Challenges for growing the share of renewables in Portugal and Chile

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Abstract

The renewable energy transition is taking reliable steps ahead, Portugal and Chile have been leading this effort and have recently achieved monthly averages above 80% of renewable electricity including more than 3 days in a row operating with 100% electricity. This is a result of long term renewable energy policies and also because of abundant renewable energy resources in both countries. However, without enough storage capabilities, the waste of renewable energy is also a reality and should be investigated more in depth. The amount of energy that needs to be stored is investigated and as well as the discussion of the risk of grid instability in case asynchronos generation continous to increase.

Keywords: Renewable electricity; Capacity installed; Storage; Chile; Portugal

1. Introduction

Portugal in Europe and Chile in south America have been leading the renewable energy transition, thanks to abundant renewable energy resources in terms of hydropower, wind power and solar. In fact some of the highest radiations on Earth take place in the Atacama Desert in Chile, with a DNI up to 3,800 kWh/m2 in the Atacama desert, which is the world's highest solar resource very suitable for Concentrated Solar Power projects. In Portugal Hydropower capacity increased sharply in the period 1950-1990, followed by eolic in 2000-2020 and solar PV with a stronger development since 2020. Aligned with PNEC2030 [1] there is a plan to further increase the capacity of renewable electricity namely increasing solar PV to 20,8 GW, increasing windpower onshore to 10,4 GW and windpower offshore up to 2 GW [1]. In Chile, renewable electricity relies on hydropower in the south, wind and solar power in the north where the big mining activity takes place. Moreover, in 2024 renewabes supplied 68% of the country‘s electricity thus it seems feasible to achieve the target of having 80 per cent of the country's electricity from renewable sources by 2030. Additionally the country shall be carbon neutral by 2050, an objective that goes along with ambitious government policies, substantial investment in renewables, and abundant natural resources like the intense solar radiation of the Atacama Desert and strong coastal winds. In 2050 there should be 100% zero-emission in electricity production.

However increasing renewable electricity production faces challenges, namely, a possible waste of electricity in case enough storage capacity is not available in certain moments, and a risk of grid instability in case asynchronos generation continous to increase. Grid instability is also a major issue under investigation in the Iberian Peninsula, namely the reasons for the over tension in the iberian grid that led to a major blackout on 28th April 2025 when most of the Peninsula was without power for more than 12 hours. In Chile on 25th February 2025 a technical problem in a high voltage transmission line, had an impact in most of the work with a blackout for about 8 hours.

2. Methodology

In order to have an overview of the renewable electricity production, data available from the grid operators “Generadoras Chile” [2] and “REN” [3] respectively for Chile and for Portugal has been investigated by means of checking the daily and monthly production values in the period from 1st January 2023 to 30th June 2025. Moreover, the change in installed renewable capacity was also investigated. Moreover, periods of more than 80% of renewable production were analyzed to identify how often they took place.

The increase in Chile renewable electricity generation has been remarkable, taking Solar PV as an example, it

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increased from 8897 MWp in March 2024 to 11.103 MWp installed capacity in March 2025, an increase of 25%. In the following table the installed capacity in Portugal and Chile is shown.

Table 1: Total electricity capacity in MW installed in Portugal and Chile as of June 2024 [2],[3]

Electricity generation form	Capacity installed in Chile [MW]	Capacity installed in Portugal [MW]
Solar PV	9,240 (27,5%)	3,145 (14,3%)
Windpower	4,592 (13,7%)	5,380 (24,4%)
Hydropower	7,483 (32,3%)	8,376 (38,0%)
Biomass	597 (1,4%)	705 (3,2%)
Non-renewable		
Coal	4,110 (12,2%)	0*
Natural Gas	3,860 (11,5%)	4,420 (20,0%)
Oil	3,489 (10,4%)	0
Total	33,580	22,054

*NB: Two Coal powerplants have been recently phased out as part of the clean energy transition

3. Results

3.1. Peak of renewable electricity

In Portugal in 2025, for a 149 hour period that occurred between October 31 and November 6, 2023 there was 100% renewable electricity generation. In 2025, for a period of 70 hours, starting on 9th March 2025, the whole electricity consumption was covered by renewable electricity. Later on 12th March 2025, a similar situation with a second period of 69 hours 100% renewable electricity.

