C1-210

Paris 2020

Impact of Decarbonization on Transmission Network Planning and Delivery: comparing the German and Chilean Experiences

J.C. ARANEDA
Coordinador Eléctrico Nacional
Chile

M. MÜLLER-MIENACK
DNV GL
Germany

SUMMARY

Germany and Chile have made significant changes on the way to integrate renewable energy, on transmission and distribution levels, improved operational procedures and introduced technological changes in order to allow flexibility on several segments of the system and energy market, and finally, prepared for a decarbonization process in the power generation industry. In 2019, the Chilean generation companies that own coal fired power plants presented to the Ministry of Energy a plan to retire eight plants in the next five years and agreed to revise the decommissioning of additional plants every five years. This plan anticipates new challenges on system planning and operation because of the market opportunity to replace that capacity with more renewable plants but losing inertia and grid robustness at critical demand areas. In Germany, significant changes and further optimizations regarding the Network Development Plan process became especially active in its 2019 version. There is no separate Offshore Network Development Plan prepared by the TSOs, since the responsibility was handed over to the Federal Maritime and Hydrographic Agency. German grid development process was changed to a two-yearly basis and the setting of scenario horizons was more flexibilized in order to allow a better integration into the overarching ENTSO-E Ten-Year Network Development Plan. For the 2021 release of German transmission network plan, for the first time a complete coal phase-out will be modelled as 2035 main scenario 2040 outlook scenario, while a further increased role will be assigned to flexibilities and cross-sectoral aspects.

This paper compares and discusses the improvements of the Chilean and German grid planning process and planning principles more in detail and will highlight the related planning results in the light of ongoing energy transition processes in both countries.

KEYWORDS

Transmission planning, transmission expansion plan, decarbonization, renewable energy.

juan.araneda@coordinador.cl

INTRODUCTION

At CIGRE Session 2016, a comparison and revision of the main drivers for transmission network planning and delivery of projects in Chile and Germany was presented [1]. There, the regulatory rules and challenges faced by both countries at that time was thoroughly revised. Now, almost four years after that time, Germany and Chile have made significant changes on the way to integrate renewable energy, on transmission and distribution levels, improved operational procedures and introduced technological changes in order to allow flexibility on several segments of the power system and energy market. In that way, both countries have become prepared for the decarbonization process in the power generation industry.

In the case of Chile, most of the challenges described and presented in 2016 paper [1] were addressed and now they are a reality, including the interconnection between the north and centre-south power systems, that formed a unique 3,100 km length National Electricity System (NES). Main changes were supported by significant transformations included in the Chilean Electricity Law, enacted in July 2016. Those changes included:

- New transmission planning and pricing rules in order to facilitate competition in generation sector, with significant reduction on bidding prices for generation-distribution contracts.
- Fully market developed generation market, leaded by renewable power plants (mostly solar PV and wind onshore), without any kind of subsidies.
- Annual revision of the transmission expansion plan, with a dynamic development of transmission projects, including an anticipated strategic environmental assessment on projects that will cross sensitive areas.
- Creation of a unique independent system operator for the NES, called the National Electricity Coordinator (NEC), in Spanish "Coordinador".

In the case of Germany, subsequently to the 2019 release of network development plan which reflected significant changes of the grid planning philosophy in order to assure the integration of the further increasing variable renewable energies (VRE), beginning of 2020 a complete phase-out of coal-based generation by 2038 at latest was found as overall consensus, being subject for enacting already within 2020. Thus, the challenge for the 2021 release of German Network Development Plan looking at the time horizons 2035 and 2040 will now especially be to determine:

- the related additional needs for transmission capacity,
- the reactive power provision needs,
- the flexibility needs to cope with the power ramps,
- the inertia's provision needs,
- the cross-sectoral potentials.

The evolution of the generation mix capacity for 2010 and 2018 and forecasting for 2025, 2030, 2035 and 2040 is presented in Figure 1, for the case of Chile, and in Figure 2, for the case of Germany.

