TOTAL EENS	0	0
TOTAL BENEFIT	**-**	**-9**

4.2.3 Scenario V2b: reduction of minimum power constraint of thermal power plants

In this Scenario V2b the effect of a reduction of the ***minimum power constraint*** for the generators is analysed, considering the same assumptions of the Base Case for Variant 2 in terms of demand, network and generation fleet with the only exception of technical minimum of thermal power plants.
Minimum power has been modified for those plants with the worst performances and it has been set to 35% of their maximum power, which is considered as a reference value for the modern technologies and is adopted in planning studies in countries with high VRES penetration. This scenario aims at simulating the impact of investment in existing and planned generation with the objective of reaching an increased flexibility of the system, which is a fundamental requirement for VRES integration.

The simulation of this scenario, brings to the following results:

- ***EENS*** does not change and remains around 0.3 GWh; it is lower than $1x10^{-6}$ of the total load
- ***Overall generation costs*** are 8,285 M$; the thermal costs decrease by about 100 M$ (-1.3%) compared to the Base Case for Variant 2. The decrease should be compared with the investment in reducing the technical minimum of thermal power plants.
- Expected ***generation by PV*** power plants is more than 35,400 GWh: The production curtailments are lower than 600 GWh (less than 1.7% of theoretical production).
- Expected ***generation by wind*** power plants is a bit higher than 41,900 GWh. The production curtailments are 164 GWh (less than 1% of theoretical production).

The results of the simulation carried out for the Base Case for Variant 2 showed a considerable amount of curtailed VRES energy due to situations with overgeneration in the system. A high penetration of VRES plants reduces the utilization of thermal power plants, and at the same time needs them to cope with high fluctuation of the residual load due to the variability of VRES production. When the system does not have enough flexibility and cannot match production and load, curtailments of demand or generation become necessary.
The Scenario V2b wants to investigate the benefits that a reduction of minimum power constraint of thermal generation can introduce in the system, ensuring higher flexibility of the generation fleet.

The variation of the minimum power constraint has nearly no impact on the EENS, which is more related to the availability of generation in the system. Only a minor effect might be observed for the EENS caused by overloaded lines.

Overall generation costs, reported in Table 157, decrease by more than 100 M$. This is due to the fact that expensive generators which often have to be available to cover the high load situations, but which often operate at their minimum, become less expensive because part of the energy produced when constrained at their minimum power can be replaced by cheaper plants.

It is also important to underline that with a higher flexibility the system needs to cut less production due to overgeneration, saving nearly the half of what was wasted in the Base Case (the total curtailments due to minimum power constraint sum up to 335 GWh against 669 GWh).

Table 157 - Scenario V1c - Total production and fuel costs

ALL GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING			VARIATION AFTER REDISPATCHING		
AREA	GWh/year	M$/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	M$/year
NEC	134,201	4,856	0	-244	1,743	96
NWE	44,062	1,135	178	-934	485	8
PAT	23,895	96	76	-210	52	0
SIC	73,482	1,079	81	-1,125	175	-24
SING	27,617	1,037	0	-200	258	3
TOTAL	**303,257**	**8,203**	**335**	**-2,713**	**2,713**	**83**

In Table 158 and Table 159, which report the production of PV and wind plants, it is possible to observe the same trend: the curtailments due to overgeneration are nearly the half of what was calculated in Base Case for Variant 2 (223 GWh against 443 GWh for PV, 93 GWh instead of 195 GWh for wind), while the curtailments due to line overloads remain nearly unchanged.

Table 158 - Scenario V1c - Total production of PV plants

PHOTOVOLTAIC GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	43	0	-2	0	2,278
NWE	21,730	176	-366	0	2,371
PAT	0	0	0	0	-
SIC	12,079	47	-2	0	2,439
SING	1,921	0	0	0	2,635
TOTAL PHOTOV. GENER.	**35,773**	**223**	**-370**	**0**	**2,407**

Table 159 - Scenario V1c - Total production of Wind plants

WIND GENERATORS	PRODUCTIONS & FUEL COSTS BEFORE REDISPATCHING		VARIATION AFTER REDISPATCHING		EOH
AREA	GWh/year	Reduction Min.Tec.Gen. GWh/year	GWh/year DP < 0	GWh/year DP > 0	h/year
NEC	14,857	0	-2	0	3,943
NWE	771	2	-36	0	2,427
PAT	16,008	76	-33	0	4,556
SIC	8,931	15	0	0	2,399
SING	1,430	0	0	0	2,673
TOTAL WIND GENER.	**41,997**	**93**	**-71**	**0**	**3,542**

The variation of the minimum power of the generators modifies a bit the conditions in which the two countries operate in low load conditions, removing some constraints which in previous simulation might have influenced the balance of the countries. Comparing Table 160, which shows the energy exchanges across the sections in the Scenario V1c, with Table 149, which refers to the Base Case for Variant 2, it is possible to note that in this new configuration the two countries are nearly balanced (Chile exports 160 GWh towards Argentina) because reducing the limitation of the minimum power of the thermal generators in Argentina, more energy produced by cheap coal plants can be imported.

Table 160 - Scenario V1c - Interconnections

AREA A	AREA B	NTC [MW]		ENERGY EXCHANGES [GWh/year]				SECTION LIMIT REACHED [h/year]	
				BEFORE RE-DISPATCHING		AFTER RE-DISPATCHING			
		A -> B	A <- B	A -> B	A <- B	A -> B	A <- B	A -> B	A <- B
SING	SIC	1,500	1,500	3,814	1,282	3,774	1,113	69	5
PAT	NEC	4,250	4,250	17,446	3	17,588	1	202	0
NEC	NWE	4,300	4,300	11,037	8,449	11,053	7,124	32	462
SIC	NWE	900	900	3,049	2,217	2,451	2,440	1,507	768
SING	NWE	300	300	883	664	784	637	582	814

Figure 68 provides a visual summary of the operation of the system in the Scenario V1c. The main difference with respect to the Base Case can be found in the lower amount of curtailed energy for power surplus.

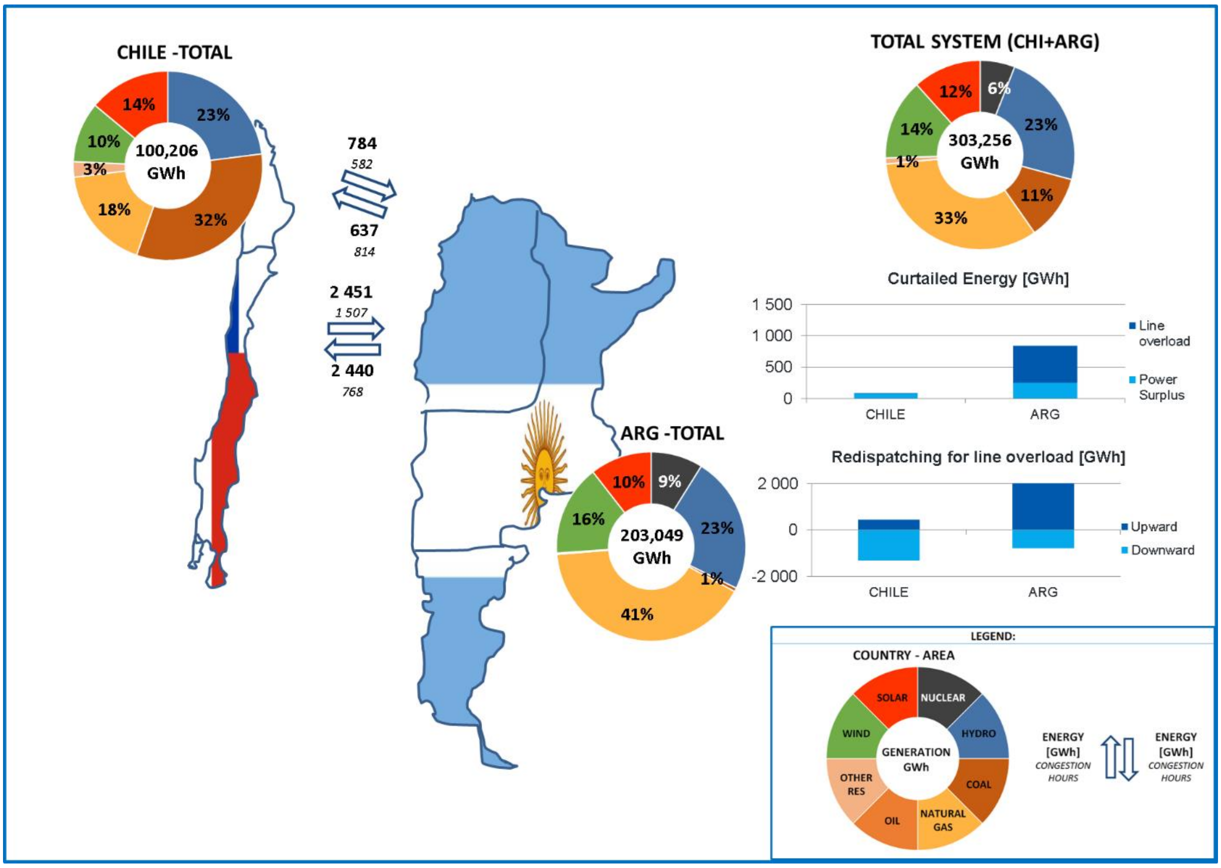


Figure 68 - Scenario V1c - Total production and energy exchanges

Finally, Table 161 reports the main economic figures for the evaluation of the benefits introduced by the reduction of the minimum power constraint of the thermal generator to values in line with international standards.

As explained above, under this assumption, the system becomes more flexible, and allows:

- not to waste more than 300 GWh of production with almost no variable costs (VRES and other imposed generation)
- cheap generation to replace more expensive ones in low load conditions

This results in an overall benefit equal to more than 100 M$, which should be compared with the costs of such improvement of the generation fleet. These costs are difficult to estimate and can greatly vary depending on generation technology and commissioning year (for existing generation). The definition of the actual costs for such upgrade should be done according to the specific project.

Table 161 - Scenario V1c - Total Benefit

	ELECTRICAL SYSTEM	ECONOMIC BENEFITS
	MW	MUSD/year
ADDITIONAL VRES	0	0
NEW CCGT AVOIDED	0	0
ADDITIONAL PUMPED STORAGE	0	0
	GWh/year	MUSD/year
TOTAL THERMAL GENERATION	-98	104
RES CURTAILMENT	-311	-
TOTAL EENS	0	0
TOTAL BENEFIT	-	**104**

4.3 Conclusions on Variants

Two Variants have been investigated focusing on a scenario of accelerated decarbonization in a strong economic development and on a scenario of enhanced energy efficiency.

