Executive Summary

Argentina | Brazil | Uruguay

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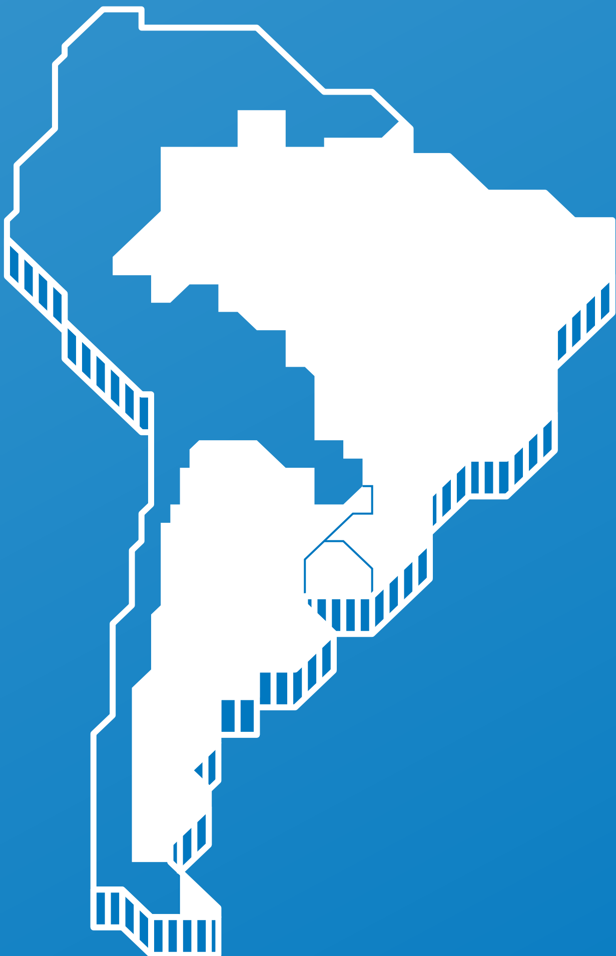

Variable Renewable Energy Sources (VRES) deployment and role of interconnection lines for their optimal exploitation: the **Argentina-Brazil-Uruguay** case study

This research series was conducted by Enel Foundation with the technical support of CESI, a world-leading consulting and engineering company in the field of technology and innovation for the electric power sector.

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List of acronyms

CAMMESA	Compañia Administradora del Mercado Mayorista Eléctrico
CCGT	Combined Cycle Gas Turbine
COP	Conference of the Parties
DNE	Direción Nacional de Energía
EENS	Expected Energy Not Supplied
EHV	Extreme High Voltage
EOH	Equivalent Operating Hours
GDP	Gross Domestic Product
GHG	Green House Gas
HV	High Voltage
HVDC	High Voltage Direct Current
LATAM	Latin America
LCOE	Levelized Cost of Energy
MIEM	Ministerio de Industria, Energía y Minería (Uruguay)
MINEM	Ministerio de Energía y Mineria (Argentina)
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine
p.u.	Per unit
PV	PhotoVoltaic
RES	Renewable Energy Sources
USD	United States Dollars
VRES	Variable Renewable Energy Sources

Introduction

Latin America is endowed with outstanding renewable energy resources, namely wind and solar energy, but some areas offer also a good potential of biomass, hydro and geothermal power production. The current decrease of upfront investment costs in RES power plants makes 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, water). 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.

Within the context recalled above, this study on *"VRES deployment and role of interconnection lines for their optimal exploitation"* aims namely at examining the optimal technical-economic penetration of Variable Renewable Energy Source (VRES) generation (wind and solar) in some Latin American (LATAM) countries and clusters of countries accounting for the possible cross border power exchanges.

The study answers the following two questions:

- *What is the optimal penetration of VRES generation within a country considering the technical constraints in system operation while minimising the production costs?*
- *To what extent reinforcing the transmission grid can help enhance the deployment of VRES generation within a country and between interconnected countries?*

1 All Latin American countries signed the Paris Agreement and 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

The analysis is performed for the target year 2030 and starts from a given set of thermal/hydro generation that includes the already existing plants, the ones under construction and the planned ones which will be built before the target year.

The first report of this study was completed in January 2018 and was focused on Chile and Argentina (Cluster 1). This second report is focused on Argentina, Brazil and Uruguay (Cluster 2) and will be followed by a third one 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 was based on data and projections collected in 2017, this second report 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%.

2 The study process

In the first part of the activity, a "Reference scenario" has been defined. It is obtained from the information gathered from available studies on the electric power system development for Argentina, Brazil and Uruguay at the target year 2030 or for years close to it. This "Reference scenario" represents the starting point to build new scenarios optimising the VRES generation deployment.
Starting from this "Reference scenario", the optimization of the VRES installation has been carried out by modifying the generation expansion pattern optimising the amount of new VRES generation, particularly PV and wind, taking into account their potential across the territory, and their costs and performances. In the optimisation process, we took into account the system operational constraints in terms of reserve to be warranted in each hour of the year, limits in the power transfer capacity in the transmission grid, requirements on inertia and system stability. However, a development of VRES technologies and the introduction of storage plants have been assumed, to consider that in 2030 they will be able to provide the system with auxiliary services, like frequency regulation, hence avoiding the need for additional upward and downward reserve, and voltage regulation. In this context, VRES will contribute to the smooth operation of the power system, supporting with their resources and not requiring external ones, allowing a higher penetration while keeping proper security of supply.
To better appraise the results of the "Reference scenario" and assess the stability of the results against uncertainties, some variants to this scenario have been investigated:

- *Variant 1*: focused on a scenario of higher demand in the countries due to combination of stronger economic growth, population increase and higher electricity penetration. A significant presence of emobility in the biggest cities is also considered.
- *Variant 2*: focused on a scenario of lower demand, with a higher overgeneration risk. The benefits related to more flexibility of the generation fleet (lower minimum production constraint of existing plants or presence of electrical storage systems) are assessed.

3 Computational tools

The optimisation process is based on a set of deterministic and probabilistic computational tools. In particular, to assess the system adequacy and the risk of overgeneration in presence of an increasing share of VRES, the GRARE (Grid Reliability and Adequacy Risk Evaluator) software has been adopted. GRARE is developed by CESI and owned by Terna, the Italian TSO. GRARE is a powerful computerbased tool which evaluates the reliability and the economic operation of large electric power systems. GRARE supports medium and longterm planning studies using probabilistic Monte Carlo approach and modelling in detail the transmission networks. 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, results depict the expected operation of the whole system, obtained analysing many real possible operational states, and detailed information about each component of the system can be evaluated.
The most interesting results are the expected benefits for the system in terms of variation of generation costs, taking into account possible differences in the Expected Energy Not Supplied (EENS[2]). Also the expected production of the VRES plants, considering potential curtailments due to system or transmission constraints, provides important information for the evaluation of their profitability and supports the definition of the optimal amount of power to install.
The definition of the VRES plants producibility based on geographical information combined with the usage of a detailed transmission system model allows to clearly identify the best areas where PV and wind plants should be developed in order to maximize the benefits for the system.

4 Reference Scenario and study assumptions

The "Reference scenario" has been built starting from the available public domain information [1]. The three main building blocks of the "Reference scenario" are: the yearly energy demand, the generation fleet and the structure of the transmission grid. As for Argentina, information on the evolution of the power sector has been made available by MINEM and CAMMESA until 2025, while for Brazil, the demand forecast and the generation and transmission expansion plan are available until 2026 in the documents published by Empresa de Pesquisa Energética (EPE). Some data for Uruguay, such as energy demand, is available up to 2030 released by the Direción Nacional de Energía (DNE) of the Ministerio de Industria, Energía y Minería (MIEM), while other information is less detailed and needed to be integrated. Hence, the perspective scenario until 2030 was completed for all Countries by applying, where needed, a load forecast computation, both in energy and peak demand and integration of the HV and EHV transmission system. The required and optimal generation expansion has been computed assessing the technical possibility and the economic convenience to invest money in new VRES (PV and wind) or CCGT power plants.

4.1 Reference scenario: Argentina

As mentioned, the *demand* forecast is available only up to 2025 and it is provided by MINEM. An extension up to 2030 has been carried out by CESI taking into account the scenario *"Tendencial"* provided by MINEM for energy demand [2] and the growth of GDP and population expected in the country. At the same time, the peak power demand 2030 was assessed taking into account the information provided by CAMMESA at year 2025. The values obtained for the year 2030 are an electrical energy demand equal to about 230 TWh and a peak power demand

2 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).

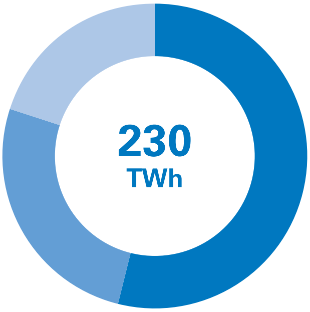
of nearly 43 GW. The most recent load hourly timeseries has been rescaled to define the hourly time series able to reach the targets 2030 in term of peak power demand and energy demand during one year. Where information is available, re-scaling has also considered how the shares of demand evolve across sectors, e.g. residential vs. industrial.