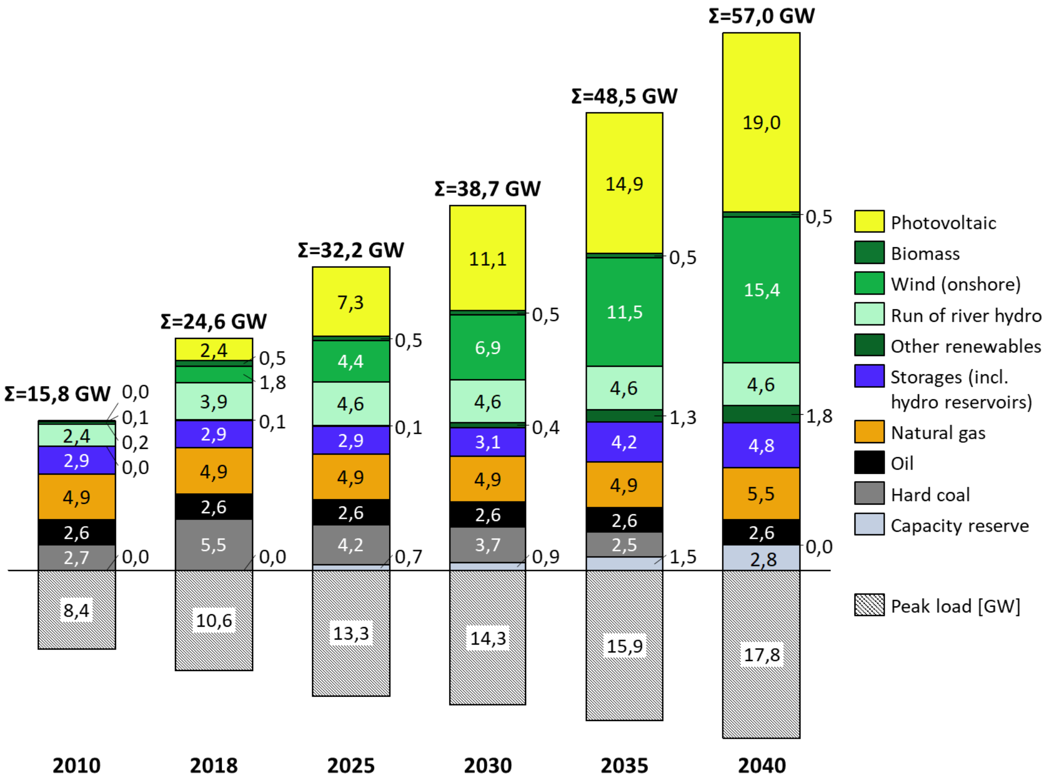

Figure 1: Evolution of generation mix capacity in Chile (Source: Coordinador)