The results of the first Variant showed that there is room for additional VRES installed capacity when the demand in the countries is higher than the one considered in the Reference scenario: in detail, for the analysed case, 2,900 MW of additional VRES plants can be added thanks to the load increase, and further 2,000 MW can be introduced if three pumped storage plants are also considered in the countries, which reduce the situations with overgeneration and risk of curtailments.

The presence of these additional VRES plants makes 850 MW of dispatchable power plants not necessary anymore to ensure system adequacy, allowing significant savings in investment costs.

Also the case without hydro pumped storage plants has been investigated, considering only 2,900 MW of new VRES plants, which correspond to the amount allowed by the load increase alone, and still replacing 850 MW dispatchable plants. This configuration shows the best economic figures, suggesting the non-convenience of hydro pumped storage plants when the evaluation is based only on the benefits generated by energy shifting and peak shaving, not big enough to cover the high investment costs for such technology. It is important to underline that the performed assessment, focused on long term planning, did not consider the advantages for the system that this kind of power plants provide in the real time operation, in particular for frequency regulation and reserve. If the corresponding benefits are also taken into account, the conclusions about their convenience might be different.

The investigation of the second Variant brought to the conclusion that although the lower load causes a strong increase of the risk of VRES production curtailments due to overgeneration when all the new plants are considered, the overall benefits remains slightly higher than the ones scored in case the VRES power plants are reduced by 3,000 MW. This means that the optimal amount of VRES plants identified in the Reference scenario still provides good benefits to the system even in case of a significant reduction of the demand, showing a good stability of the solution.

Moreover, the assessment of the system operation when minimum power constraint of some thermal generation units are relaxed, considering the minimum production limit equal to 35% of the nominal power, showed a good potential for further benefits when this higher flexibility of generation fleet is possible. The detailed evaluation should be carried out based on the comparison of project specific costs needed to allow such flexible operation and the benefits generated for the system.

5 LOAD FLOW ANALYSES IN SELECTED SNAPSHOTS

At the end of the activity during which the operation of the system(s) has been analysed with a probabilistic approach, simulating thousands of different operating conditions which might actually happen during a year, some Load Flow calculations have been performed[16], to describe some deterministic snapshots representative of particular situations.
The focus is to highlight some possible critical conditions which might require special countermeasures during the real time operation, and identify whether local reinforcements might be needed.
For this reason, four conditions have been selected among the thousands analysed in the probabilistic simulations by GRARE, characterized by:

- Low or high load
- Different level of renewable generation (PV, wind and hydro)

For each analysed scenario, a quick description of the power flows between areas and a list of the most overloaded lines is provided.
No overloads are expected in N condition, as the generation of the different power plants has been derived from the optimized active power dispatching performed by GRARE which already considered the network constraints, but it is expected that the same critical lines highlighted by the probabilistic analysis are operating at their limits also in these analysed snapshots.
N-1 analysis can identify some areas where the outage of a line causes critical overloads of other ones. If temporary overloads are acceptable, the system can be operated in such conditions provided that a fast redispatching to reduce overloads is possible in case of line fault. Otherwise, different transmission limits should be considered to ensure proper safety margins.
However, it is important to underline that this static analysis is focused on extreme conditions with high penetration of RES generation, and it is likely that criticalities will appear. These have been also taken into account during the probabilistic analysis, and brought to VRES production or even load curtailments (EENS). These risks have been evaluated with GRARE, weighted by their probability to happen, while the static analysis checks in a deterministic way what happens in the critical situations.

5.1 High load and high renewable production

In this paragraph a situation with high load and high renewable production is presented: in particular, in the selected case the load is equal to 57,629 MW and the value of renewable production is nearly 29,000 MW (i.e. about 50% of the demand).
Table 162 shows for this scenario the capacity factor, i.e. the ratio between the production in the analysed condition and the installed capacity for each type of RES: as it is possible to note the power generated by PV is equal to 91%, while the capacity factor of the wind is equal to 55%.

[16] DC LF have been performed, for sake of consistency with the results obtained in the previous analysis.

Table 162 - Capacity Factor for every type of renewable generation

Type	CF [%]
PV	91%
Wind	55%
Hydro	71%

Table 163 and Figure 69 summarize the power flows between the different zones resulting from the Load Flow calculations. It is interesting to note that NWE exports nearly 1 GW towards other areas and Patagonia, where the load is not big and there is a strong presence of hydro and wind plants, exporting 1,260 MW towards NEC.

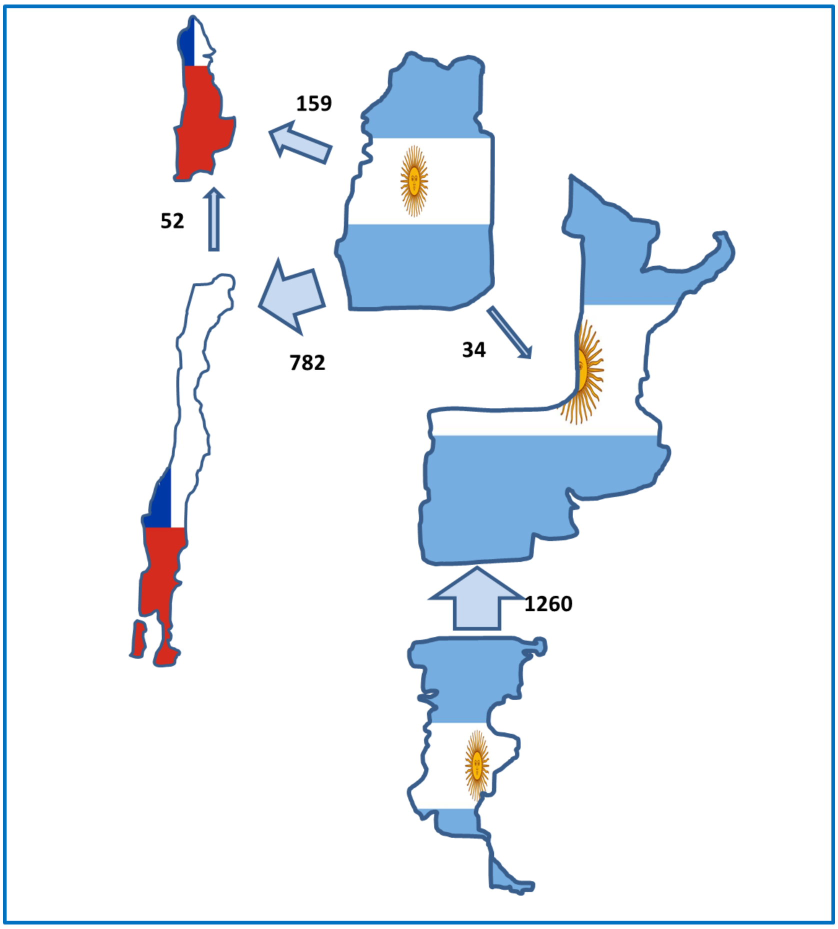


Table 163 – Power exchanges

From	To	[MW]
SIC	SING	52
PAT	NEC	1260
NWE	NEC	34
NWE	SING	159
NWE	SIC	782

Figure 69 - Static Analysis - Power exchanges with high load and high RES production

As expected, no line is overloaded in sound network condition, as the active power dispatching is obtained by the GRARE optimization which already considered the network constraints.
The most loaded lines are listed in Table 164: it can be noted that the ones which are closest to their transmission limit are art of the lines Rio Diamante-Charlone-Junin and Recreo-Malvinas, which are the most critical lines already identified during the probabilistic simulations.

Table 164 – Most loaded lines

Line	Un [kV]	I [%]
Rio Diamante - Charlone	500	99
Recreo - Malvinas	500	94
B.Blanca - Pbuena1	500	89
Henderson – 25 de Mayo	500	83
Olavarria - Abasto	500	80

The loading of these lines represents a warning signal in N condition. When the N-1 calculation is performed, the line between Recreo and Malvinas and the line between Rio Diamante and Charlone are overloaded for many contingencies, which modifies the distribution of the power flows in the area close to the NWE-NEC section. Therefore, in order to avoid redispatchings, renewable production curtailments or load shedding, network reinforcements might be needed. The effect of these reinforcements has been analysed with the probabilistic approach in paragraph 3.4.1.3.

5.2 High load and low renewable production

In this paragraph, the result of the Load Flow calculation performed on a situation with high load and low renewable production is presented. The value of load is 56,666 MW and the renewable production is a bit higher than 15,000 MW, about 26% of the total generation. A night case, with no production by PV plants, has been chosen.
Table 165 shows for this scenario the capacity factor of each different RES technology.

Table 165 – Capacity Factor for every type of renewable generation

Type	CF [%]
PV	0
Wind	71
Hydro	31

Table 166 and Figure 70 summarize the power flows between the different zones. It is possible to note that the interconnection between NWE and SIC is at the maximum limit (NTC on this section is defined equal to 800 MW), and that in this condition NWE needs to import more than 2,000 MW due to the absence of the PV production. In Argentina, power flows from PAT to NEC remains nearly unchanged because the wind production is high in this snapshot. In Chile, SING exports nearly 400 MW towards SIC.