The basis for the definition of the *generation* fleet in the Argentinean system at 2030 is the information provided by CAMMESA and MINEM with the power plants expected at 2025: with respect to the generation fleet available today, an increase of the installed capacity up to 20 GW is expected, out of which nearly 10 GW PV and wind, 2.5 GW hydro, nearly 7 GW thermal and a new nuclear power plant. It is expected that the resulting generation fleet is inadequate to supply the load and cover the peak demand at 2030, as the increase from 2025 to the target year is respectively nearly 40 TWh and more than 7 GW. The performed analysis is aimed at defining the optimal needed generation mix.

Finally, the *transmission* system considered in the "Reference scenario" for Argentina corresponds to the configuration of the network estimated in 2016 by CAMMESA at 2025. The network reinforcements assumed in this configuration include all the interventions proposed by Transener (the Argentinean company owning and operating the 500 kV transmission network), and in particular a strong improvement of the transmission capacity between Patagonia and Gran Buenos Aires area thanks to a 3,500 MW HVDC link. Some other local and minor network reinforcements were included in the model to remove possible constraints which were caused by the load increase and not by the presence of VRES power plants. In this study the Argentinean system has been considered divided in three macro areas (North West, Centre and Patagonia, respectively called in the document NWE, NEC and PAT), with a Net Transfer Capacity (NTC) between areas defined applying the N-1 criterion to the physical transmission lines belonging to the cut-sets.The planned developments already represent a challenging target due to the massive investments required, and no further network reinforcements are foreseen from 2025 to 2030. The present study wants to highlight whether some bottlenecks in the transmission capacity can cause a limitation in the VRES exploitation at 2030 and whether other network improvements might be necessary and economically profitable to allow a higher penetration of VRES generation in the Argentinean system.
Figure 1 shows a graphical illustration of the main assumptions considered in the Argentinean "Reference scenario": electrical energy demand, peak power demand and generation fleet, divided among consumer typology, geographical zones and technology respectively, plus a simplified scheme of the geographical division of the Argentinean system, with the values of the NTCs between areas.

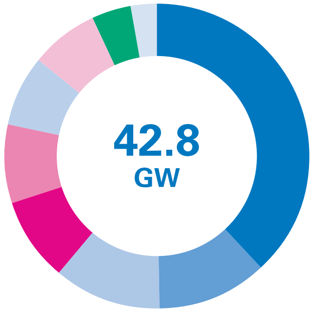
Argentina

Electrical Energy Demand
2030



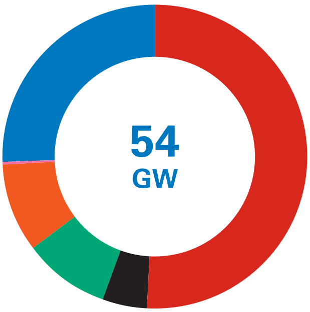
■	Residential	**53.7%**
■	Commercial	**26.2%**
■	Indust./Large Com.	**20.1%**

Peak Power Demand
2030



■	GBA	**38.1%**
■	LIT	**11.8%**
■	BSAS	**11.4%**
■	CEN	**8.9%**
■	NOA	**8.3%**
■	NEA	**7.7%**
■	CUY	**7.2%**
■	PAT	**4.0%**
■	COM	**2.7%**

Generation fleet
2030



■	Thermal	**51.0%**
■	Hydro	**25.5%**
■	PV	**9.3%**
■	Wind	**9.3%**
■	Nuclear	**4.7%**
■	Biogas/Biomass	**0.3%**

Interconnections between areas
2030

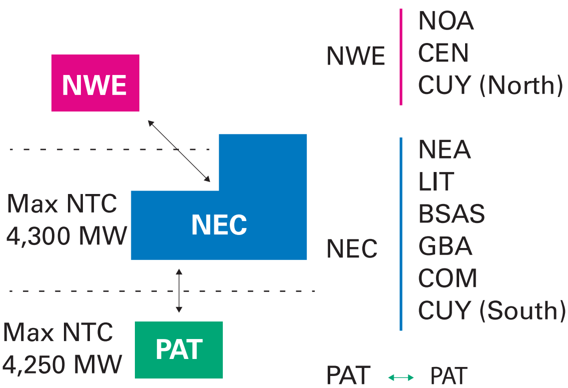


Figure 1 - Reference scenario for Argentina in 2030: electrical energy demand, peak power demand, generation fleet and NTCs
Note: GBA: Gran Buenos Aires; BSAS: Buenos Aires; COM: Comahue; LIT: Litoral; NEA: Noreste Area; CEN: Centro; CUY: Cuyo; NOA: Noroeste Area; PAT: Patagonia.
[Source: MINEM and CAMMESA, data elaborated by CESI]

4.2 Reference scenario: Brazil

The long term *demand* forecast for Brazil is available up to 2026, published by EPE [3]. An extension up to 2030 has been carried out by CESI adopting the growth rate considered by EPE, resulting in nearly 875 TWh and 138.6 GW peak. The 2030 hourly load profile is obtained starting from the most recent time series published by Operador Nacional do Sistema Eléctrico (ONS), reflecting the peak power demand and energy demand forecasts

From the same "Plano Decenal de Expansão de Energia" referred to 2026, it is taken the reference for the *generation* fleet to be adopted in the "Reference scenario". It consists in about 215 GW of capacity, half of which hydro. Wind and PV are foreseen present in an already great amount (more than 38 GW in total), and additional power plants of different technologies will be required to cover the load increase from 2026 to 2030.

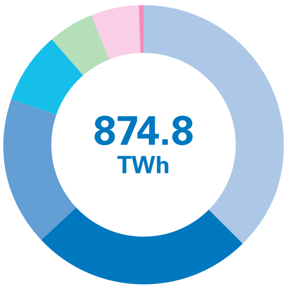
Also the model of the *transmission* system has been based on the information released by EPE. The Brazilian transmission system is considered divided in four macro areas (Norte, NordEste, SudEste/CentroOeste, Sul). Huge development is planned from today to 2026, with the construction also of important HVDC corridors needed also to connect new big hydro plants with load centres.
The NTC expected defined by EPE at 2025 are reported in the scheme, and will be considered also for 2030.

Figure 2 depicts the distribution of electrical energy demand among the different classes of consumers, the composition of the generation fleet and the value of the NTC assumed between the areas systems.

Brazil

Electrical Energy Demand

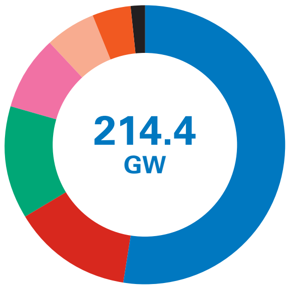
2030



Industrial	37.6%
Residential	25.6%
Commercial	17.2%
Public	8.3%
Agriculture	5.3%
Energy Sector	5.7%
Transportation	0.4%

Generation fleet

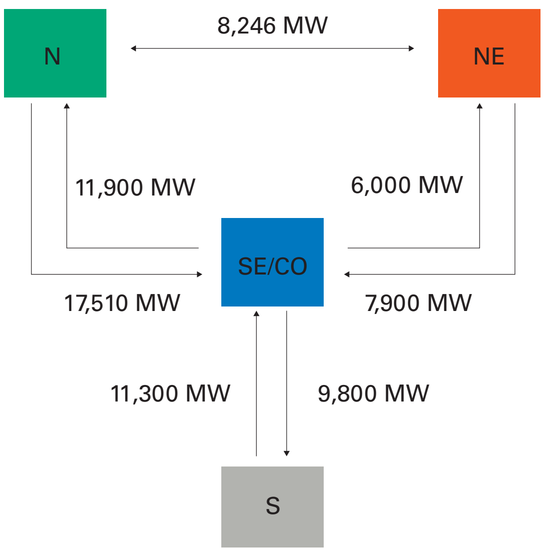
2030



Hydro	52.7%
Thermal	13.7%
Wind	13.3%
Biogas/Biomass	8.5%
Peak Load	5.7%
PV	4.5%
Nuclear	1.6%

Interconnections between areas

2030



- Norte
- Nord-Este
- Sud-Este/Centro-Oeste
- Sul

Net Transfer Capacity (NTC)

N+NE → SE/CO ≤ 20,850 MW
SE/CO → N+NE ≤ 19,800 MW

Figure 2 - Reference scenario for Brazil in 2030: electrical energy demand, generation fleet and NTC [Source: EPE, data elaborated by CESI]

4.3 Reference Scenario: Uruguay

The 2030 energy *demand* forecast for Uruguay is provided by MIEM DNE [4] while the expected 2030 peak power demand has been calculated considering the average peak demand growth of the last 15 years (about 2%). The load profile is published by the Uruguayan market operator (ADME).

As far as *generation* capacity is concerned, over the last few years, installation of VRES plants has increased considerably, and a new thermal power plant, called "Punta del Tigre" entered in operation. No further detailed generation development plan is available for the future, and for this reason the generation fleet included by the system operator (UY) in the network model for 2021 has been deemed the most reliable forecast and used accordingly. The same network model has been adopted as basis for the *transmission* system. Special attention has been paid to some possible reinforcements of the 500 kV lines. One single area has been considered for the whole Uruguayan system. Figure 3 shows electrical energy demand and generation fleet considered at 2030 for Uruguay.