On the other hand, in Chile during 1 hour there was 92,6% of renewable sources registered on the 02nd February 2025 at 14:00 of the afternoon and an even higher value of 94,8% was registered on 02 January at 12:00 hrs. On March 2025, country wide, in 0,3% of the time there was a value of 90% or above of renewable electricity.

In 2024 for several months it was possible to register a % higher than 70% renewable electricity both in Portugal and in Chile. In 2024 it was quite a dry year in Portugal and this had an impact on hydropower production, originating a renewable elecricity share between 50% and 70%, during the humid months of the year the renewable share was between 65% and 90% (Table 2).

Table 2: Total electricity monthly consumption in GWh in Portugal and Chile [2], [3]

Electricity	PT-Electricity	PT-Renewable %	CL-Electricity	CL-Renewable %
Apr-24	4.359 GWh	83%	6 820 GWh	53%
Mai-24	3.295 GWh	84%	7 540 GWh	52%
Jun-24	3 939 GWh	57%	7 234 GWh	64%
Jul-24	4 315 GWh	53%	7,340 GWh	69%
Aug-24	4 119 GWh	55%	7,157 GWh	71%
Sep-24	4075 GWh	55%	6,685 GWh	75%
Oct-24	4327 GWh	68%	6.872 GWh	80%
Nov-24	4250 GWh	68%	6,797 GWh	83%
Dec-24	4654 GWh	52%	7,341 GWh	79%
Jan-25	5007 GWh	76%	7.311 GWh	74%
Feb-25	4409 GWh	79%	6.602 GWh	68%
Mar-25	4652 GWh	87%	7.259 GWh	62%
Apr-25	4359 GWh	83%	6.820 GWh	53%

Chile is a country with more than 4000 km long, has a long coast with avundant solar radiation in the north and precipitation in the south. A map showing the electrcity generation in the Summer and in the Winter (Fig 1) shows that only for 3 regions, there is a significative share of non renewable plants, in all the other regions renewable represents more than 75% of the source. All in all, it has possible to see that Chile and Portugal are achieving a very high incorporation of renewable electricity and in Portugal it was posisble to manage up to 7 days in a row with 100% renewable electricity.