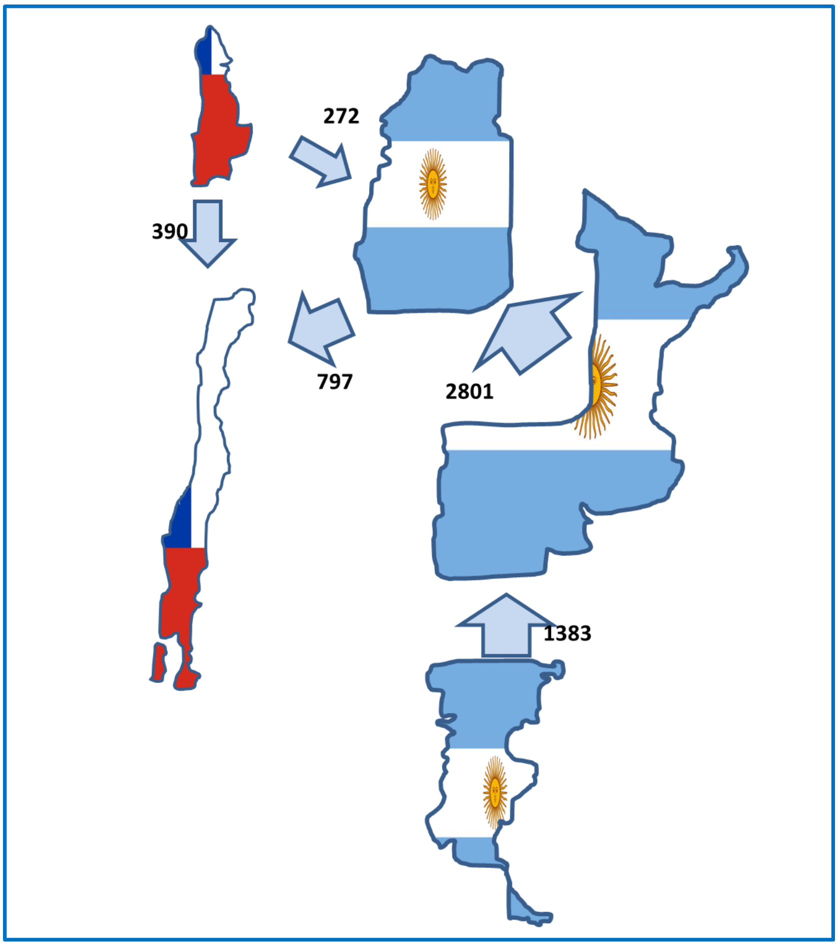


Table 166 – Power exchanges

From	To	[MW]
SING	SIC	390
PAT	NEC	1383
NEC	NWE	2801
SING	NWE	272
NWE	SIC	797

Figure 70 - Static Analysis - Power exchanges with high load and low RES production

As the Table 167 shows, in the analysed electric system there are some lines with high loading: in particular the 500 kV line starting from the area of Gran Mendoza and Rio Diamante and going eastwards towards Gran Buenos Aires are loaded close to their maximum. On the contrary, the absence of PV production in NWE area reduce the loading of the Recreo – Malvinas line.

Table 167 – Most loaded lines

Line	Un [kV]	I [%]
Rio Diamante - Charlone	500	99
Henderson – 25 de Mayo	500	99
Lujan – Gran Mendoza	500	93
Olavarria - Abasto	500	92
Cerrito de la Costa - Planicie Banderita	500	91
B.Blanca - Pbuena	500	89

The lines which are at their maximum transmission capacity can become overloaded in N-1 conditions. To avoid this situation, special attention should be paid during operation to ensure that generators can be redispatched to bring the power flows back in the allowable ranges in case of line faults.

5.3 Low load and high renewable production

As a third step, the system was analysed with low load and high renewable production: in particular the selected condition is characterized by a load equal to 31,787 MW and the value of renewable production is 19,403 MW, which corresponds to more than 60% of the demand.
The Table 168 shows for this scenario the capacity factor of each type of RES: as it is possible to note the selected snapshot has a quite even distribution of the RES generated power among the different technologies.

Table 168 – Capacity Factor for every type of renewable generation

Type	CF [%]
PV	49
Wind	53
Hydro	45

Regarding the power exchanges between the areas, Table 169 and Figure 71 summarize the results of the Load Flow calculations. With low load, the areas with high penetration of RES increase the export: in particular the power flow from PAT to NEC is nearly 2,000 MW, and from NWE to neighbouring areas more than 2,000 MW. In Chile, SIC exports more than 700 MW towards SING.

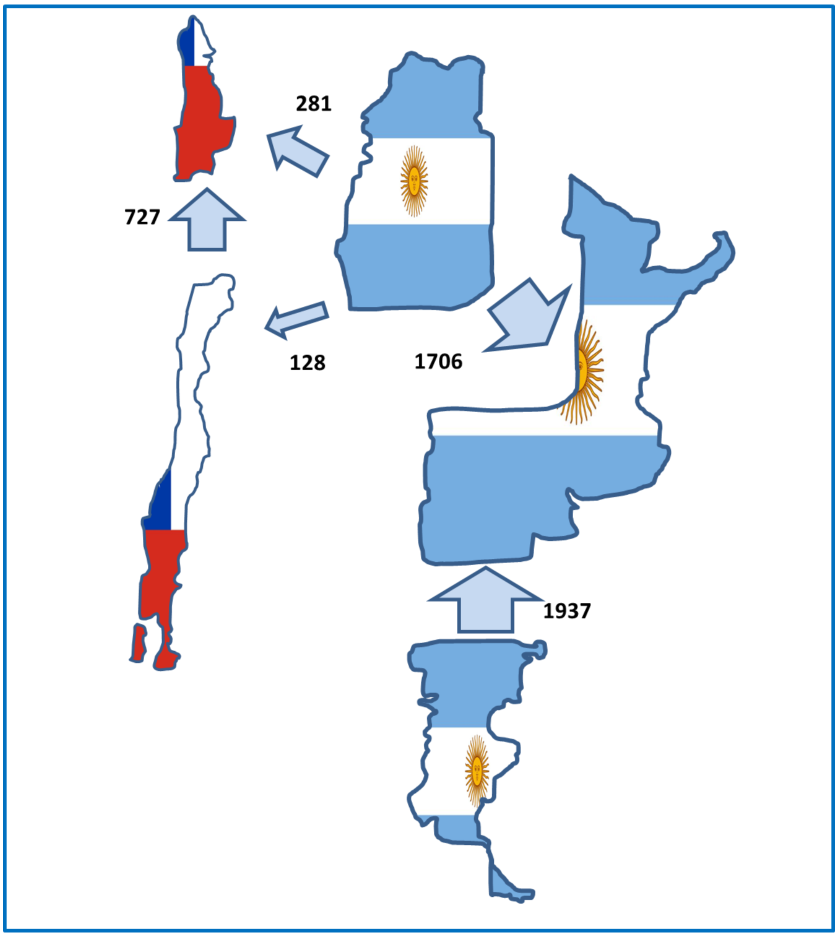


Table 169 – Power exchanges

From	To	[MW]
SIC	SING	727
PAT	NEC	1,937
NWE	NEC	1,706
NWE	SING	281
NWE	SIC	128

Figure 71 - Static Analysis - Power exchanges with low load and high RES production

In low load condition the transmission network is in general less stressed than in the previous snapshots. In fact the list of most loaded lines, reported in Table 170 is shorter. In addition to the Charlone – Rio Diamante line which was critical also before, in this case it is present also the line Santa Cruz Norte – Comodoro, which belongs to the corridor that from Patagonia brings the power to the Gran Buenos Aires area.

Table 170 – Most loaded lines

Line	Un [kV]	I [%]
Rio Diamante - Charlone - Junin	500	99
Santa Cruz Norte - Comodoro	500	83

Due to the high value of wind production and the low load in Patagonia, the lines in this region are loaded more than in previous snapshots, and in N-1 conditions there might be some violations of transmission capacity, for instance for the line Santa Cruz Norte – Comodoro in case of fault of the parallel line. These overloads can be solved with a fast reduction of the hydro or wind power in the southern part of Patagonia, so they are not critical for the system provided that upward reserve is available at north of the bottleneck.

5.4 Low load and low renewable production

The last situation analysed is characterized by low load and low renewable production: in particular the value of load is 26,334 MW and the value of renewable production is 9,924 MW, which covers 37% of the demand.

In the Table 171 the capacity factor of each type of RES is presented: as it is possible to note this is a night case since the power generated by PV is equal zero. The capacity factor of the wind is equal to 23%.

Table 171 – Capacity Factor for different type of renewable generation

Type	CF [%]
PV	0
Wind	23
Hydro	45

In this condition, the power exchanges between the different zones are the ones reported in Table 172 and Figure 72 and it can be noted that NWE imports more than 1100 MW from neighbouring areas due to the absence of PV production. Also the power flow from PAT to NEC is reduced, due to limited wind generation.

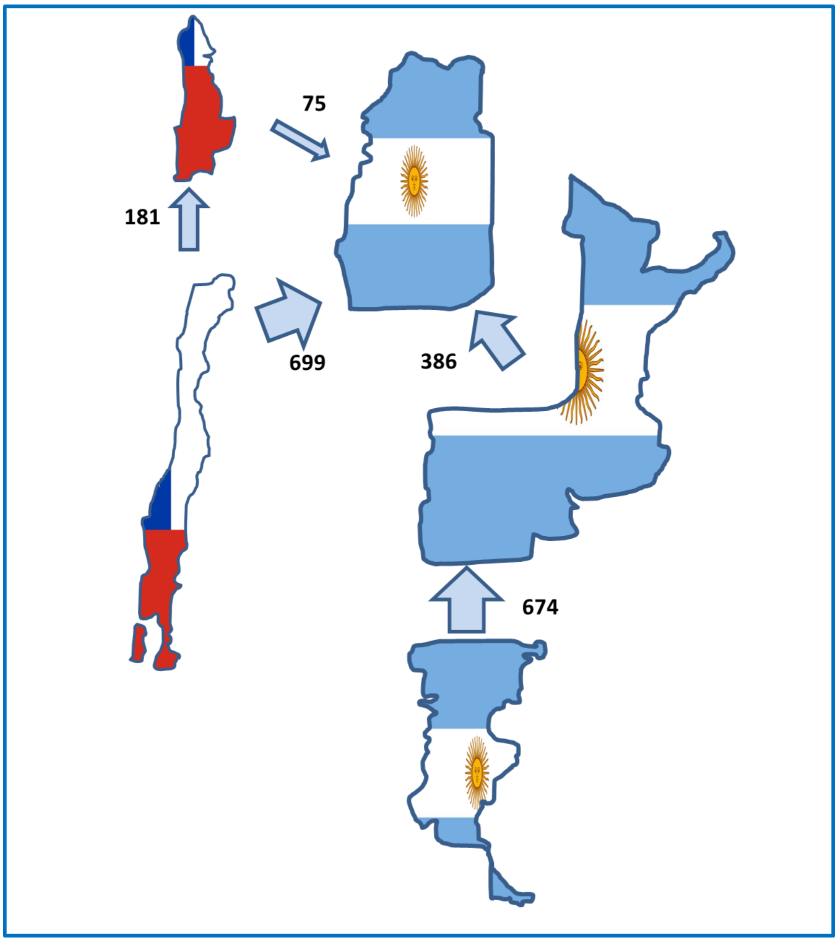


Figure 72 - Static Analysis – Power exchanges in low load and low RES production

Table 172 – Power exchanges

From	To	[MW]
SIC	SING	181
PAT	NEC	674
NEC	NWE	386
SING	NWE	75
SIC	NWE	699

Regarding the line loading, in sound network condition no line operates at its maximum transmission capacity. Table 173 shows the most loaded lines, which do not reach 70% of their limit. Interesting to note that the interconnection Polpaico - Gran Mendoza represents the most critical case, which is used in this case to bring in Argentina the cheap energy produced in Chile.