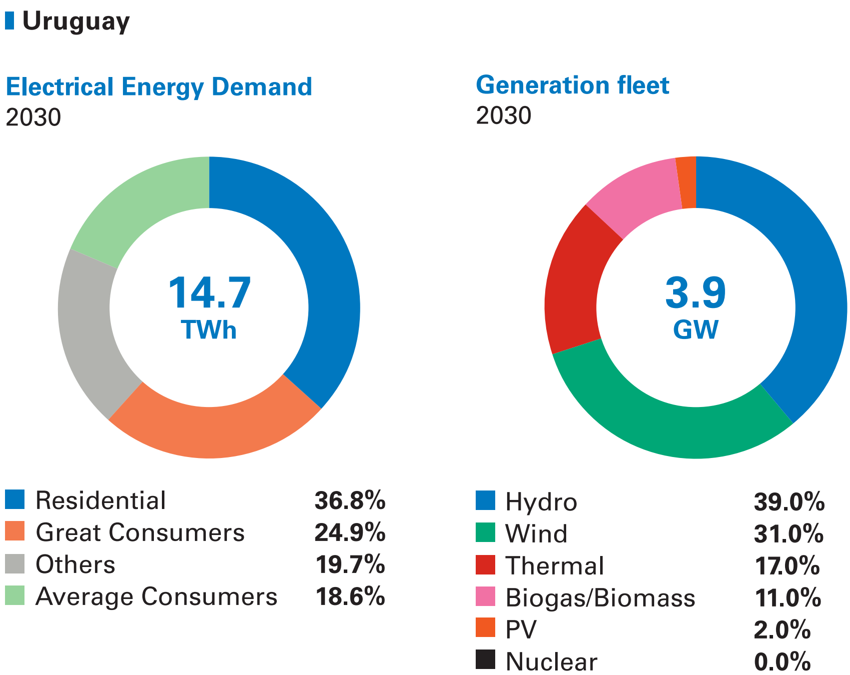


Figure 3 - Reference scenario for Uruguay in 2030: electrical energy demand and generation fleet [Source: MINEM DNE and UY, data elaborated by CESI]

4.4 International interconnections

In a first step, the assessment of the optimal technical and economic penetration of VRES power plants in the Argentinean, Brazilian and Uruguayan systems is performed on each single country, considered as isolated. The assessment takes into account possible transmission network reinforcements aimed at allowing a better exploitation of PV and wind resources. No energy exchanges with neighbouring countries are taken into account, looking for the best development of the VRES penetration to meet energy and peak power demand internally to each country.
Once the solution for each isolated country is found, the operation of the interconnected systems is simulated, to evaluate whether the possibility to exchange power across the border can increase the optimal amount of installable VRES capacity. Also in this case, no energy exchange with other countries is simulated. The following interconnections are modelled:

Between **Argentina and Brazil:**

- The existing lines Rincón de Santa María - Nodo Frontera Garabí with back-to-back solution allowing up to 2,000 MW power exchange
- A new 1,000 MW interconnection (San Isidro - Puerto Iguazù - Foz de Iguacu)

Between **Argentina and Uruguay**:

- Two existing 500 kV lines in Salto Grande and between C.Elia (AR) and San Javier (UY) with maximum power exchange up to 2,000 MW

Between **Uruguay and Brazil**:

- The existing line Santana do Livramento (BR) – Rivera (UY) with back-to-back solution allowing 70 MW power exchange.
- Interconnection between the conversion substation in Melo (UY) and P. Medici/Candiota (BR), with back-to-back solution allowing up to 500 MW power exchange

5 Optimal VRES penetration

The performed analyses allowed defining the generation fleet at 2030 and in particular the optimal technical and economic penetration of VRES power plants that can be introduced in the "Reference scenario". Thanks to probabilistic simulations performed with GRARE software, the expected yearly operation of the systems is evaluated considering operational constraints (system reserve, power transfer capacity of the transmission network, uncertainty in the PV and wind production) and production costs, thus enabling the calculation of possible benefits for the systems compared to the "Reference scenario". The results are presented for each country considered as isolated from the others, and then the expected operation of the interconnected system is described, together with benefits and variations in the optimal VRES configuration due to the possibility to have energy exchanges between countries.

5.1 Argentina – isolated system

At the end of the computational process, the optimal amount of additional VRES with respect to the installed power already considered in the Reference scenario is about 5,000 MW of PV and 9,000 MW of wind power plants, with a total of installed battery storage of about 2,000 MW.

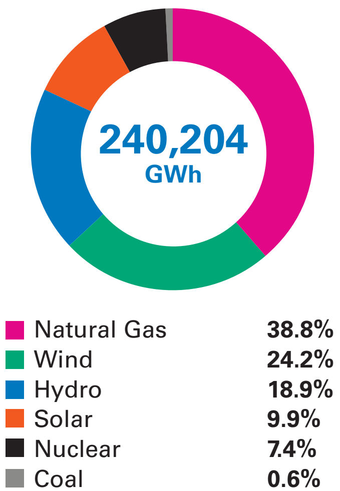
Additional 3,000 MW of new CCGT power plants had to be considered in order to reach a good adequacy of the power system with a value of EENS around 0.9×10^{-5} of the total demand. The investment in such technologies provides benefits for the system higher than USD 1,300 million/year. These benefits are evaluated as the difference between savings in the generation costs and lower EENS compared to the investment costs in new generation. The expected LCOE for PV is 45.4 USD/MWh, and for wind 43.7 USD/MWh. The amount of additional power turns out to be quite balanced between the VRES technologies 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. Table 1 shows the resulting installed capacity per technology in each area of the Argentinean system.

Table 1 - Argentina: Additional and total VRES installed power in the Scenario with optimal economic amount [MW]

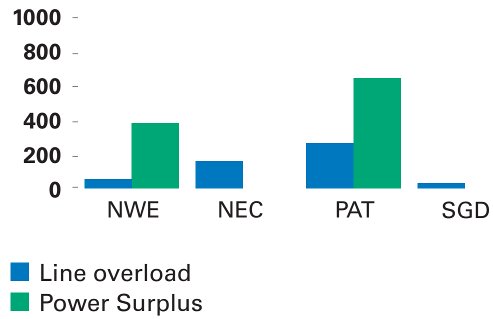
AREA	PV installed power		Wind installed power	
	Added to reference scenario	Total	Added to reference scenario	Total
NEC	1,082	1,100	5,950	8,400
NWE	4,000	9,000	0	300
PAT	0	0	3,000	5,200
TOTAL	5,082	10,100	8,950	13,900

In this scenario, PV plants produce nearly 24 TWh per year and wind plants more than 58 TWh per year. There is a risk of PV production curtailment, evaluated in 380 GWh, mainly due to the possible overgeneration conditions in NWE and network constraints close to the interconnection between NWE and NEC; wind production is affected by a risk of curtailment around 1 TWh due to both overgeneration conditions especially in PAT and network constraints in PAT and NEC. In total, the risk of curtailments is lower than 2% and still convenient for the system thanks to the positive impact that VRES plants have when not curtailed. The presence of battery storage helps keep the EENS below the 10^5 threshold and reduce the VRES curtailments, thanks to the possibility to shift generation from overgeneration periods to periods with lack of resources. In fact, without batteries, EENS would increase 6 times and VRES curtailments by nearly 50%. They also has a positive effect on the reduction of the VRES production variability which might affect the operation of the power system. Furthermore, the fast and effective regulation capability of distributed storage systems allows partially relaxing some operational constraints (for instance strict N1 criterion on some sections or limits due to dynamic performances) because batteries might effectively support a quick redispatching of the production/absorption of the power, modifying load flows in case of some contingency and keeping the system in a safe state. The NTC limit of the cut-set NWE - NEC is reached in some operating conditions with the power flowing from NWE to NEC, for a duration equal to about 220 hours, while the interconnection PAT – NEC is saturated 720 hours from PAT to NEC. Figure 4 shows the mix of energy sources used in each area to supply the load, the energy exchanges between areas and the risk of RES curtailments with the amount of energy required to be redispatched due to network constraints.