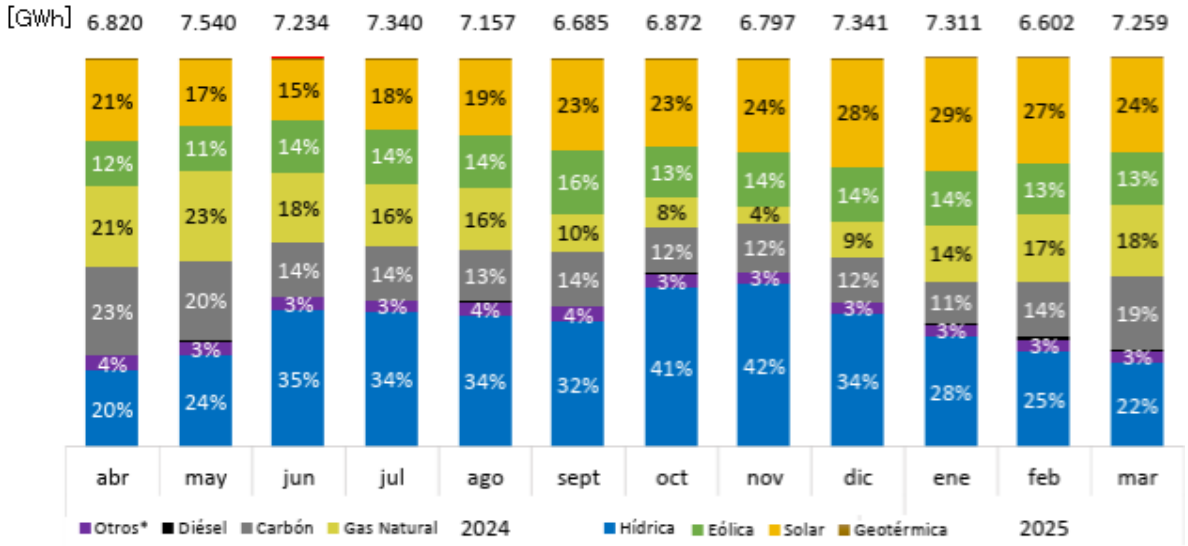

Fig. 1: Production of renewable electricity and non renewable (in red) in Chile from April 2024 to March 2025 [2]

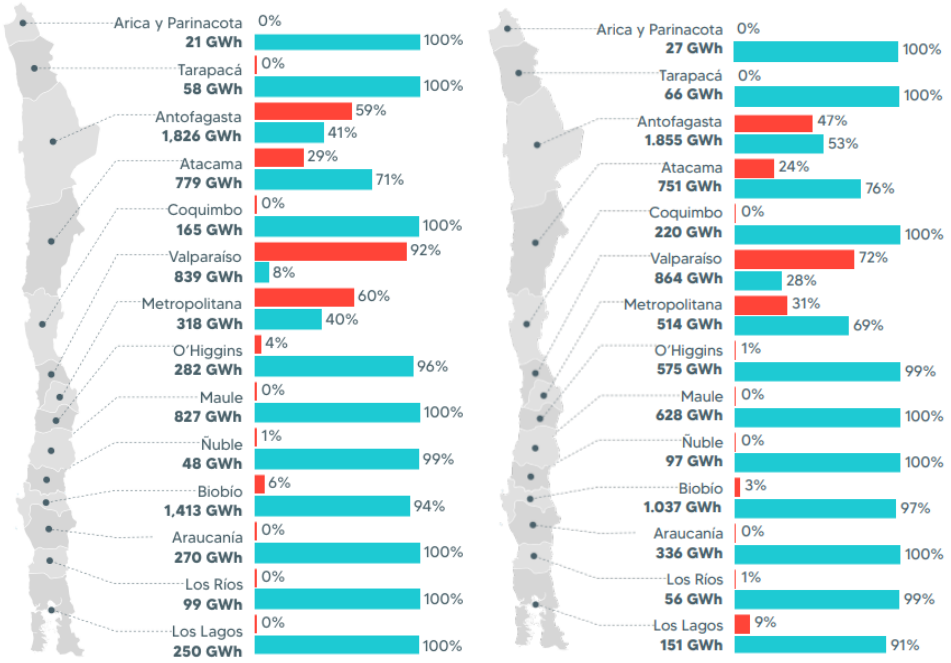

Fig. 2: Production of renewable electricity (in blue) and non renewable (in red) in Chile, left: June 2024, right: Jan 2025 [2]

3.2 Electricity curtailment in Chile

In 2024, the waste of renewable electricity in Chile was estimated to be 5,909 GWh mainly produced by wind and solar power [5]. This value is greater than all the new solar energy injected into the system. This value of 5,909 GWh wasted in 2024, was 148% more than in 2023.The lost electricity corresponds to 20% of all wind and solar generation in 2024. This energy could have supplied the annual electricity consumption of 2 million homes in Chile. This factor has the tendency to increase if there are no specific measure to increase the storage

capability of the system. This results in lost revenue for investors and highlights the need for a stronger grid.

Since 2022, curtailments have represented estimated losses of $562 million dollars [5]. 11,900 GWh of renewable electricity was curtailed between January 2022 and May 2025 [5], leading to under utilisation of renewable generation infrastructure and causing a reduction in income for investors.