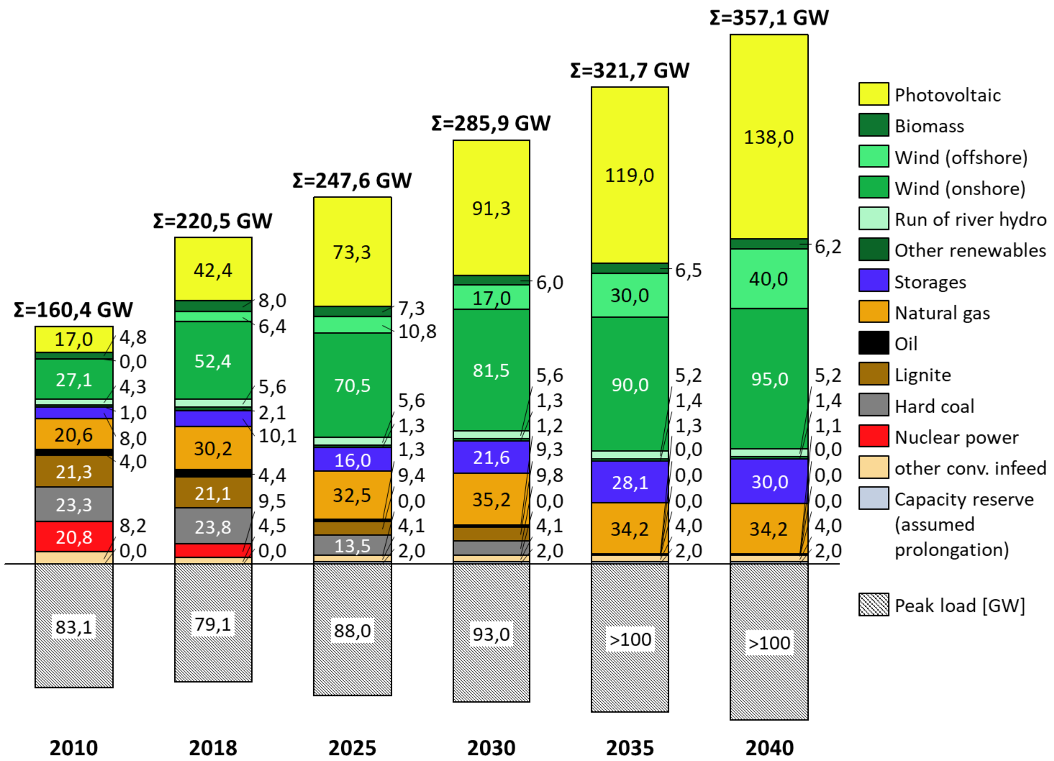

Figure 2: Evolution of generation mix capacity in Germany (Source: 2010/18 BNetzA-Monitoringbericht 2011 & 2019, ENTSO-E Memo 2010, ENTSO-E Statistical Factsheet 2019, 2025/30: NEP 2019, 2035/40: Entwurf zum Szenariorahmen zum NEP 2035, Version 2021)

DECARBONIZATION PROCESSES IN CHILE AND GERMANY

The Chilean process

In June 2019, the Chilean government announced the energy decarbonization plan "Energía Zero Coal", which includes important announcements that put Chile on the road to achieving carbon-neutrality in 2050, with milestones, which will enable a sustainable development for the community [2]. The announcement provides the following objectives:

- Withdrawal of eight (8) coal-generating units by 2024, with a capacity of 1,047 MW (20% of coal-fired installed capacity).
- Total withdrawal of coal-fired power generation by 2040.
- Carbon neutrality to the year 2050.

Additionally, the generation companies and the Ministry of Energy undertake that every 5 years after 2025, they will integrate working groups in which they will analyze the following issues [3]:

- Conditions prevailing in the NES based on studies carried out by the National Electricity Coordinator.
- Energy and environmental regulation.
- The social and employment effects of the withdrawal of the plants.
- The conditions of system adequacy and the units and studies of companies with respect to the local and individual situation of each company that owns coal-fired plants that are still operating.

The Ministry of Energy together with the National Energy Commission (regulatory body) are considering an amendment to the Regulations on Power Transfers between Generating Companies, aimed on including a new operating state called the State of Strategic Reserve, which may be applicable to coal-generating units requesting their withdrawal from the system, in order to provide security of service, adequacy and efficiency to the NES.

This withdrawal process should be developed in such a way as to meet the following objectives:

- Effective reduction of carbon emissions.
- Preserve the security and quality and service of the power supply.
- Have a resilient electrical system.
- The process is cost effective and provides competitive tariffs to all consumers.

This plan anticipates new challenges on power system planning and operation because of the market opportunity to replace that capacity with more renewable energy plants but losing inertia and grid robustness at critical demand areas.

In order to assess the effects of a withdrawal schedule of coal-fired plants the Coordinator carried out a study of operation and development of the NES without coal-fired power plants [4], presented at the decarbonization meetings coordinated by the Ministry of Energy during 2018. The assessment required defining NES generation and transmission expansion scenarios, as these will allow for a sizing and reference characterization of the infrastructure needed for the future supply of the electricity demand under this new condition, and will therefore allow for a notion of the future investment and operating costs of the electricity system.

The methodology used by Coordinator [3] was consistent with the main factors listed below:

a. Effective reductions in carbon emissions must be achieved, i.e. decommissioned power plants must be replaced by lower carbon reductions
b. Change in the transmission pricing mechanism and absence of a long-term location signal

c. Potential for VRE with development costs downwards and located in areas far from large consumption centers
d. Need to recognize flexibility requirements and other attributes in models that simulate system operation, such as inertia and participation in frequency control, due to the projection of massive integration of VRE

The methodology includes the analysis of a decarbonization schedule of the power generation matrix, which required the definition of NES expansion plans, allowing a future reference costs of operation and investment. The identification of efficient generation developments represents a good initial reference to study the future development of the system. While generation plans are not binding because of free entry to the generation market, they allow the identification of efficient and necessary future developments for the secure supply of demand.

The German process

Since Germany assumed that it will miss its climate protection targets for 2020 unless it begins to phase out coal-fired power generation (causing about 80 % of Germany's power plant sector emissions), different short-term measures were discussed, starting 2016 with the introduction of a so-called "lignite safety preparedness". According to the German Energy Act § 13g [8], this measure contains the transition of eight of the oldest lignite-fired power plant units with a total capacity of 2.7 GW between 2016 and 2019 into a safety readiness (respectively sleeping) status, followed by their final shutdown after four years. The total cost of the measure is expected to amount to approx. 1.6 billion euros and will be financed through the grid fees. During the period of safety readiness, the start-up of these power plants needs to be assured within 10 days on request by the TSOs.