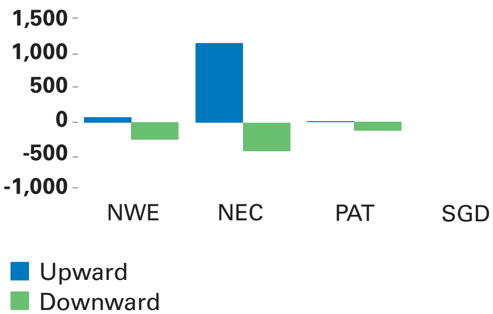
Total system (ARG+SGD)



Curtailed Energy [GWh]



Redispatching for line overload [GWh]



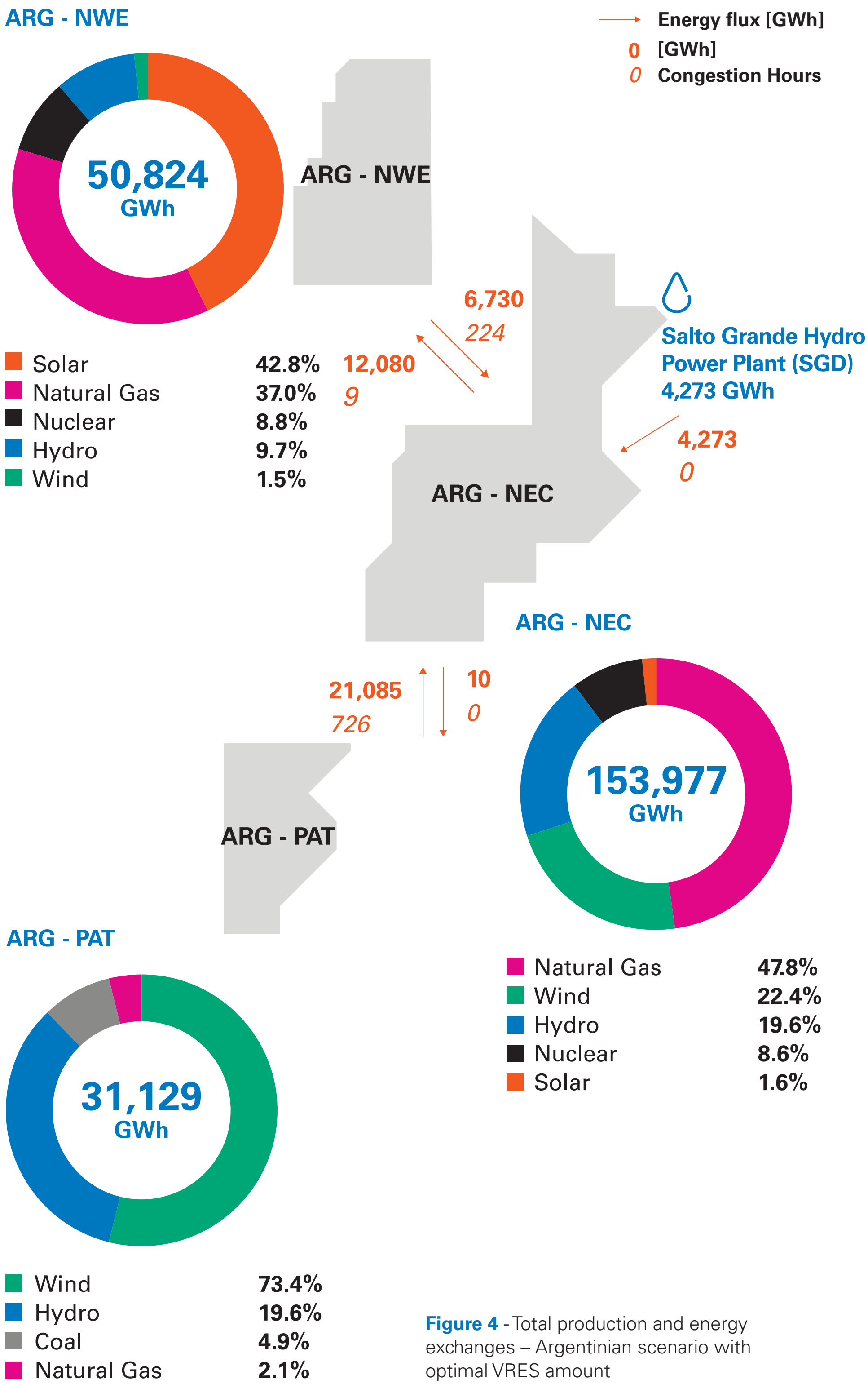


Figure 4 - Total production and energy exchanges – Argentinian scenario with optimal VRES amount

5.2 Brazil – isolated system

At the end of the computational process, the optimal amount of additional VRES with respect to the installed power already considered in the Reference scenario is about 11,000 MW of PV and 10,000 MW of wind power plants, with a total of installed storage of about 3,400 MW. The total amount of VRES power plants in the system reaches nearly 60 GW, divided 35% PV and 65% wind. The expected LCOE for PV is 44.7 USD/MWh, and for wind 49.6 USD/MWh.

Overall generation costs decrease thanks to the VRES production which replaces thermal expensive generation, and considering the investment cost needed for the new plants, the total benefit for the system is equal to about USD 3,200 million. No significant network congestions are present.

Expected generation by PV plants is almost 40 TWh, with curtailments increasing up to 1.5 TWh, while expected generation by wind power plants is higher than 145 TWh with a curtailment of about 5.9 TWh. The risk of VRES production curtailments is a bit lower than 4% of their production.

Table 2 provides the total VRES installed capacity resulting from the optimization process in the "Reference scenario", divided between the technologies and the different areas.

Table 2 - Additional and total VRES installed power in the Scenario with optimal economic amount [MW]

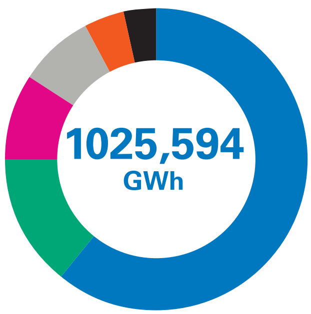
AREA	PV installed power		Wind installed power	
	Added to reference scenario	Total	Added to reference scenario	Total
BRA - N	1,360	1,460	430	670
BRA - NE	6,720	8,470	5,220	28,990
BRA - S	0	0	4,480	8,910
BRA - SE/CO	2,790	10,590	0	30
TOTAL	10,870	20,520	10,130	38,600

It's worth highlighting that no need for new thermal generation emerges for the coverage of the load increase from 2026 to 2030, and that the generation planned by EPE at 2026 plus the additional wind and PV plants individuated in this study is enough to ensure a good adequacy of the system. Also the transmission system defined in the PDE2026 [3] shows adequate exchange capacities between the areas and the states. Local network reinforcements might be needed to connect the huge amount of new plants resulting from the performed analysis, and the definition of the specific projects must be evaluated with detailed studies focused on the real requests for connections, identifying for each case the best solution.

The simulations showed an already high level of flexibility for the system thanks to the massive presence of hydroelectric power plants with regulation capacity. This characteristic allows a high penetration of the VRES plants (wind and PV reach in the optimal scenario 25% of the installed capacity and supply more than 20% of the load). The high share of hydroelectric generation is on the other hand also the limiting factor for further VRES penetration, as the introduction of additional generation would cause an increase in the risk of curtailments due to the over-production situations, making the construction of new plants not convenient from the economic point of view.

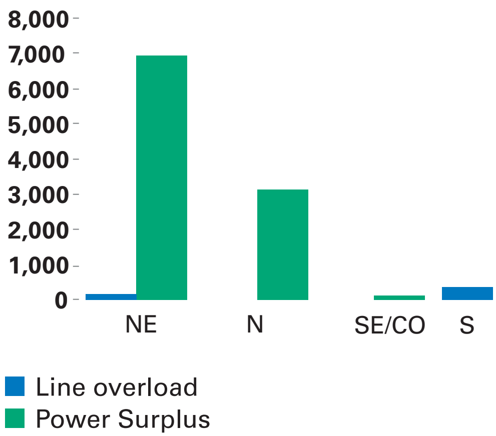
Figure 5 provides a visual summary of the operation of the Brazilian system in the optimal scenario, highlighting the generation mix per areas, the energy exchanges between areas, the curtailed VRES production and the amount of thermal energy to be redispatched to solve network congestions.
With respect to the "Reference scenario", the wind production increases from 11% to 15% mainly replacing energy generated by Natural Gas plants, which decreases from 14% to 10%. PV, due to lower installed power and lower equivalent hours, has a more marginal part in the energy mix of the country. Energy exchanges between the areas increase, and this cause also an increase of the network losses, so part of the benefit due to the new VRES generation (more than 6 TWh) is lost.

BRA - Total

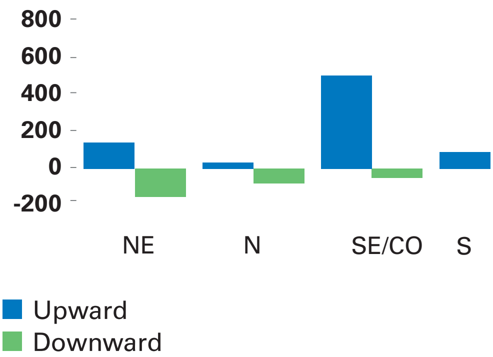


Hydro	60%
Wind	14%
Natural Gas	9%
Other res	8%
Solar	4%
Nuclear	3%
Coal	0%

Curtailed Energy [GWh]



Redispatching for line overload [GWh]