Table 173 – Lines loaded more than 60%

Line	Un [kV]	I [%]
Polpaico – Gran Mendoza	500	69
Rio Diamante - Charlone	500	64

In this snapshot, where the transmission network is not stressed due to low load and low RES production, there are no critical cases even in N-1 condition.

5.5 Connection of new VRES power plants to transmission network

At the end of the analysis on the Argentinian and Chilean electrical systems, performed with the probabilistic approach to simulate the expected operation over one year and with the deterministic approach to analyse some snapshots characterized by extreme load or RES generation, the optimal amount of VRES power plants has been defined. Thanks to the good potential in the two countries, a high quantity of PV and wind plants is obtained and will be concentrated in the regions with the best availability of natural resource. These locations are mainly far away from the most populated areas, and there the transmission network is often poorly mashed and composed by long 500 kV lines.

The actual development of VRES plants will have to deal with the need to effectively connect them to the transmission network because the difficulty to get an access point to the grid where to inject the power might increase the cost of the projects. Many local improvements also at lower voltage levels will be probably needed to enable the new power plants to reach the transmission system, and this detailed evaluation is part of the activities to be performed during the short-mid term planning of the system.

Looking also at examples from other countries where the VRES penetration have been already increasing for the last years, it is reasonable to foresee that new substations on the 500 kV lines will be required to make available more frequent points of possible access to the transmission system. This is valid in particular in the areas with high solar irradiation or wind availability where the lines are long and the amount of power that should be transferred is high. Some examples of new line or substations which improve the accessibility to the transmission network are already included in the planning proposed by Transener in its “Guía de Referencia” [6], for instance with the new substation of Vivorata and the relevant line foreseen close to the coast in the southern area of Buenos Aires, or the new substation Comodoro Rivadavia in Patagonia, planned along the line Puerto Madryn-Santa Cruz Norte.

Probably, also in NWE some new 500 kV substation will be needed to collect the production of the PV power plants and reducing the distance that might be present between clusters of PV projects and the closest access point to the transmission network.

In Chile, the development of the 500 kV corridor from North to South will generally reduce the loading of the 220 kV lines connected below, which at present connect, especially in some areas, a quite dense network of 220 kV substations. They might represent already a good opportunity to allow the access of new VRES to the transmission network, but in case in some areas with particular availability of renewable source the concentration of new plants becomes too high, it is possible that reinforcements of existing substations or new ones turn out to be necessary.

The detailed planning of these needed reinforcements, not part of the present study, will have to be performed based on the actual development of the projects, identifying cluster of projects that might be collected in one area minimizing the construction of long lines at lower voltage levels.

BREAKTROUGH IN VRES GENERATION TECHNOLOGIES

6 ALTERNATIVE SCENARIO AND RESULTS ADOPTING NEW TECHNOLOGIES

Starting from the results of the BAT scenario, which showed in some cases very competitive LCOE from PV and wind power plants also thanks to the favourable environmental conditions present in Argentina and Chile, a more aggressive scenario is investigated aiming at an accelerated decarbonisation of power systems in the two countries.
In the BAT scenario the penetration of VRES was limited by system operational constraints, such as the reserve need, which impeded to increase the amount of VRES plants to ensure an adequate security of supply most of the operating conditions.
In particular, the main limiting factors could be identified in the reduced possibility for the VRES plants to support the system with frequency regulation and inertia, and in the introduction of high production forecasts errors because of the difficult predictability of the natural resource (in particular wind). For these reasons, in order not to jeopardize the security of the system, it was necessary to define technical limits despite of the interesting economics of PV and wind plants when located in areas with a high potential.
In this Chapter, the outcomes of the analysis carried out on the Argentinean and Chilean power systems loosening these system constraints are presented, together with the relevant main characteristics and assumptions.
This scenario can be considered as a possible example of the conditions towards which the power systems might tend in the future in case technological developments will allow overcoming their current existing operational limitations. In general, it can be stated that any action aimed at relaxing operational constraints without affecting the security of the systems, improving the flexibility of the generation fleet and the demand and creating the conditions for an easier matching between them, would increase the possible penetration of VRES plants.

6.1 Main characteristics and assumptions

As described above, the simulation of this new scenario is aimed at evaluating the possible variation of the best economic penetration of VRES generation in the systems when some operational constraints are not binding anymore or become weaker. This condition can happen when solutions which improve the predictability of operational conditions or which increase the ability of the system to cope with big and fast variations of the demand or the generation are put in place.
Some possible examples are the following:

- improved methods for weather and production forecasts, which allows the definition of the expected production profiles of PV and wind plants with higher accuracy, thus limiting the required support by dispatchable units;
- a regulatory framework which allows the possibility to consider production profiles of groups of generators, also with different technologies, enabling the owner to reduce the discrepancies between the forecasted production profile and the actual one;
- fast power production control of the generation fleet, also including the VRES generators to the possible extent;
- wider operational capabilities of generators;
- presence of energy storage systems.

Moreover it is possible to make the hypothesis that in the next years new technologies will be available which are able to provide system auxiliary services, such as frequency and voltage regulation, hence limiting the need for additional upward and downward reserve.
In this context, storage systems can play a significant role dealing with the variability of renewables. In fact they are capable of performing multiple functions, improving the flexibility of the power system and its controllability, providing also those ancillary services needed to ensure safety and stability of electric network. In particular, storage systems can have an important peak shaving function, reducing peak power demand and limiting situations with overgeneration in presence of low load or high VRES production. But can also play a key role in the frequency regulation, both in the short term (thanks to their fast dynamics) and mid-term (when the storage capacity is enough to allow high power injections or withdrawal for longer periods).
Battery energy storage systems (BESS) are supposed to play a major role thanks to their flexibility and the expected cost reduction in the next years. Moreover, they are modular, easily scalable and do not require special geographical characteristics, such as big amount of water or high differences in altitude which for instance are required by hydro pumped storage systems. This makes BESS easily installable in almost all the locations, allowing also a widely distributed diffusion, which helps support also remote locations of the power system.

Thanks to the repetitive typical pattern of the PV generation, which is characterized by the succession of periods with high production during the central hours of the day and periods with no production during the evening and the night, BESS fit very well this technology: they can be charged during periods with overgeneration during the day and get discharged, injecting in the grid the stored energy, when the production is lower or null. This cycling allow a good exploitation of the storage systems, which daily are used to shift energy from high to low PV production periods, saving a great part of energy which otherwise would have to be curtailed. Figure 73 provides a graphical explanation of what is described above, showing that the typical cycles are followed by storage level.

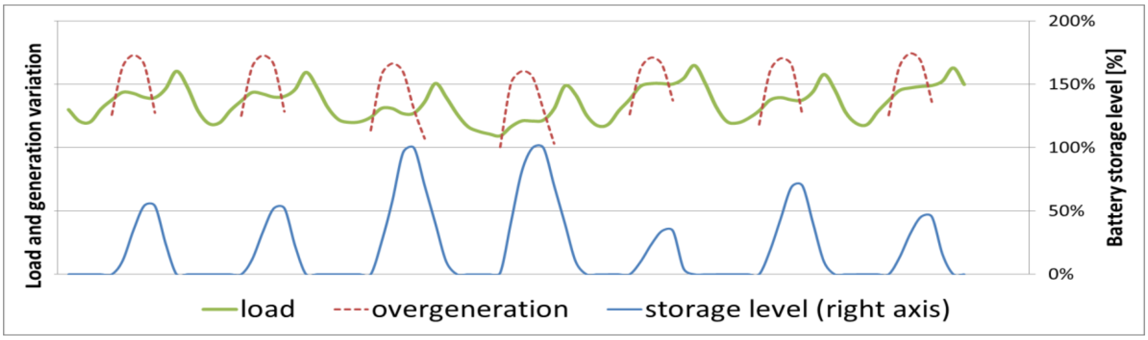


Figure 73 - Typical storage level cycles when associated to PV generation

On the contrary, in case the overgeneration conditions last for several hours and days, as possible in presence of high amount of wind power plants and periods with very good wind regimes, energy storage systems would not be able to recover great part of the energy surplus, because they reach their maximum storage capacity. A design of the storage systems aimed at ensuring the full energy recovery would result in a overdimensioning of the systems, which would be used only seldom during the year, increasing the costs without a corresponding benefit. Figure 74 shows a possible example of how the energy storage systems can store only a small part of the energy surplus during long lasting overgeneration conditions.

In this condition, the best solution to avoid wasting high amount of energy would be the availability of a higher transmission capacity ensuring the possibility to evacuate the excess of power.

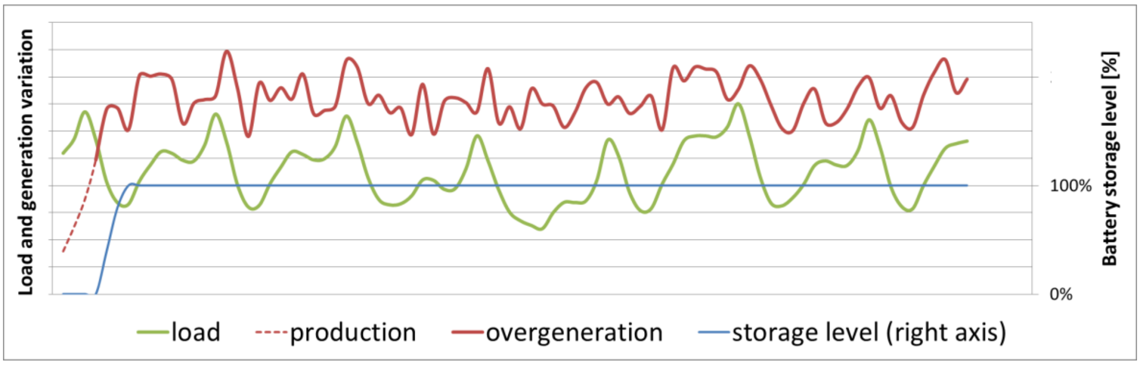


Figure 74 - Energy storage limit in case of long lasting overgeneration

The dimensioning of the capacity of the energy storage systems must be then defined considering costs and benefits of different solutions, taking into account that they must be able to support the system and provide the ancillary services in coordination with VRES power plants.