To overcome this challenge, following measures are under evaluation in Chile:

- Transmission Bottlenecks: A major issue is the mismatch between the location of prime renewable resources (north and south) and population centers (central). Insufficient transmission capacity has led to significant energy curtailment, where generated wind and solar power is wasted.
- Infrastructure projects: while major projects to address transmission issues are planned it can take years to be in operation, thus significant investments and faster approval processes are needed.
- Small storage capacity: battery storage capacity is growing, however it remains insufficient to manage the intermittency of solar and wind power and reduce curtailment. In 2025, battery storage could only absorb a small fraction of the curtailed energy. Additionally most battery storage is located in the northern region where generation is highest, rather than strategically placed to serve demand centers, limiting its effectiveness.
- Grid Instability: the grid's vulnerability was exposed during a major blackout in early 2025, which highlighted the need for greater resilience through grid modernization, diversification, and decentralized generation.
- Dependence on Fossil Fuels: Despite rapid renewable growth, fossil fuels still make up a portion of the energy mix, and in times of crisis, thermal plants (including coal) have been reactivated to ensure stability. How management of renewable sources can play a relevant role is being investigated.

3.3 Major challenges in Chile

From the data gathered and the discussion with experts, it has been identified four major challenges to modernize the grid in Chile in order to enable an effective energy transition towards a 100% renewable electricity target. The challenges are bottlenecks in the transmission grid, grid modernization, insufficient energy storage and regulatory hurdles. Thus, in order to make a more robust energy system in Chile, recommendation is that all these four challenges are addressed in the coming years.

3.3.1 Transmission grid bottlenecks

There is a North-South mismatch since most of Chile's renewable energy is generated in the northern regions, particularly solar power in the Atacama Desert, while the majority of energy demand comes from central and southern population centers. This necessitates long-distance transmission, which the existing grid cannot handle efficiently. Congestion occurs frequently because of the limited capacity of the transmission grid causes significant congestion, leading to large amounts of generated renewable energy being curtailed, or "dumped". For example, in 2024, Chile curtailed 5,909 GWh of solar and wind power [5], a significant increase from the previous year. Moreover, there has been a slow expansion in building new transmission lines, which have not kept the pace with the rapid construction of new renewable generation capacity. While solar parks can be built in one year and wind farms in about 1.5-2 years, new transmission infrastructure can take up to 5 years to complete.

3.3.2 Insufficient energy storage

Chile relies more on solar and wind energy, the intermittency of these sources becomes a major challenge for grid stability. The power system is inflexible and struggles to manage the fluctuations in the generation which has led to very low electricity prices during the day. Currently, albeit growing the low storage capacity is still low since it still remains insufficient to manage the curtailment issue. As of May 2025, battery energy storage capacity could only absorb 6.2% of the solar and wind generation that was curtailed in 2024. Nevertheless, it is expected in Chile that the 2030 battery capacity target of 2 GW could be met already by 2026, and the 2050 target of 8 GW is now expected to be reached within the next two years.

3.3.3 Grid modernization

Chile's grid has traditionally been highly centralized, making it vulnerable to large-scale failures. A single high-voltage transmission line failure in early 2025 caused a nationwide blackout, exposing the grid's fragility. Additionally, the grid is susceptible to damage from natural disasters and extreme weather events, which are exacerbated by climate change. Also relevant to highlight that the infrastructure of Chile's transmission and distribution networks is aging and needs significant upgrades to support the expansion of renewables.

3.3.4 Regulatory issues

There is a perception that the permitting process is slow and complex creating delays for new renewable energy and transmission projects. Uncertainty over new legislation and regulatory frameworks has impacted investor confidence, with some regulatory changes making conditions less predictable for small- to medium-sized generators. The development of new energy infrastructure often clashes with the mining sector and other land claims, creating obstacles to project development.

3.4 Renewable Electricity in Portugal

In Portugal in 2024 there were 776 MW of new photovoltaic installations connected to the grid, doubling its installed capacity to 1555 MW, compared to the 779 MW operational at the end of 2023 [2].

Solar production in 2024 was 4899 GWh, representing approximately 10% of total consumption on the public grid (51.4 TWh), a 37% increase compared to 2023. This is the highest ever share of solar photovoltaic in the national electricity consumption [2].

It should be noted that on September 5th 2024, the accumulated solar production in 2024 equaled the total solar energy produced during the entire year of 2023 in Portugal. In the first nine months of 2024, 3.99 TWh were generated surpassing the 3.6 TWh produced between January 1st and December 31st of 2023, making 2024 a record year in terms of solar production in Portugal, reached already in September [2].