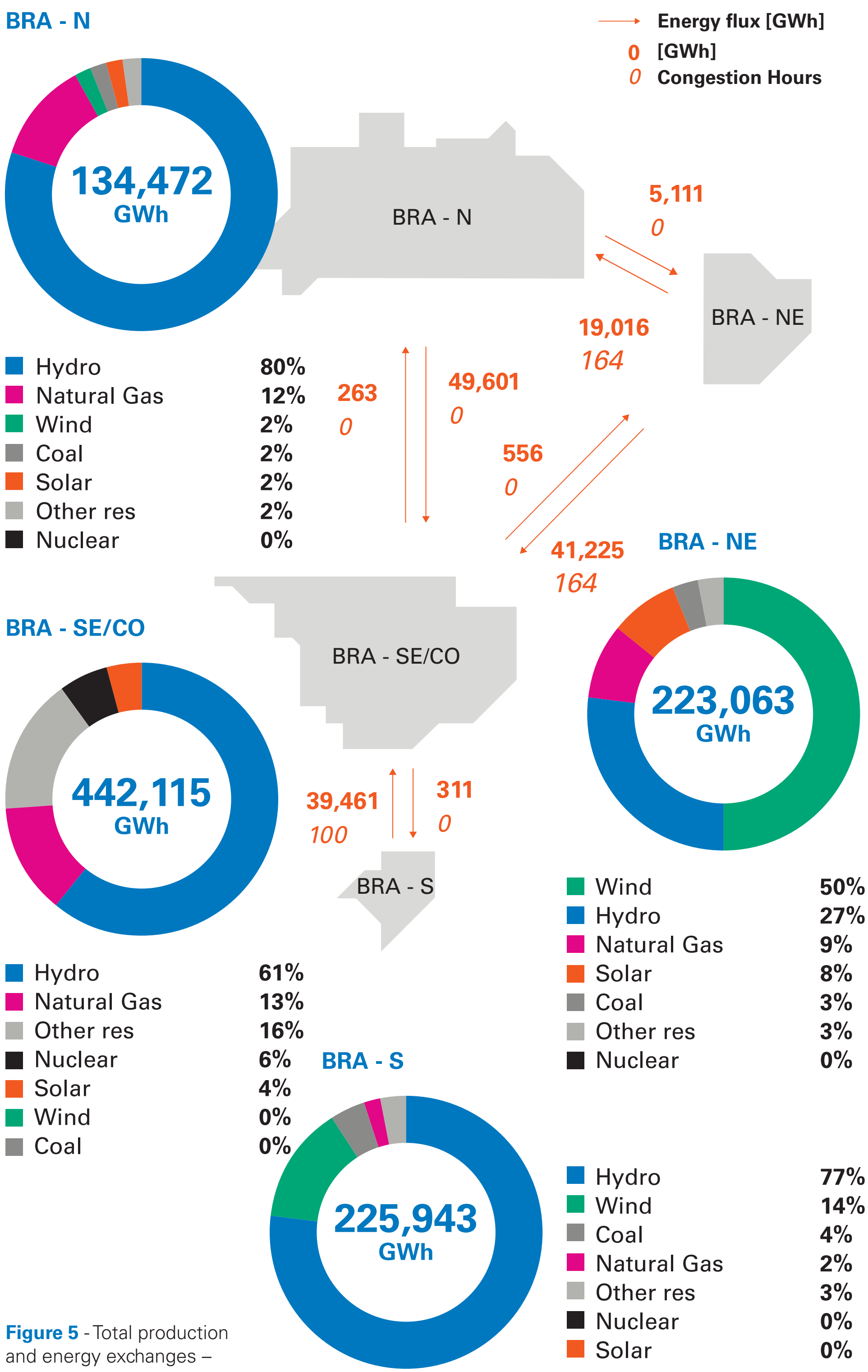


Figure 5 - Total production and energy exchanges – Brazilian optimal scenario

Moreover, an additional simulation of the expected operation of the Brazilian system has been carried out on the scenario with the calculated optimal amount of VRES and storage plants, considering also that the installed power of some selected hydropower plants is increased, for a total amount of nearly 5 GW. This possibility is currently under evaluation in Brazil[3], to increase the flexibility of the generation fleet where technically most feasible.
The results show that the improved possibility to exploit the hydro power production when most needed would allow the system to obtain a benefit of USD 15 million/year, with a more optimized usage of water resource and consequent saving in thermal generation, and improvement of the system adequacy. In general, this action should not modify considerably the optimal amount of VRES plants, as does not affect significantly their economic figures, but might reduce investment in batteries (hydropower plants provide a higher regulation capacity than before) and in other thermal power plants. Finally, further benefits related to realtime operation might appear thanks to the increased regulation capacity which makes available more balancing resources at low cost, though a different detailed analysis should be done to quantify them.

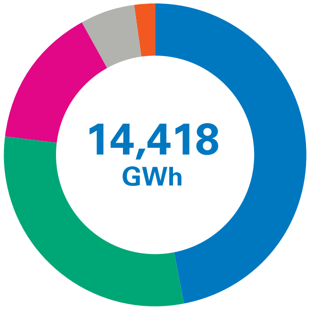
5.3 Uruguay – isolated system

The simulation of the Uruguayan system isolated from the other countries showed that the generation fleet considered in the Reference Scenario is already sufficient to cover the load at 2030, and the introduction of further VRES plants is not convenient form an economic point of view.
This conclusion is due to the fact that the system already can rely on a significant contribution of hydropower plants, able to provide a considerable amount of energy with a high level of flexibility, and that a new CCGT power plant has just entered in operation which can supply a significant part of the demand with cheap and dispatchable energy. Moreover, more than 1,500 MW of wind power plants and 230 MW of PV power plants are already included, and their total capacity already corresponds to nearly half of the peak load.

Figure 6 provides an overview of the main results with respect to the amount of energy and the contribution of the different technologies to the demand coverage.

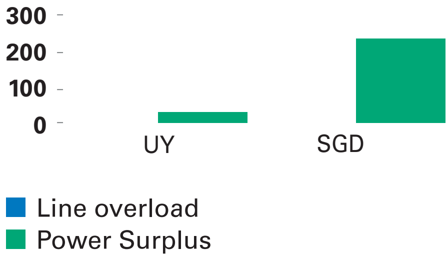
3 Reference to SRG/ANEEL Technical Note No. 026/2011

Total system (UY+SGD)

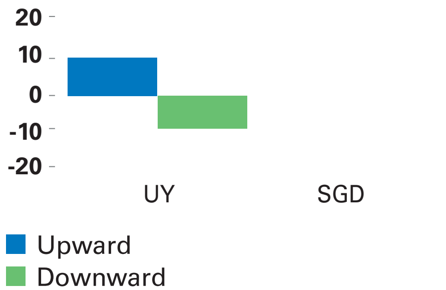


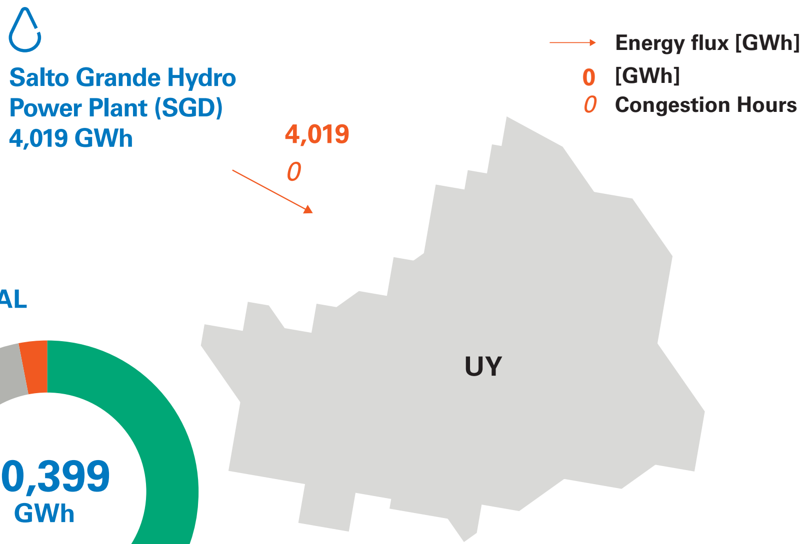
Hydro	47%
Wind	30%
Natural Gas	15%
Other res	6%
Solar	2%

Curtailed Energy [GWh]

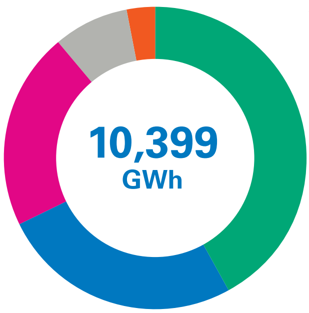


Redispatching for line overload [GWh]





UY - TOTAL



Wind	42%
Hydro	26%
Natural Gas	21%
Other res	8%
Solar	3%

Figure 6 - Total production and energy exchanges – Uruguayan scenario

The amount of wind power plants is already the optimal economic one when considering the system as isolated, so with high risk of production curtailment in case of overproduction (as already happened in significant way in the past years) due to impossibility to evacuate the power in excess towards neighboring countries. LCOE of PV and wind plants is expected to be about 5860 USD/MWh, in case curtailments similar to the ones happened in the past have to be maintained also in the future.
In case equivalent operating hours (EOH) for wind generation can increase up to 3500 h (corresponding to a 40% capacity factor, possible with the available resource) thanks to reduction of curtailments, the corresponding LCOE would decrease to values lower than 50 USD/MWh Due to the high interconnection capacity compared to the dimension of the Uruguayan power system, different conclusions might appear when the system is considered connected to others, as the VRES production might be exploited with lower curtailments.