Moreover, in 02/2019 the establishment of a capacity reserve of 2 GW outside the electricity market was laid down in the German legal framework [9], to be realized from winter 2020/2021 onwards. The capacity can be provided by generation plants, storages and/or controllable loads in to support the system balance in exceptional and unforeseeable situations, but the TSOs may also request the capacity reserve in cases system security issues caused by grid congestions.

In parallel to the measures above, in 2018 the German government set up a "Growth, Structural Change and Employment Commission", the so-called "Coal Commission" in order to elaborate a compromise proposal for a complete phase-out of the generation of electricity from lignite and hard coal. In 01/2019, this Coal Commission concluded that Germany should stop generating electricity from coal by the end of 2038 at the latest, and in 2032 shall be examined whether the exit can be completed as early as 2035. By 2022 a total of 12.5 GW of capacity is now to be taken off the grid, including three gigawatts of lignite. And by 2030, the capacity of coal-fired power plants will be more than halved to 17 GW. As financial support to overcome the resulting social impacts, in total 40 billion Euros shall flow over 20 years into the affected regions. Due to their short-term nature, the recommendations of the Coal Commission [10] could not be fully considered by the TSOs in the German Network Development Plan 2019 for the respective time horizons 2025, 2030 and 2035 [6].

Finally, after long negotiations between the Federal Ministry of Economics, the Federal States concerned and the big energy suppliers, based on some deviations compared to the Coal Commission proposal a consensus for a draft coal phase-out law [11] was found, which is subject for enacting within the first half of 2020. According to this consensus, the draft coal phase-out law envisages that lignite-fired power plant capacity will decline to 15 GW in 2022 and to 9 GW in 2030. Lignite will no longer be used to generate electricity in Germany by 2038 at the latest. Regarding to hard coal power plants, by 2022 the related power will drop by 8 GW to 15 GW, and by 2030 to 8 GW. The generation of electricity from hard coal will end by 2038 at the latest, same as for the lignite fired coal power plants. In contrast to the Coal Commission's proposal, however, the coal phase-out law stipulates that the hard coal-fired power plant Datteln 4 (1,100 MW), which is currently under construction, may still go into operation, but must then also be taken off the market by 2038.

Whereas for the lignite power plants a concrete decommissioning plan is elaborated, the decommissioning of hard coal power plants will be subject of respective tenders (considering the lowest cost per ton of CO2) in the period 2020 to 2026, connected with financial compensation. In the period 2027 to 2038, decommissioning will take place purely in accordance with regulatory requirements, i.e. without compensation. In 2026, 2029 and 2032 it will be reviewed whether the reduction and termination of coal-fired power generation can be achieved already be end of 2035 instead of 2038, what is reflected by TSOs' scenario proposal for the 2021 Network Development Plan looking at 2035 and 2040 [7], see also Fig. 2. The Figure 3 compares the coal phase-out scenario of the Network Development Plan 2021 for 2035 with the coal phase-out consensus of 01/2020.