3.5 Storage in Portugal

In Portugal storage has been increasing to support the higher penetration of renewables since Portugal is increasingly relying on solar and wind power, storage is essential for balancing the grid. It stores surplus energy generated during peak production (e.g., sunny or windy days) and releases it during peak consumption or when intermittent sources are unavailable. Additionally it provides a higher level of grid stability by providing flexibility, pumped hydro helps maintain a stable and secure electricity supply, reducing market price volatility. Another advantage is that pumped hydro is considered one of the most efficient energy storage methods, with minimal atmospheric emissions. Both national grid operator REN and energy companies have made strategic investments in pumping technology, indicating its central role in Portugal's energy transition. A 2023 study suggested that Portugal's planned capacity would be sufficient for its renewable targets through 2030, without needing additional pumped hydro or battery investments by that point.

Several major projects contribute with the capacity to operate in reverse mode, that is, pumping back the water to a big water reservoir after being collected downstream. This is the case with the hydropower Alqueva – Pedrogão system [Alqueva Multipurpose Project] in the south east of the country. In case of high availability of wind or solar electricity in the Iberian Peninsula, spot prices tend to drop significantly reaching almost zero. In those moments, using electricity to pump water back is a strategy that has been pursued to store surplus electricity.

In fact, the high availability of renewable energy sources, both in Portugal and Spain, has led to the highest ever use of pumped hydroelectricity in Portugal on the same day, with a total of 41.7 GWh registered on 24th November 2024 when wind power reached a value of 110 GWh. The figure of 41.7 GWh is 24% higher than the previous record of 33.7 GWh, registered on May 1, 2024 [6]. The new hydroelectric pumping record demonstrates the System's ability to adapt to a greater availability of renewable energy in the Iberian Peninsula.

Another good example is the Tâmega hydroelectric complex in northern Portugal, which is one of Europe's largest energy storage facilities. It has a total installed capacity of 1,158 MW across three plants: Gouvães, Daivões, and Alto Tâmega. The Gouvães plant alone provides 880 MW of pumped storage.

Altogether, the complex has a storage capacity of 40 GWh, which is enough to power the whole population of

Portugal, about 11 million people, for 24 hours.

In the future it is foreseen that hydropower plants with storage will shift their role of main contributors to renewable electricity generation towards a role of arbitraging (taking advantage of surplus of renewable electricity production) and balancing the power system.

3.6 Renewable electricity forecast

Portugal is a global leader in integrating renewable energy, highlighted in the International Energy Agency's (IEA) Renewables 2025 report. One of the reasons for such success is the availability of historical data and a good planning of the renewable generation through the electricity forecast (solar, wind) made one day ahead according linked to the weather data, as well as the real-time data on consumption and renewable generation mixes, which can be accesses online in the „REN data hub“ [4].

This allows the individual electricity producers as well as the grid operator to manage better the system, and to foresee in advance how the equilibrium between load and production can take place at any given moment of the day, as can be seen in Fig.3.