5.4 Argentina, Brazil and Uruguay interconnected systems

After the analysis of the Argentinean, Brazilian and Uruguayan systems considered as isolated, in this paragraph the results of the analysis of the interconnected systems are presented. The evaluation of the operation of the whole system together and the assessment of the benefits that an additional amount of VRES plants can bring to it is carried out starting from the configurations obtained at the end of the isolated systems analysis, i.e. including the VRES plants resulting at the end of the previous optimizations.
A key issue for the simulation of the expected operation of the interconnected system is the definition of the Net Transfer Capacity (NTC) values between the countries. Different simulations have been carried out varying the NTC values depending on possible assumptions, to identify the most appropriate transfer capacity for the values for the sections. It is worth underlining here that the systems are operated at different frequencies (Argentina and Uruguay at 50 Hz, Brazil at 60 Hz), and this has an impact on the way how the interconnections can be exploited. In fact, the links between countries operated at different frequency are controlled by means of static converters, which allow imposing the desired active and reactive power flows (within the design parameters of the lines and the equipment), with great flexibility and independency of each interconnection line with respect to the others.
This fact allows the exploitation of the transmission capacity between the countries at the maximum without the risk of an unbalanced distribution of the power flows on the different lines. On the contrary, power flows on interconnections between countries operated at the same frequency without special regulation devices (such as Phase Shifter Transformers or controllable series capacitors) depend on the network characteristics and NTC might have to be kept significantly lower than the thermal capability of the conductors because of risk of unbalance and unacceptable dynamic operation during transient conditions.
The values assumed for the NTCs between the countries are reported in Table 3.

Table 3 - Considered cases for the interconnected scenario [MW]

NTC ARG-UY	NTC ARG-BRA	NTC UY-BRA
1,000	2,500	500

Applying these NTCs, the operation of the interconnected system shows significant improvements and brings the following benefits:

- Increase of the overall security of supply, as EENS reduces by more than 75%;
- Reduction of risk of VRES curtailments by 25%;
- Reduction of overall generation costs by 5%, thanks to higher VRES production and the possibility to share the cheapest resources between countries.

It is useful recalling here that the simulations assumes that the electricity markets are fully integrated among the countries, and interconnections are exploited at the maximum values technically admissible (NTC) to maximize the economic benefits for the system. For this reason, these results represent a sort of maximum benefit that might be reachable when proper regulatory and operative conditions are set to ensure the maximum coordination between the different national systems.

The improvement of the security of supply of the whole interconnected system due to the better usage of the available generation capacity and in particular to import energy when needed offsets the need for the additional dispatchable generation introduced in the Argentinean isolated system to ensure the generation adequacy and keep the EENS below the 10^5 threshold. Thanks to the interconnections, the Argentinean system maintains the adequacy even without considering the 3,000 MW CCGTs proposed in NEC and NWE areas, saving the related investment costs.

This money can be invested in VRES in the areas which take advantage from the presence of the interconnections, i.e. NEC in Argentina, Sul in Brazil and Uruguay. In these areas, the main VRES resource is the wind, and a total of additional 4,500 MW can be distributed there. Due to the dimensions of the systems and the need of energy, it is proposed to install 3 GW in Brazil, 1 GW in Argentina and 500 MW in Uruguay, but in particular the distribution of the plants between Argentina and Uruguay might be also different because the interconnection between the two countries does not represent a real constraint for the wind production and in some areas the potential is similar.

As a summary, Table 4 reports the final amount of PV and wind installed power in the resulting optimal interconnected scenario.

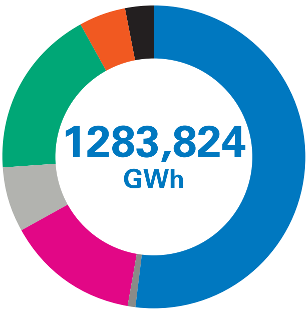
Table 4 - Total VRES installed capacity in final optimal scenario for ARG, BRA and UY interconnected [MW]

COUNTRY	AREA	PV installed power [MW]	Wind installed power [MW]	Total VRES [MW]
ARGENTINA	NEC	1,100	9,400	10,500
	NWE	9,000	300	9,300
	PAT	0	5,200	5,200
	Total	10,100	14,900	25,000
URUGUAY	UY	230	2,050	2,280
	Total	230	2,050	2,280
BRAZIL	N	1,460	670	2,130
	NE	8,470	28,990	37,460
	SE/CO	10,590	30	10,620
	S	0	11,910	11,910
	Total	20,520	41,600	62,120
Whole power system	**Total**	**30,850**	**58,550**	**89,400**

Figure 7 provides a visual summary of the operation of the Argentinian, Brazilian and Uruguayan power system in the final optimal scenario. With the new added wind plants, Uruguay exports part of the produced energy mainly towards Argentina, for an amount equal to about 1.5 TWh. Argentina is quite balanced, and most of the energy imported from Uruguay is then exported towards Brazil. In the whole system, wind energy covers almost 20% and PV 5% of the total production.
The introduction of a considerable amount of additional PV and wind plants increases the situations with overgeneration, and the need for curtailments. This amount is significant in Brazil, where there is the risk to curtail more than 8 TWh, and in Argentina, where the risk is relevant for about 1 TWh. Transmission network does not introduce strong limitations but in some conditions causes limited curtailments which must be compensated with dispatchable generation.

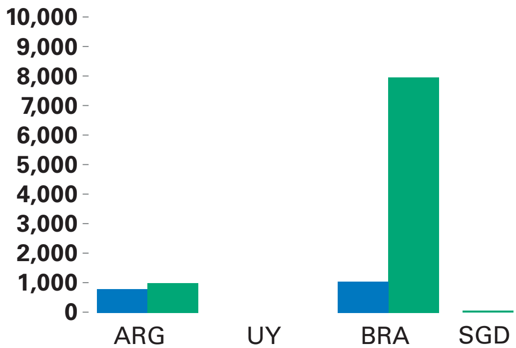
In conclusion, the optimal configuration for additional VRES installations includes a total of 30,850 MW of PV power plants and a total of 58,550 MW of wind power plants as reported in the Table 4. With these additional VRES plants and the related storage systems, the system is able to cover the load increase from 2026 to 2030 only with carbon free generation, maintaining a good adequacy and providing economic benefit to the countries. The increase of installed power is then limited mainly by the risk of curtailments due to overgeneration conditions, which represent the most significant constraint in the areas with highest wind and PV potential.

Total system (BRA+ARG+UY+SGD)



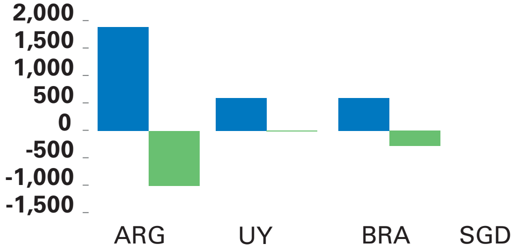
Hydro	52%
Wind	18%
Natural Gas	14%
Other res	7%
Solar	5%
Nuclear	3%
Coal	1%

Curtailed Energy [GWh]



- Line overload
- Power Surplus

Redispatching for line overload [GWh]