Moreover, especially in the Chilean case, the energy storage systems must ensure that enough energy and power can be shifted from the high PV production hours to the evening and night, to limit the EENS and keep a suitable level of system adequacy.

The higher is the capacity of the systems, the higher the amount of energy which can be recovered, but the increase at every step gets lower, because the added storage capacity is used only in situations where there is a high overgeneration and lasting so much time to need it.

From some preliminary evaluations focused on ensuring that the amount of recovered energy is enough to cover, with proper margins, the EENS which might appear in the evening and in the night, it is considered that a storage capacity up to 5 equivalent hours can represent a possible solution which fits

different conditions. This value might change depending on the actual operating conditions which have to be faced in the specific locations, for instance if storage systems are closer to PV or wind power plants in areas with high potential or installed in areas with higher or lower overgeneration. It is important to underline that such capacity is also enough to ensure that energy storage systems can provide, when properly controlled, ancillary services and in particular frequency regulation and upward and downward reserve.
Based on these considerations, it is assumed also that a share of VRES power plants is associated with storage devices, the role of which is basically load shifting which also constitutes a support for a better "dispatchability" of PV and wind production within a limited time frame and power.
Main information about the state-of-the-art and future development of BESS are available in [7] and [8]. Among the different technologies analysed and presented in these reports, the focus is kept on the Lithium-ion one, thanks to the technical characteristics which well fit with the proposed application and with the significant expected cost reduction, which makes them very interesting from an economic point of view.
Starting from the values presented in these reports and adapting them to the analysed case, a cost equal to $ 0.5 million for a 1 MW turnkey system FOB[17] with a storage capacity of 5 MWh, plus 10% costs for transport, have been assumed. An efficiency of 0.9 has been included as a ratio of the energy that the storage systems are able to inject in the system and the energy that they have stored, taken from the system. Finally, a lifetime equal to 10 years is considered, to take into account the degradation which the Li-ion batteries are subject to. Variations of these parameters would have an impact on the final cost of recovered energy because of the different required investment (in case the cost for installed MW is different) or because of the different amount of energy injected back in the grid after the storage (in case the efficiency varies).

The analysis is focused on the evaluation of how much additional amount of PV and wind power is convenient to be installed in the system and in the different areas. Moreover, from the performed calculation it is also possible to assess how much energy can be recovered thanks to the energy storage system, providing a useful information about their usage and the costs of the recovered energy, which can be estimated from the annuity of the investment needed for the batteries, divided by the amount of energy they are able to inject back into the grid.
In this scenario, the energy produced by the additional VRES power plants replaces more expensive generation, fulfilling in each considered time step the energy balance in the areas. In particular, the maximum power transfer constraint between areas is taken into account. Other operational constraints such as reserve needs or inertia have been relaxed.
The optimal VRES installation level is obtained when their LCOE remains below the cost of the thermal generators that are substituted. The LCOE of renewable plants is calculated considering the investment costs and the expected production which is also affected by the risk of curtailments.
No externalities, such as reduction of GHG, have been taken into account, which would represent additional benefits brought about by the introduction of VRES plants. Then, the inclusion of externalities would further increase the convenience to install PV and wind plants.

[17] Free On Board, according to the definition of Incoterms 2010.

6.2 Results of optimal amount of additional VRES capacity in the Breakthrough scenario

In the following paragraphs, the results of the calculations performed to assess the optimal amount of additional VRES installed power in the Breakthrough scenario are presented. The analysis have been performed, initially, on the Argentinean and Chilean system considered as isolated, to evaluate the differences with respect to the results obtained in the BAT scenario. Then, there is an assessment of the two interconnected systems, in order to verify if the interconnection brings benefits on the possibility to install additional VRES capacity.

6.2.1 Argentina – isolated system

Argentina isolated system has been investigated starting from the results obtained in the BAT scenario, isolated case (paragraph 3.4.1.2), where the optimal technical and economic amount of PV and wind plants was equal to 15 GW.

In that Scenario, the PV power plants were all installed in NWE area, the one with highest potential, causing some network congestions and consequently some curtailments. In the Breakthrough scenario PV plants have been considered in a wider area, to avoid that additional plants installed only in a critical area can increase the problems, being subject to curtailments. The presence of BESS helps the resolution of network congestions thanks to the possibility of not injecting full power into the grid during most loaded conditions and shifting the production in periods where there are no or less network issues. This provides the network operator with an additional possibility of control of the power flows on the lines and between areas, but would be not enough to avoid a high increase of curtailments due to the transmission network constraints.

As far as the wind production is concerned, the presence of BESS is not always effective to avoid production cuts due to an insufficient evacuation capacity, because of its storage limitation, as explained in paragraph 6.1 and Figure 74. For this reason, if the NTC between PAT and NEC is kept at the value considered in the previous analysis (4,250 MW), the possible increase of wind power installations in PAT is not very big. But the presence of a great amount of BESS with an adequate storage duration can help the transmission operator to consider an increased NTC value between the areas. Thanks to the presence of high amount of storage systems in NEC and NWE, it would be possible to loosen the strict N-1 criterion on the PAT-NEC cut-set and increase the NTC. As explained in paragraph 3.3.3, 4 lines belong to this section, and the transmission capacity of the biggest is equal to 1,750 MW. The value of 4,250 MW considered so far was calculated to ensure that even in case the most capable line would be lost, the remaining three are able to transmit the power flow (strict N-1 criterion), thus not causing any issue in the connected areas.

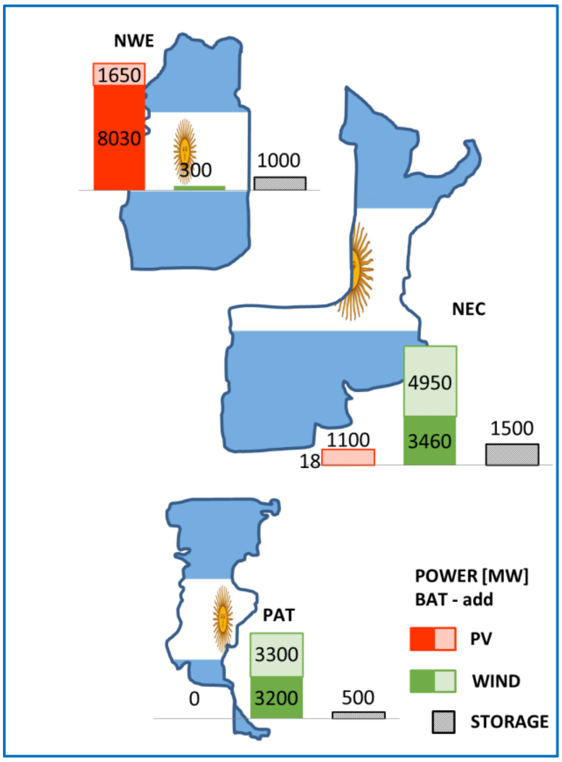
When a great amount of BESS is installed widespread in the different areas with high power and long storage duration, they would be able to quickly compensate the variations of imported or exported energy in each area. For this reason, it would be possible to allow a higher power exchange between the areas: in this case, when a line belongs to the section trips the remaining ones would not be able to transfer the power, because is too high; nevertheless, a coordinated control of the power plants and the BESS in the whole system would be able to very quickly reduce the excess of power in the PAT area, limiting the export through the PAT-NEC section, and at the same time increase the power produced in the NEC area, compensating the curtailed import. Specific analysis should be required to properly evaluate the dynamic performances of the whole system including the BESS, and define the acceptable increased NTC value. The system operator would be in charge of performing these activities and evaluating the best NTC values that also depend on the operational conditions. The possibility to revise and increase NTC between areas without construction of new lines is of great interest to improve the economic operation of the system. For the purpose of this study, the NTC has been considered increased from 4,250 MW to 5,400 MW, which ensures a 10% margin with respect to the sum of the transmission capacities, comparable also with the power of the biggest plant.

Since in the Breakthrough scenario the system technical constraints such as inertia and reserve needs are not binding, the possibility to include additional 11 GW of VRES plants turns out to be economically viable with respect to the BAT scenario. It is also necessary to install 3,000 MW of storage capacity suitably distributed in the system and preferably close to the new plants. As explained above, the introduction of high amount of BESS in the power systems gives a positive contribution because allows to:

- facilitate the VRES penetration increase, ensuring these plants can support the system;
- recover part of the energy that otherwise would be curtailed due to overgeneration in the system;
- shift production, in particular by PV, from hours with high VRES generation to evening and night hours, when the risk of not being able to meet the demand is higher;
- improve the NTC between areas, loosening the strict N-1 criterion thanks to coordinated control of power plants and BESS in the system.

Additional PV plants are distributed in NWE and in NEC area, because, as already seen in BAT scenario, the interconnections between NWE and NEC are not strong enough to evacuate the power when full PV production is concentrated in the first area. So part of the new PV plants are installed also in NEC area, where the solar irradiation is a bit lower, but no risk for curtailments due to overgeneration in the area or transmission line overload is present.
Wind plants are also widespread in PAT and NEC, because, even if increases, the transmission capacity from PAT to NEC can become a bottleneck during periods with high wind regimes.

Figure 75 and Table 174 show the amount of PV, wind and storage installed capacity added to the Argentinean system in the Breakthrough scenario with respect to the BAT scenario, under the assumption of an increased NTC between PAT and NEC.



AREA	PV installed capacity	Wind installed capacity	Storage
NEC	1,100	4,950	1,500
NWE	1,650	-	1,000
PAT	-	3,300	500

Figure 75 **Table 174**

Argentina: added VRES and storage installed power in the Breakthrough scenario with respect to BAT [MW]

The production of the new added plants can be divided in a part which is not subject to curtailments because does not take place in conditions with overgeneration in the system or in one area, and a part which must be curtailed because the system is not able to absorb it due to overgeneration (typically in periods with low demand and high VRES generation). The first part, which is injected directly into the grid and contributes to the supply of the load, replacing expensive thermal generation, is the biggest one and counts more than 40 TWh, while the risk of curtailments attains 600 GWh. Thanks to the BESS, considering the storage availability and efficiency, 450 GWh can be recovered and injected back into the grid in hours with no overgeneration problems and with higher lack of power risk.