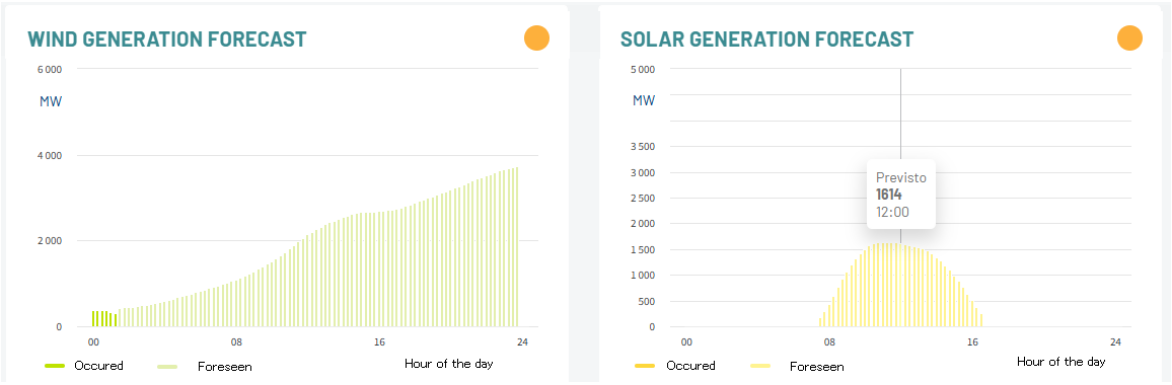

Fig. 3: Daily forecast of electricity production, wind generation (left) and solar generation (right) in Portugal [source: REN]

A similar system exists in Chile, where daily and monthly forecast of electricity production is made, as shown in Fig 4 up to January 2026.

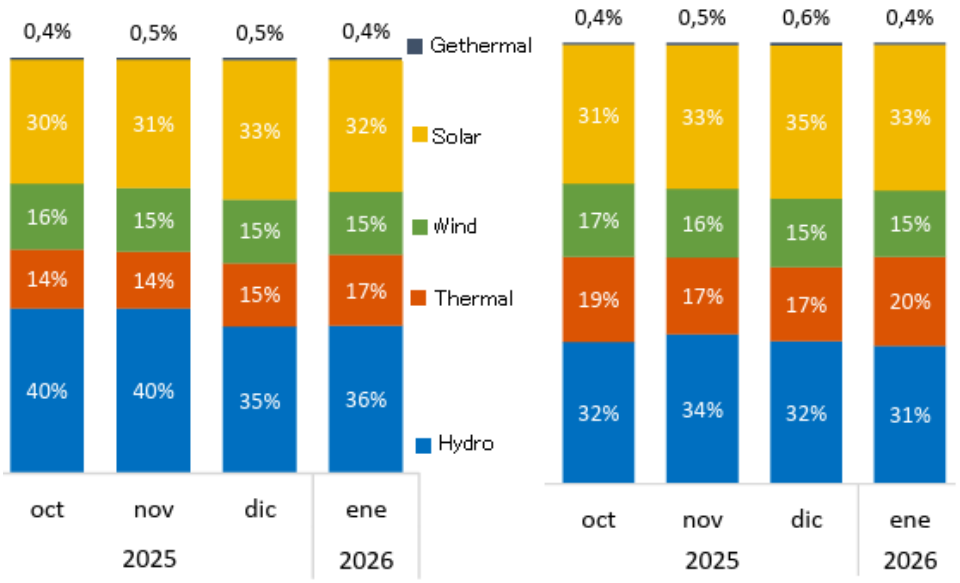

Fig. 4: Monthly forecast of electricity production in humid scenario (left) and dry scenario (right) in Chile [source: CEN-Chile]

4. Conclusion

Portugal in Europe and Chile in south America have been leading the renewable energy transition in clean electricity reaching 100% of renewable electricity generation in periods of more than 6 consecutive days. This high share of renewable generation faces also major challenges namely the increase in wasted renewable energy and a higher need of storage capabilities. Reverse pumped hydropower has been used extensively in the Iberian Peninsula in order to store energy in periods where spot price is very low due to high availability of solar photovoltaic or wind power.

The analysis for one year of renewable electricity production and its challenges was performed for Chile and Portugal in the period April 2024 to April 2025. From the data gathered and the discussion with experts, it has been identified four major challenges to modernize the grid in Chile in order to enable an effective energy transition towards a 100% renewable electricity target. The challenges are bottlenecks in the transmission grid, grid modernization, insufficient energy storage and regulatory hurdles. Thus, in order to make a more robust energy system in Chile, recommendation is that these four challenges are addressed in the coming years.

Moreover, in the near future it is foreseen that hydropower plants with storage will shift their role from main contributors to renewable electricity generation, and shift more towards a role of arbitraging (taking advantage of surplus of renewable electricity production) and also being crucial to balance the power system since hydropower plants are synchronous plants that can stabilize the grid and avoid major network failures like the ones that occurred in Chile in February 2025 and in Portugal on 28th April 2025.

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