- Upward
- Downward

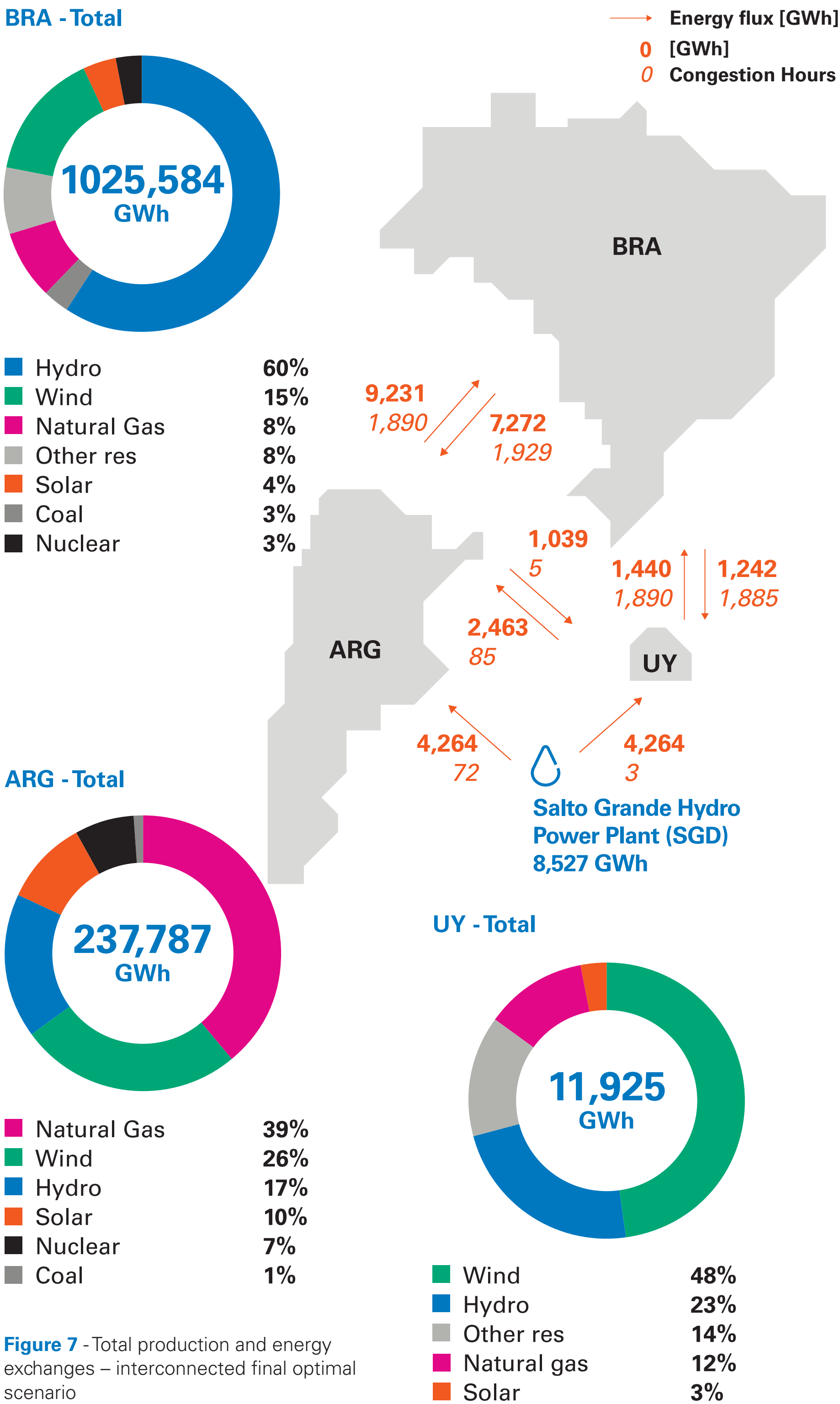


Figure 7 - Total production and energy exchanges – interconnected final optimal scenario

5.5 Sensitivity analyses on final optimal configuration for the interconnected system

Some sensitivity analyses have been carried out on the interconnected system resulting from the performed evaluation. The investigation, aimed at checking how the power systems with the amount of VRES plants defined in an average scenario operate also in different conditions, has been focused mainly on: variations of the transmission system, especially possible delayed development of important corridors between areas of the same country (in particular, the HVDC Graca Aranha – Silvania connecting the Norte region to the area of Brasilia in Brazil) or between countries (such as the third interconnection between Argentina and Brazil); variation of hydrological conditions.

The first sensitivity simulation has been performed considering a delay on the construction of the HVDC Graca Aranha – Silvania, proposed by EPE in the PDE2026 to increase security of supply, fostering the expansion of VRES plants in N and NE areas and optimizing the usage of hydro and thermal generation. The aim of this simulation is to verify the impact of the significant future transmission system development on the results obtained in the previous simulation. This HVDC is able in fact to transfer 4,000 MW from N to SE/CO, improving considerably the evacuation capacity of the N and NE areas, thus reducing the overproduction problems. Without this HVDC, the NTC between N and SE/CO is reduced by 4,000 MW, and higher curtailments in low load/high VRES conditions and higher production costs are expected with respect to the final case considered in chapter 5.4.

The results show an increased risk of curtailment of VRES capacity in N and NE areas by about 1.2 TWh, and thermal generation costs higher by more than USD 50 million/year, due to the need to use more expensive generation. Further benefits are connected with the presence of HVDC link (for instance, increased flexibility in the real time operation, higher security of the system against N1 and N2 events, less dependency on many projects of development of 500 kV network) which should be added to the one related to the energy cost, for a more detailed evaluation of the investment. In the second analysis, the impact of reduced interconnection capacity between Argentina and Brazil has been simulated, assuming that the third 500 kV interconnection line included in the Reference scenario (San Isidro – Foz de Iguacu) is not in service at 2030, causing a reduction of the NTC between the countries. In this condition the system suffers an increase of EENS and of the generation costs, respectively up to +80% and + USD 120 million, depending on the new assumed NTC value.

Important sensitivity analyses have been performed also on hydrological conditions, simulating the expected operation of the whole system in a dry and a wet year. In fact, the optimal amount of VRES has been defined considering an average production of the hydroelectric power plants. On the other hand, it is necessary to ensure that in different hydrological conditions, such as dry periods, the system has enough generation available to supply the load, avoiding a dramatic deterioration of the adequacy, which would cause a high EENS value. In these conditions, there must be other generation resources, even expensive ones, to be used to cover the demand. In case the simulation shows critical results, some countermeasures, based on thermal generation or other technologies, should be considered in the power system planning.

The “dry hydrological condition” has been defined based on historical series and

assuming the availability of water resource typical of the 15th percentile of the series, which corresponds also to a 15% reduction of the corresponding energy.
In this condition, EENS increases significantly in the system reaching about $2.9x10^{-4}$ of the total load, and the deterioration of the security of supply is focused especially in SE/CO, NE and N areas in Brazil, strongly dependent on hydro resource and not strongly interconnected to other systems. To ensure a better adequacy, additional generation or ways to better exploit the existing one should be considered. Solutions such as Open Cycle Gas Turbines (OCGT), reversible plants and introduction of additional storage or demandresponse mechanism, already examined in the PDE 2016 by EPE might be required.
Energy flows change with respect to the optimal scenario based on average hydrological conditions. Brazil strongly imports energy from Argentina and Uruguay due to the lack of hydro resource, and interconnections are often loaded at their maximum limit.
On the contrary, in case a "wet year" happens (still defined based on historical series assuming the conditions of the 85th percentile), the system has abundancy of generation from hydro, reducing EENS nearly to zero and requiring much higher curtailments of production by renewable sources, which increase by nearly 10 TWh. This condition is expected to take place only a very limited number of times during the lifetime of VRES plants, and for this reason these considerable curtailments have no significant impact on the overall profitability of the plants and do not change the optimal values of installed power for the whole system.

5.6 Geographical location of VRES plants and connection process

The best mix of PV and wind installed power determined in the "Reference scenario" represents the optimal solution in a long term planning. In case of network constraints, the optimal solution can be slightly adjusted to ensure that constraints are not violated. However, the detailed roadmap for deploying a massive VRES installed capacity as the one resulting from the optimization depends on specific constraints such as the availability of terrains (and not only of the best primary energy potential) and the authorisation time needed for the project development and the connection of the VRES power plants to the transmission grids. This latter issue is of utmost importance. In fact, the actual development of VRES plants will have to deal with the need to effectively connect them to the transmission network since the difficulty to get an access point to the grid where to inject the power might increase the cost of the projects. Many local network 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 that need 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.

6 Variants

Two Variants have been examined with respect to the "Reference scenario", aimed at appraising to what extent the optimal solution identified during the performed analysis fits against possible different evolutions of the power systems.
The main key parameters that are modified with respect to the "Reference scenario" are:

- electric demand;
- generation evolution;
- possibility to have big electrical storage systems.

Both Variants have been investigated on the system with interconnected countries starting from the amount of PV and wind plants defined there.

6.1 First Variant

In the first Variant a higher demand scenario has been evaluated, under the hypothesis of a stronger economic growth of the countries and a high penetration of the emobility in the biggest cities. The overall demand is increased by 8% with respect to the "Reference scenario", and the load pattern modified especially during the night as a consequence of the presence of electrical vehicles.
Also an important change in the generation fleet has been taken into account, with a significant step to support the transition to a carbonfree condition of the system: coal plants have been tentatively replaced by equivalent VRES power plants or with Natural Gas power plants with higher efficiency and lower specific CO_2 emissions in case the increase of VRES plants is not sufficient to substitute all of them keeping a suitable level of generation adequacy.
Also the need of storage systems has been evaluated, to increase the flexibility of the overall system, reducing the constraints on the minimum production and increasing also the ability to cope with the peak load. With reference to the hydro power plants, the higher flexibility has been obtained considering an increased installed power in some specific plants in Brazil, with the approach followed also in chapter 5.2. Moreover, as done in the previous analysis, additional batteries are introduced related to the installation of new VRES power plants.
Thanks to the load increase, there is the possibility to include in the whole interconnected system additional 17,500 MW of PV power plants and 22,000 MW of wind power plants, distributed between the countries and areas considering the load increase, the lack of generation due to the switchoff of the coal plants and system constraints highlighted in previous analyses. The resulting values are reported in Table 5.

Table 5 - Additional VRES installed power in Variant 1 [MW]

COUNTRY	AREA	PV installed power [MW]	Wind installed power [MW]	Total VRES [MW]
ARGENTINA	NEC	300	1,200	1,500
	NWE	1,200	0	1,200
	PAT	0	300	300
	Total	1,500	1,500	3,000
URUGUAY	UY	0	500	500
	Total	0	500	500
BRAZIL	N	3,000	1,000	4,000
	NE	5,000	9,000	14,000
	SE/CO	8,000	0	8,000
	S	0	10,000	10,000
	Total	16,000	20,000	36,000
Whole power system	**Total**	**17,500**	**22,000**	**39,500**

These additional VRES plants alone are not able to ensure a proper security of supply, as the EENS would result higher than 10^5 p.u. To reduce it to more acceptable values, other dispatchable generators must be introduced in the system, and in particular in the Brazilian areas which suffer the highest EENS. A proposal is done based on OCGT technology which represents the cheapest one in case the generation is needed only in specific and short operational conditions when there is lack of production. The resulting total amount to be considered sums up to 2,700 MW of new OCGT plants.