Hence, the total energy which the system can absorb from the additional VRES power plants is equal to 40.5 TWh, which replaces an equivalent amount of energy produced with expensive thermal generators. These 40.5 TWh have to be added to the 48.2 TWh produced by PV and wind in the "BAT scenario", totalling 88.7 TWh, which correspond to more than 38% of the net load.

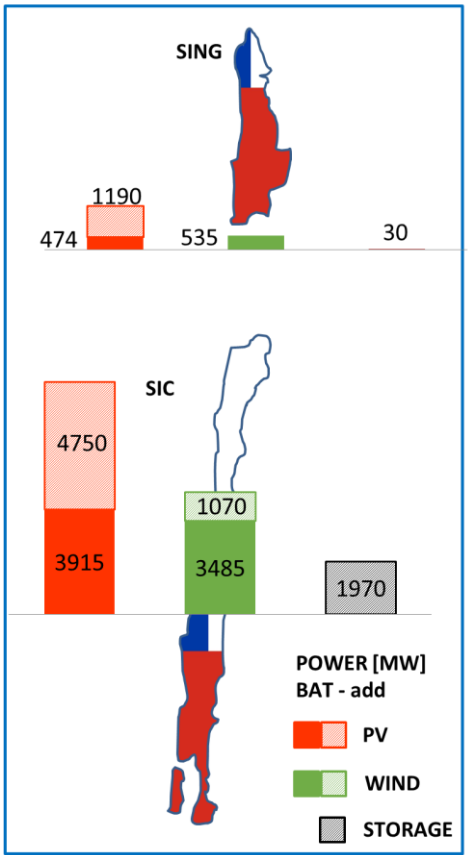
For the sake of completeness, also the situation with the same configuration of the new plants and with the NTC between PAT and NEC kept at 4,250 MW has been simulated: in this case the energy curtailments would attain 1,350 GWh, more than twice as much as the curtailments needed with the improved NTC, and the recovered energy would remain on the same level, because the BESS would not have enough storage capacity to save more production.

The LCOE of the new PV and wind generation when the increased NTC is considered remains in the range 44.5 $/MWh - 46 $/MWh, higher than in the BAT scenario because new added plants are installed also in areas with lower irradiation and wind resource. It is confirmed that wind generation is characterized by a slightly lower LCOE than PV.

Considering also the cost for the BESS which is necessary to allow the installation of a so huge amount of VRES plants, the average overall LCOE of PV, wind and storage together reaches nearly 52 $/MWh. In this case it is not possible to provide costs for each specific technology because it is not possible to clearly divide the cost of BESS between PV and wind, while it is possible to consider the overall costs and the overall expected production. The costs of the energy purely recovered by the BESS is very high (higher than 500 $/MWh), because the amount of BESS required in the system is big, and the recovered energy is not so high. It is clear here that the investments in BESS cannot be evaluated only based on the economic convenience of the avoided curtailments, because it would turn out that so big BESS are not convenient, but also on the opportunity they represent for a higher diffusion of PV and wind technologies, which are very competitive.
In fact, there is a high economic convenience when VRES plants produce 40.5 TWh, replacing the more expensive thermal generation. A possible saving for the system up to $ 575 million/year (about 7% of the thermal generation costs in the BAT scenario) has been calculated. Moreover the introduction of a big amount of PV and wind power plants, supported by BESS which makes them more programmable and dispatchable at least in the short term operation, makes not necessary anymore the fossil fuelled dispatchable generation introduced in the Reference scenario (and still present in the BAT scenario for an amount equal to 5,500 MW) that was required to meet the power peak and load demand increase from 2025 to 2030.
This means that in the Breakthrough scenario there are no investments required in traditional fossil fuel plants in addition to the one already foreseen in the official development plans.

6.2.2 Chile – isolated system

Also for the Chilean system, the starting configuration for the Breakthrough scenario is the result of the BAT one, reported in paragraph 3.4.2.2, i.e. 4,400 MW PV and about 4,000 MW wind installed capacity, plus the thermal and hydro generation present in the Reference scenario.
In the previous analysis, the high economic convenience of PV with respect to wind has been highlighted. BESS can further support additional installation of PV plants, because, as explained in paragraph 6.1, the repetitive pattern of the PV production allows a good exploitation of the storage and the recovery of a good amount of energy that would be curtailed. Moreover, BESS can support the system shifting production for hours with high availability of solar resource to evening and night hours, when the risk of not being able to supply the load is more concentrated.
The performed analysis showed that when a reduced need of reserve for the system is considered, and with the presence of BESS, there are the conditions for the installation of additional 7,000 MW of VRES plants.
The amount of new PV and wind plants resulting from the calculations and their geographical localization is shown in Figure 76 and Table 175. The partition between the technologies and the distribution over the territory reflect the results of the BAT scenario, confirming the economic convenience of PV. Storage is mainly concentrated in SIC area as it represents the one with the largest share of demand and generation.



AREA	PV installed power	Wind installed power	Storage
SIC	4,750	1,070	1,970
SING	1,190	-	30

Figure 76 **Table 175**

Chile: added VRES and storage installed power in the Breakthrough scenario with respect to BAT [MW]

These new added plants are able to inject 15.5 TWh directly into the grid, while there is a risk to cut 1.8 TWh in conditions when the system or an area suffers overgeneration.
Thanks to the storage system, more than two thirds of this curtailed energy can be saved, and, taking into account the overall efficiency, the net energy recovered and injected back into the grid is more than 1.1 TWh. Hence, in total the new added plants can contribute to the fulfilment of the demand with a production equal to 16.6 TWh. The production by PV and wind in the BAT scenario was equal to 20.7 TWh, and as a consequence the total production attains 37.3 TWh, corresponding to more than 34% of the net load.

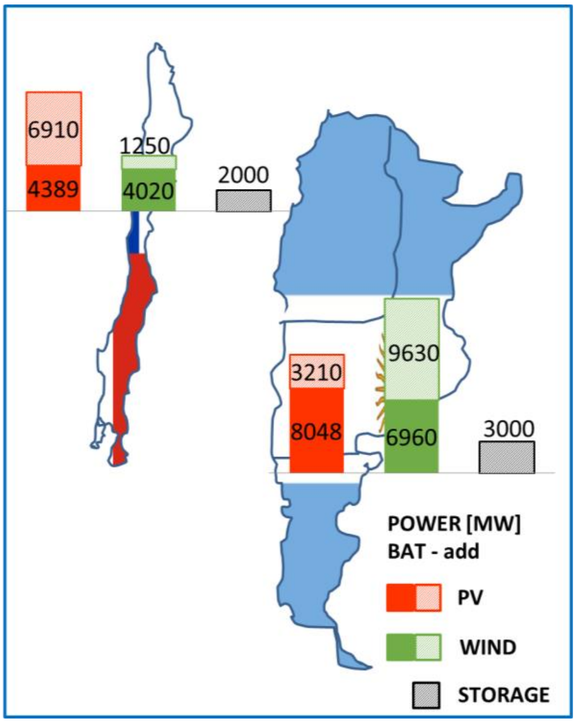
The amount of energy recovered by the storage systems is enough to avoid most of the EENS present in the Reference scenario if 2,800 MW dispatchable generation were not included in the generation fleet. As a consequence, the new 7,000 MW VRES plants can be deemed able to substitute the additional fossil fuelled dispatchable generators required in the Reference scenario, keeping a suitable level of generation adequacy thanks to the storage systems. This means that in the Breakthrough scenario there are no investments required in traditional fossil fuel plants in addition to the one already foreseen in the official development plans.
The interconnection between SING and SIC does not represent a strong constraint and does not limit the exploitation of the additional VRES plants.
The cost of the storage systems is high, and even if it is often used to save PV production which otherwise would get curtailed, the resulting cost of the recovered energy remains above 140 $/MWh, calculated

as the annuity for the BESS (about $ 160 million) divided by the amount of energy injected back in the grid (1.1 TWh).
Considering the whole PV-wind-storage system, the resulting LCOE is about 44.4 $/MWh, still competitive against many traditional thermal plants.
It is possible also to conclude that the investment in 7,000 MW PV and wind plants and 2,000 MW of storage systems would remain more profitable than the investment in 2,800 MW dispatchable generators (CCGTs) to produce 16.6 TWh, giving to the system a benefit of about $ 350 million/year.

6.2.3 Argentina and Chile interconnected systems

Finally, the case with the Argentinean and Chilean systems interconnected has been evaluated. Starting from the results obtained in the analysis of the Breakthrough scenario for the isolated systems (with the amount of PV, wind and storage installed power defined in Table 174 and Table 175), the aim is to assess the benefits which the whole system can experience when the countries are interconnected. The main effects due to the presence of the interconnection found in the BAT scenario (paragraph 3.4.3) were the improvement of the security of supply, the lower operating costs and the reduction of the expected VRES curtailments. Thanks to the first and the last one, it has been possible to increase the total PV and wind installed power by 3,000 MW, which was equal to the sum of the maximum acceptable values by each country thanks to the possibility to increase the export.
Similar effects are expected also in the Breakthrough scenario.
In fact, when the systems are interconnected, the total energy which the additional PV and wind power plants can inject directly into the grid without the risk of overgeneration is 56.2 TWh, 0.7 TWh higher than the sum of what would be possible for the two isolated systems alone. This confirms the role which the interconnection can have in the exploitation of VRES power plants. But it is interesting to note that in this condition, the energy recovered thanks to the BESS is slightly higher than 1 TWh, against more than 1.5 TWh as sum what happens in the countries when they are not interconnected. As a final result, the total curtailed energy in presence of the interconnection is 180 GWh lower than the sum of the curtailed production when the countries are separated .
It is worth underlining here that both the presence of the storage system and the interconnections support a better exploitation of the VRES plants. When storage systems are already available in a country, the benefits obtained thanks to the interconnections are partially offset, since part of the curtailed energy is already recovered by the storage.

Thanks to the better exploitation of the PV and wind resource with lower risk of curtailment and to the favourable conditions of the interconnected system, it is confirmed that 3,000 MW of new VRES plants can be further added in the system as also happened in the BAT scenario. These additional PV and wind power plants have 8.7 TWh of net production (considering a curtailment of 1 TWh and a recovery of 0.9 TWh thanks to storage system, both referred only to the production of the additional plants).
The distribution of the plants in the different areas of the systems is reported in Figure 77 and Table 176. The amount of BESS is also reported, even if it is kept equal to the values found at the end of the analysis of the isolated countries.