6.2 Second Variant

In the second Variant a lower demand scenario has been considered, under the assumption of a generally reduced economic growth and an increase of the energy efficiency. Taking into account the plans of energy efficiency already available and committed in the national development plans of future systems and what already included in the "Reference scenario", the load is reduced 15% in Argentina, 10% in Brazil and 8% in Uruguay.

The generation fleet assumed in the Variant 2 is the same as the one present in the "Reference scenario" of the each single country. In this condition, the optimal amount of VRES power plants that can be added with respect to the "Reference scenario" is limited to 1,000 MW PV, inserted only in Argentina, and 3,500 MW wind, distributed mainly in Argentina. Due to the high hydro resource availability and low demand, there is no convenience to install further VRES in Brazil in addition to the 38 GW already present in the "Reference scenario". In this condition, Brazil tends to export the excess of energy, while Argentina would import about 6 TWh. The optimal amount of PV and wind plants would increase especially in Brazil in case some of the nonVRES power plants (thermal, hydro, biomass…) considered in the generation fleet foreseen at 2030 will not be developed because not profitable in a scenario of lower demand growth (as they would be operated a lower number of hours) or because might incur difficulties during authorization process. In such a context, flexibility, modularity and shorter installation time of VRES plants with respect to other technologies, in addition to the competitive LCOE, might represent positive characteristics which can foster the penetration of PV and wind plants in the generation development plan also in a lower demand scenario.

7 Conclusions

The analysis aimed at assessing the optimal economic and technical amount of PV and wind power in the Argentinean, Brazilian and Uruguayan systems at 2030 taking into account the transmission system. It has been assumed that new VRES technologies can actively support the system, sharing the burden for balancing and reserve usually assigned only to the dispatchable plants. Storage systems have been allocated to new installed VRES plants, aimed at mitigating the variability of their production, which negatively affects the operation of the electric power system, and providing required ancillary services. The results showed that in these countries there is the opportunity for a massive deployment of VRES generation. The best mix of new generation varies in the countries, depending on the availability of natural resource and on the expected installation costs.

Under these assumptions, the optimal solutions in the isolated systems are the following:

- In Argentina, the installation of more than 10,000 MW of PV and nearly 14,000 MW of wind power plants, plus storage systems up to about 2,000 MW represents the optimal economic amount of VRES. Improvements of corridors from south to north in PAT and from north to southwest in NWE are then considered, focusing on lines which already have conductors with higher transmission capacity than the limits actually applied due to other factors (constraints by other equipment or due to system security during dynamic transients).
  The calculated amount of VRES plants is able to cover nearly 35% of the Argentinean load, but to ensure a low EENS in the isolated system it is necessary to introduce also 3,000 MW dispatchable generation which can supply the load when VRES production is not available.
- In Brazil, the optimal solution consists in the installation of 20,500 MW PV and 38,600 MW wind, located in the areas with higher potential, which exceed by respectively 11,000 MW and 10,000 MW the values foreseen by EPE at 2026. An amount of 3,400 MW of storage has been also introduced, even if, due to the particular generation mix in the Brazilian system, strongly dependent on hydropower plants often with huge basins and modulation capacity, the need of electric storage might be reduced by a proper coordination of hydroelectric power plants and VRES production, exploiting the storage capacity of the hydro plants to mitigate the variability of VRES plants.
  The production by PV and wind plants is able to cover about 18% of the load, and VRES become the second source after hydro. There is no need of more dispatchable power plants than the one planned by EPE at 2026 because the load increase from 2026 to 2030 can be fully covered with the additional VRES plants, keeping a good level of generation adequacy.
- In the Uruguayan isolated system there is no advantage when new VRES plants are added to the assumed generation fleet, due to the small dimension of the country and the presence of an already significant amount of hydropower plants (including the portion of Salto Grande), wind farms (which cover 30% of the load) and a new CCGT just entered in operation. When the system is considered as isolated, the production of these already existing plants is enough to cover the load; as a consequence, the introduction of new VRES is not profitable for the system because often curtailed due to overgeneration conditions, because excess of power cannot be exported to neighbouring countries.

When the systems are interconnected through the existing and planned lines, there are significant benefits in terms of improved system adequacy and better exploitation of the generation, especially VRES and hydro one.
Thanks to the possibility to exchange energy between the countries and to evacuate excess of power to neighbouring countries, Argentina does not require the additional 3,000 MW of dispatchable generation to ensure proper adequacy, because the lack of generation that was present in the isolated system can be compensated with import from the other countries. The removal of the dispatchable generation creates the conditions for the introduction of additional 4,500 MW of wind power plants distributed in the interconnected areas (NEC in Argentina, Sul in Brazil and Uruguay).
Thanks to these new plants, in this final scenario VRES production covers 36% of the demand in Argentina, nearly 20% in Brazil and more than 40% in Uruguay. Interconnections allow a better optimization of the investments in new generation, increasing system adequacy and reducing the need of dispatchable plants and favouring the coverage of the demand by VRES plants.

Some sensitivity analyses have been carried out aimed at checking how the power systems with the amount of VRES plants defined in an average scenario operate also in different conditions, with significant variation of the interconnection capacity between some areas or countries or in different hydrological conditions (dry and wet year).
In the simulations with a reduced interconnection capacity between some areas or countries, the main effect is a negative impact on the generation costs which increase due to the usage of more expensive generation and the higher VRES and hydro curtailments. The reduction of the NTC between Argentina and Brazil increases also the EENS, as predictable when considering that Argentina isolated didn't reach a good adequacy and required additional dispatchable generation.
In the dry scenario, Argentina and Uruguay are able to maintain a good adequacy of the system, increasing the production by thermal generation with the relevant higher costs, while Brazil, due to its strong dependency on the hydro resource, suffers a significant EENS increase up to about $4x10^4$ of its load. This result suggests that a proper development of dispatchable generation must be considered in Brazil to guarantee the resources to face dry periods, and that VRES alone are not enough to avoid negative impact of water shortage. It is worth underlining that in such conditions it is necessary a very close coordination of the whole system in real time operation, based on proper production forecasts by VRES and consequent optimization of the hydro resource.
On the contrary, in the wet conditions there is plenty of hydro resource, which on one hand increase the security of supply, but on the other causes more frequent overgeneration conditions, with consequent risk of curtailments of hydro and VRES productions. The expected VRES energy to be reduced increases by nearly 10 TWh, equal to 3% of their production, and this can also be assumed as impact on the profitability of the plants in the very wet conditions.

In the second part of the study, two Variants have been examined, characterized by higher or lower load and differences in the generation fleet.
In the first one, the demand increases by 8% and coal plants are shut down. In these conditions, there is economic benefit to introduce additional 17,500 MW PV and 22,000 MW wind plants, which are able to produce the energy needed

to supply the load increase and replace coal production. However, the new VRES plants are not able to ensure a good security of supply, and additional OCGTs are considered to bring the EENS to lower level, providing the needed power in the periods when there is unexpected unavailability of VRES production.
The second Variant considers a lower demand as a result of slower economic growth and energy efficiency improvements, keeping the same generation fleet of the "Reference scenario", as defined in the available development plans, which already include 55 GW of PV and wind plants. Due to the reduction of the load, the introduction of additional VRES plants becomes nearly not profitable anymore, especially in Brazil where the hydro resource and the already foreseen biomass and VRES plants are able to cover almost all the demand. The result shows that only in Argentina and Uruguay there is convenience to install 1,000 MW PV and 3,500 MW wind power plants. In these conditions, Argentina strongly depends on the import from the other countries (the net balance for Argentina is –6 TWh) and in particular from Brazil, which export the excess of energy due to hydro and VRES plants. To reduce the need for import, Argentina might install additional PV and wind plants, which can represent a positive benefit for Argentina, even if they constitute a cost for the overall system (curtailments also become significant).
In case, especially in Brazil, some nonVRES power plants (thermal, hydro, biomass…) foreseen at 2030 will not be developed because not profitable in a scenario of lower demand growth, VRES plants might represent a good alternative to be considered, thanks to their competitive LCOE and to flexibility, modularity and relative celerity in the execution of the projects with respect to other technologies.

The analysis carried out in the present study showed a big potential and economic advantages for a development of PV and wind in the regions with highest resources. VRES are able to gain a significant role in the load coverage at 2030, avoiding the need of new thermal generation from 2025 - 2026.
The availability of huge amount of hydro resource, especially in Brazil, on one hand fosters the development of VRES plants, because hydropower plants can compensate VRES variability reducing the negative impact on the systems, but on the other hand represents a limiting factor, especially in low load conditions, because of the possible overgeneration conditions and because VRES production would compete with generation without fuel costs.
Interconnections between countries support the deployment of the VRES power plants, as increase the flexibility of the systems and make available more generation resources in periods when PV and wind are low and allow evacuation of excess of production in periods when they are high. The positive effect of interconnections on the system adequacy also create the conditions for a more optimized generation expansion plan which can reduce the amount of dispatchable thermal power plants, enabling VRES production to cover a higher share of the total demand.

8 References

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