AREA	PV installed power	Wind installed power	Storage
NEC	1,925	0	1,500
NWE	1,285	5,775	1,000
PAT	0	3,855	500
SIC	1,375	0	1,970
SING	5,535	1,250	30

Figure 77 **Table 176**

Added VRES and storage installed power in the Breakthrough scenario - Interconnected countries [MW]

The total amount of generation in this final configuration is then characterized by 21 GW more VRES plants with respect to the BAT scenario. The total production of all the VRES power plants considered in the Breakthrough scenario, including the ones added thanks to the interconnection is divided between the countries in the following way:

- in Chile: 19.6 TWh, considering 1.1 TWh recovered by BESS;
- in Argentina: 46.4 TWh, of which 0.8 TWh recovered by BESS.

This production must be added to the one calculated in the BAT scenario, reaching 40.3 TWh in Chile (which corresponds to more than 37% of the net load) and 94.6 TWh in Argentina (more than 41% of the net load).

7 CONCLUSIONS

Argentina and Chile set ambitious targets of RES penetration in the coming years. The analysis performed in the present study confirmed that these targets are achievable and the planned electrical systems are able to operate effectively also with the forecasted amount of PV and wind power plants.
Moreover, space for additional VRES generation is available at 2030 (especially for Argentina, which so far has defined targets up to 2025). VRES penetration would be even fostered in case the electrical systems of the two countries were interconnected, allowing a better exploitation of the available natural resources.
Thanks to very favourable environmental conditions and the expected decrease of installation costs for PV and wind production technologies, the expected LCOE of the plants installed in areas which ensure high producibility is competitive against traditional generation.

Two main scenario have been analysed, which differ in the contribution that the VRES plants can give to the secure operation of the power system. In the first one, called “Best Available Technology” (or BAT), PV and wind plants are assumed to operate according to today’s best practice, and the operational system constraints, such as reserve needs or inertia, are provided by dispatchable generation. In the second scenario, called “Breakthrough Technology” (or “Breakthrough”), it has been considered that new technologies (among which also a wide diffusion of storage systems) enable the VRES plants to support the system operation, reducing or eliminating some operational constraints.

In the BAT scenario, the presence of the additional PV and wind power plants introduces benefits in the systems, reducing considerably the cost of fuel for thermal generation and above all substituting investments for other generators that would be necessary to ensure generation adequacy. On the other hand, the higher variability of the production in the system due to the higher penetration of variable generation increases the costs due to the network congestions and also causes the growth of the amount of energy to be curtailed due to overgeneration or required to solve possible overloads on critical lines. This effect partially limits the overall benefit that VRES can introduce in the system.
In particular, in Argentina two lines close to the section between NWE and NEC have limited transmission capacity, impeding the full exploitation of the cheapest generators.
The role of these transmission lines in the optimal development of VRES has been investigated, and possible solutions to avoid their overloads, including the possibility to improve their transmission capacity, have been analysed, showing some further potential benefits for the system to be compared with the relevant costs.
The interconnection of the two countries also introduces benefits for the system, allowing the exchange of cheap energy from one country to the other depending on the operational condition and reducing the risk of VRES curtailment thanks to the possibility to export production in excess to the other country.
Moreover, the presence of the interconnection improves the security of supply in the system and allows the installation of an additional amount of VRES plants in both countries, which brings further benefits.
In the optimal scenario corresponding to the final analysed configuration, in Argentina are installed about 16,500 MW PV and wind plants, and in Chile about 10,000 MW.
Some sensitivity analyses have been carried out in order to verify how the operation of the system characterized by the generation fleet resulting from the BAT scenario and with the two countries interconnected is impacted by a lower installed dispatchable power in Argentina and by different

hydrological conditions in both countries (dry and wet year). Results showed a significant decrease of the generation adequacy in case less dispatchable power is available in Argentina, and a reliable operation when different production by hydro plants is considered.
Moreover, the analysis of Variants characterized by higher or lower load and the differences in the generation fleet, showed that the systems are quite robust and able to be operated with the additional amount of VRES plants defined in the BAT scenario: when the load is higher, there is room for even further PV and wind plants, while when the load is lower, the system suffers higher curtailments due to overgeneration. In this case, there is a high risk that the limitations to the exploitation of the VRES plants due to high penetration and the low flexibility of the system cause them to become less profitable or even a cost for the system.
In the Variants, solutions aimed at increasing the flexibility of the system have also been assessed, simulating the benefits introduced by pumped storage plants and by reducing the minimum power constraint for thermal generation. The first solutions wants to compensate the high variability of VRES generation with the usage of storage plants, allowing the dispatchable generators to have a flatter production plan, while the second solution wants to increase their flexibility to make them able to cope with a higher required variability.
The exploitation of VRES plants improves in presence of these solutions, but the associated benefits must be compared with the required costs, and preliminary estimations of the investment needed for pumped storage plants show that such technology is not convenient, when used only to improve the VRES penetration. The evaluation of the benefits introduced by such plants in the system should take into account also the advantages brought in the frequency regulation and in the real time operation, which was not possible to assess in the present study focused on long term planning.
The reduction of the minimum power constraint of thermal generators also ensures great savings in fuel costs, which should be compared to the costs required to improve the plants, strongly dependent on the technology and the project specific configuration.

Load Flow calculations have been performed at the end of the analysis of the BAT scenario, to analyse with a deterministic approach some snapshots characterized by low or high load and variable RES generation.
Power exchanges across some sections change considerably depending on the analysed situation, and particularly for those areas where there is a high amount of PV and wind plants, such as NWE.
In high load conditions, there are some lines loaded close to their maximum transmission capacity, including the two Argentinean critical lines identified during the probabilistic analysis.
Load Flow results confirm that in presence of a high amount of VRES power plants, the system is subject to wide variations of the operating conditions, which can be faced with flexible generation fleet and transmission network.

In the Breakthrough scenario, some system operational constraints such as reserve needs and inertia, have been loosened, assuming that new VRES technologies can actively support the system, sharing the burden usually assigned only to the dispatchable plants. In this condition, further PV and wind plants can be installed in the Argentinean and Chilean systems. The installation of new VRES plants must be associated with the installation of a significant amount of Battery Storage Systems (BESS) which contribute to make the PV and wind plants more dispatchable and allow to recover high amount of energy which would have to be curtailed in conditions of overgeneration.

From the assessment of the isolated countries, it turns out that in Argentina additional 11,000 MW PV and wind plants can be installed (along with 3,000 MW of storage) and 7,000 MW in Chile (plus 2,000 MW of BESS).
BESS improve the flexibility of the power systems, allowing:

- a better exploitation of VRES plants, especially PV: in the two countries up to 1.6 TWh are recovered and injected back into the grid;
- a higher security of supply, because recovered energy is shifted to periods with higher EENS;
- the possibility to increase NTC between areas, if generators and the BESS are controlled in a coordinated way.

Also in this case, when the Argentinean and the Chilean systems are interconnected, it is convenient to install additional 3,000 MW of PV and wind plants in both countries.
In this Breakthrough scenario, the total production of the PV and wind power plants is high enough to supply the demand without requiring any further dispatchable generator in addition to the already planned ones. The presence of BESS is essential to ensure that part of this energy can also be shifted to evening and night hours when the risk of not being able to fulfil the demand is the highest. In this way, the combination of PV, wind and storage plants ensures that the system adequacy is kept to a suitable level, and the EENS does not reach critical values.

At the end of the report, which described the analysis performed on several different scenarios and variants, Figure 78 provides a clear picture of the impact of VRES production on the net load coverage in the countries. Starting from the today situation where PV and wind power plants have a marginal part in the energy mix, it is possible to appreciate the increase which can be expected in the future years, leading PV and wind power to play a significant role. In the BAT scenario they are able to cover around 20% of the load, which can be even more in case the power systems are interconnected, while in the Breakthrough scenario the percentage reaches 38% in Argentina and 34% in Chile in case the systems are isolated and 37% and 41% respectively, in case they are interconnected. The expected net load coverage by “green” generation can be obtained adding to these values the production from other renewable sources, among which the most important is hydro that in the simulated scenario covers more than 20% of the demand in both countries. Considering also these “green” resources, the total net load coverage by renewable energies reaches values which are higher than 60% in the Breakthrough scenario.

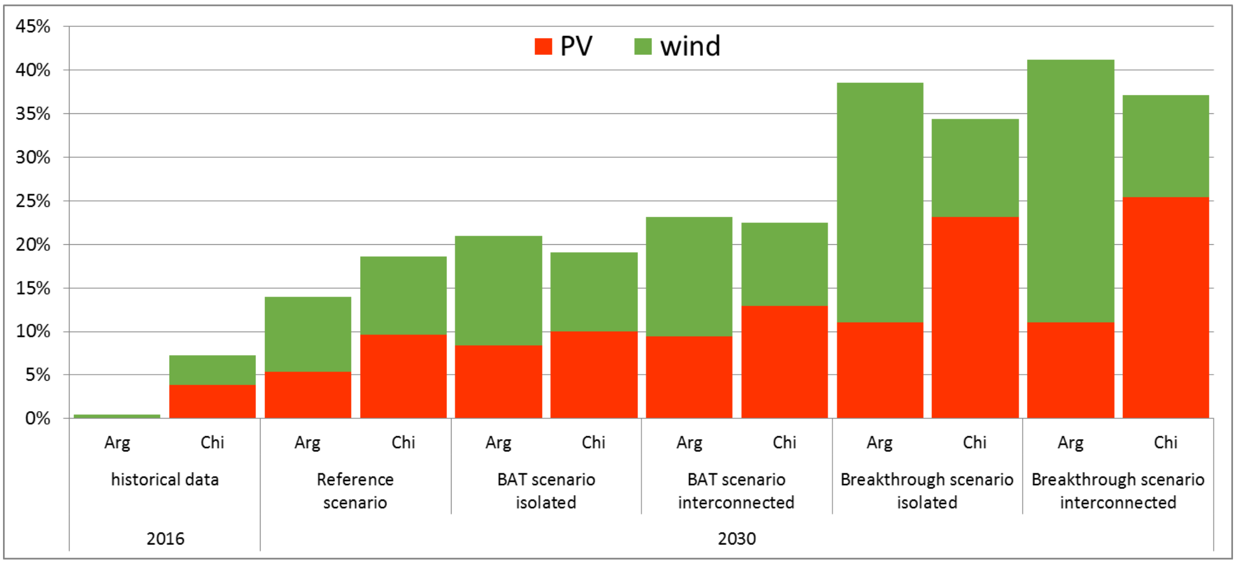


Figure 78 - Net load coverage by PV and wind plants in different scenarios

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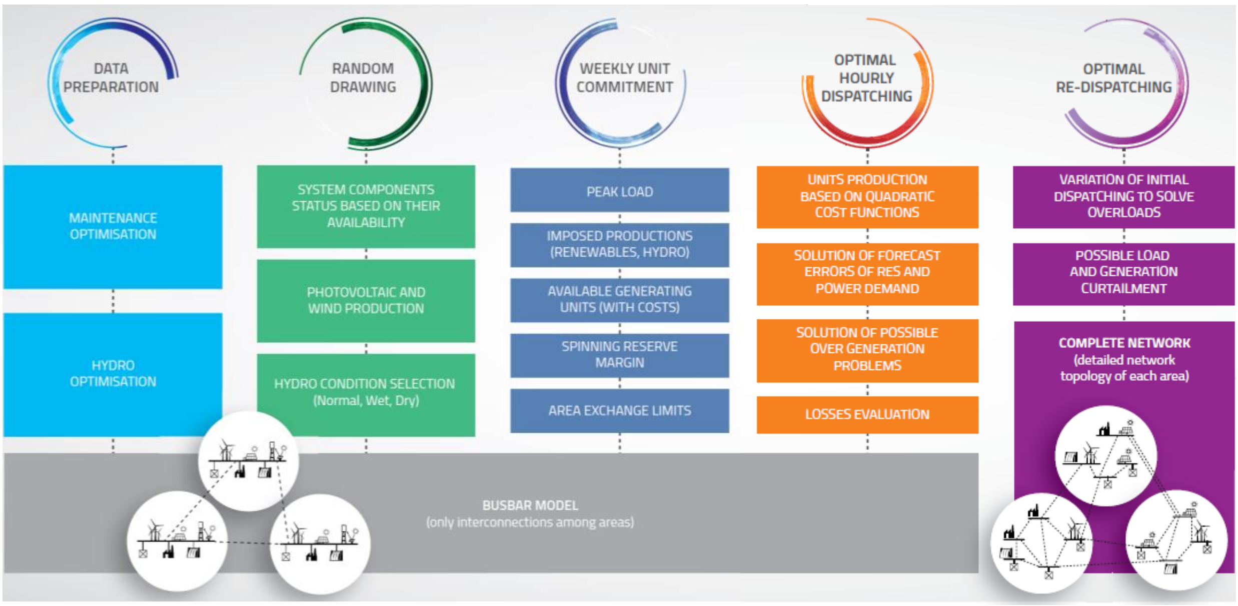
APPENDIX 1 – GRARE SIMULATION TOOL

GRARE, Grid Reliability and Adequacy Risk Evaluator, is a powerful computer-based tool of Terna, developed by CESI[18], which evaluates reliability and economic operational capability using probabilistic Monte Carlo analysis.

GRARE has been developed to support medium and long-term planning studies and is particularly useful for evaluating the reliability of large power systems, modelling in detail the transmission networks.

The tool is developed taking advantage of a high performance multi-threaded code and it is integrated in SPIRA application, that is designed to perform steady-state analyses (e.g. load-flow, short-circuits, OPF, power quality) and is based on a network Data Base of the system being analysed.

The calculation process is performed as a series of sequential steps starting from a high-level system representation and drilling down to low-level network details. Thanks to the ability to couple the economic dispatch of the generation with the complete structure of the electrical network, GRARE is able to offer a unique support for the planning and evaluation of the benefits related to network investments.



The **complete network model** (lines, generators, transformers, etc.) includes different voltage level detail and the power flow derived from generation dispatching to feed the load is obtained applying a DC load flow with the possibility to obtain power losses and voltage profile estimation. Starting from a complete network model, GRARE is able to automatically obtain a simplified bus-bar model to complete unit commitment and market analyses where the network detail is not needed. The analysis of the full network model allow to verify the feasibility of the economic dispatching and the necessity to apply a re-dispatching or load shedding to operate the network in accordance to security criterion.

[18] www.cesi.it\grare

Algorithm and main optimization process

- The time horizon is a single year with a minimum time unit of one hour. Many Monte Carlo Years (MCYs) can be simulated, each one being split into 52 weeks with each week independently optimized.
- Probabilistic Monte Carlo method uses statistical sampling based on a “Sequential” or “Non Sequential” approach.
- Monte Carlo convergence analysis to verify the accuracy of results obtained.
- Optimized Maintenance schedule based on residual load distribution over the year.
- Reservoir and pumping Hydro optimization mindful of water value as an opportunity cost for water in respect to other generation sources.
- Different hydro conditions managed (dry, normal, wet).

System model

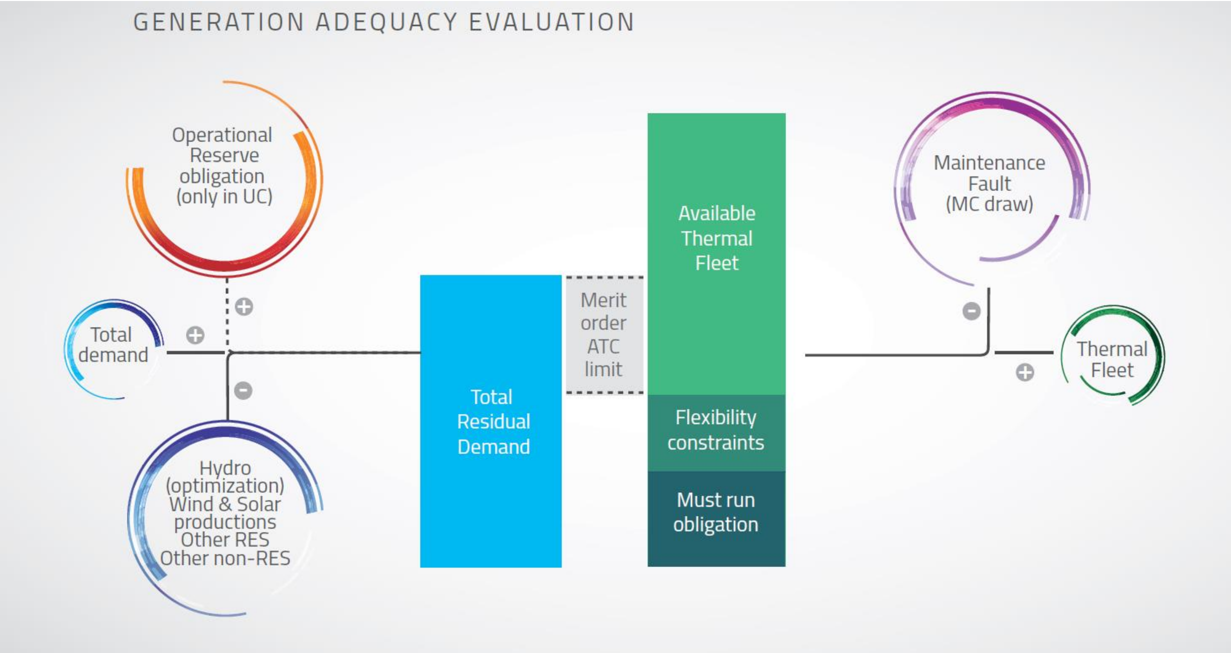
- Network detail to represent each single area (grid dimension up to 5,000 buses). A DC load flow is calculated and an estimate of voltage level can be obtained using the Sauer algorithm.
- Area modelling to optimize Unit commitment and Dispatching consistent with transfer capacities.
- Unit Commitment and Dispatching with Flow or ATC based approach.

Market analyses

- Single year day-ahead Market analysis with area modelling detail, but with no Monte Carlo drawings.
- The general restrictions of the Unit Commitment like minimal uptime and downtime of generation units are taken into account for each optimization period.
- Dispatchable units characterised by power limits, costs, must-run or dispatching priority, power plants configurations, start-up and shutdown flexibility and CO2 emissions.

Adequacy analyses

- System adequacy level measured with Reliability Indexes (EENS, LOLE, LOLP).
- Renewable production calculated by a random drawing starting from producibility figures.
- Operational reserve level evaluation taking account of largest generating unit, uncertainty of load and RES forecast, possible aggregation of Area and fixed % of load.
- Demand side management as rewarded load to be shed with priority without impact on adequacy.
- Over-generation management with possible priority on generation to be reduced.



Main applications and results

The high level of versatility and flexibility of the GRARE tool has been appreciated in Europe first and then in several countries all around the world. The program has been developed to be applied in the design phase for the Italian framework and it is now used for ENTSOE-E adequacy studies. Various TSO/Institutions have benefited from the potentiality of the tool by using it directly or through specialist consultancy services.

- Designed for technical analyses of large electric systems.
- Evaluation of electric systems.
- Generation & Transmission adequacy.
- Optimal level of RES integration.
- Cost Benefits Analysis for network reinforcements and storage which factors in Security of Supply, network overloads, RES integration, network losses, CO2 emissions and over-generation.
- Calculation of Total Transfer Capacity of interconnections.
- Generation reward evaluation for Capacity Remuneration Mechanism.
- Point Of Connection and sizing for new power plants.

RELIABILITY INDICES
Expected energy not supplied
Loss of load probability
Loss of load expectation
NETWORK ANALYSIS
Single branch & interconnections monitoring
Marginal gain for EENS reduction associated to the increase in capability of single network elements
Generation re-dispatching to solve network overloads or over-generation problems
AREA & SYSTEM BALANCING
Area & system costs
Productions & gen. costs for each unit
Area & system electrical losses
Energy exchanges among areas
AREA & GRID ANALYSES
RES curtailment
EENS distribution due to lack of power, lack of interconnection, overloads
COST BENEFIT ANALYSIS
Social Economic Welfare (SEW) and Variation of CO2 emissions
Energy not supplied (EENS) reduction
Integration of renewable resources
Savings in the ancillary services market
Grid transmission capacity increase (GTC) and Energy losses variation related to the network flows
Avoided investments
CAPACITY REMUNERATION MECHANISM
Reliability Options Model
Estimation of option premium based on system costs, value of lost load, interconnection capacity

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