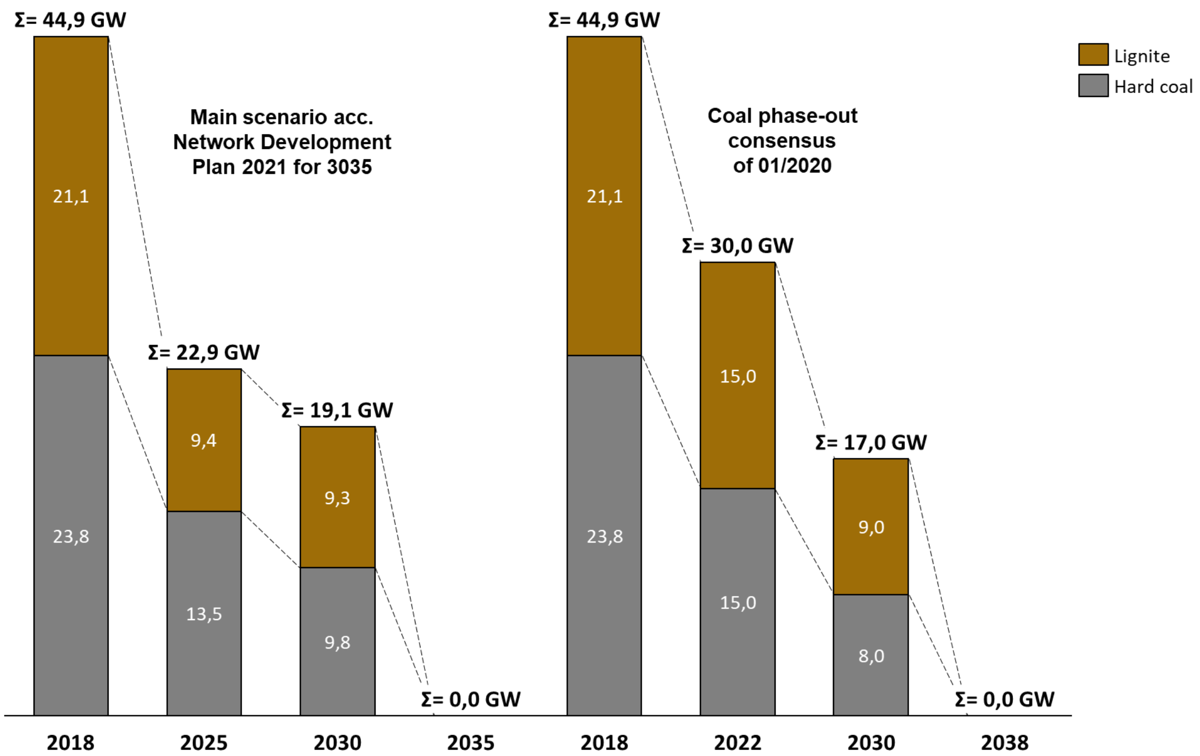

Figure 3: Comparison of the proposed coal phase-out scenario of the Network Development Plan 2021 for 2035 with the coal phase-out consensus of 01/2020

TRANSMISSION PLANNING AND DELIVERY

Impact on the Chilean transmission development plan

According to the energy scenarios defined by the Ministry of Energy in the Long-Term Energy Planning (LTEP), released in 2018 without considering decarbonization, Coordinador released a study to evaluate the impact on the expected operation and development of NES with a test-base schedule of coal-fired plants withdrawal [4]. In that study, the generation and transmission expansion were determined via a co-optimization of the investment and operation costs of candidate generation plants and transmission lines. In Figure 4 are presented the scenario defined by Coordinador (NEC

Study) and the three scenarios (SC) determined in the Ministry of Energy's LTEP update [2] in December 2019.

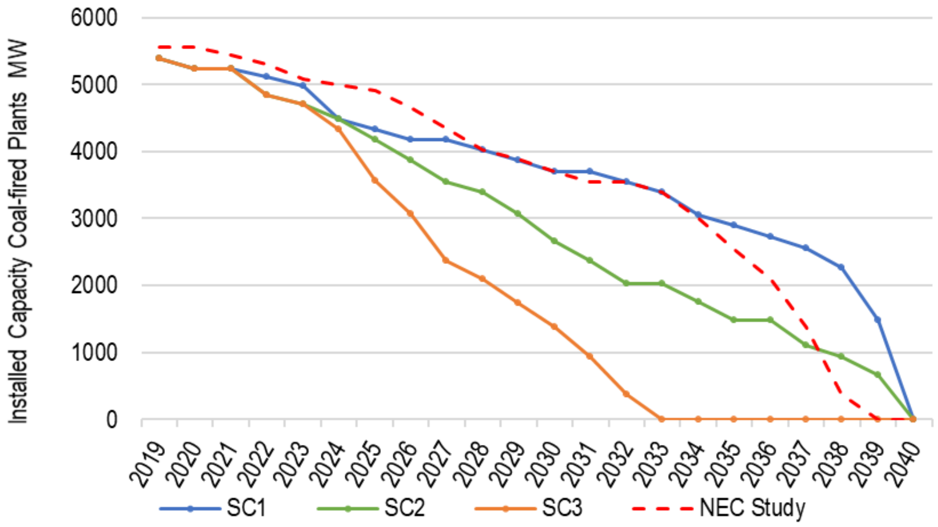

Figure 4: Scenarios of Coal-fired Plants withdrawal: PELP update and Coordinador (NEC)

Concerning the impact of decarbonization on the annual Transmission Expansion Plan, the withdrawal of coal-fired plants has local effects according to the allocation of the existing plants, which have been analyzed in the 2020 transmission expansion proposal [12].

- Great north: there are located the most important, new and efficient set of local coal power plants (3,200 MW), which were developed driven by contracts for power supply to local copper mining companies. This are is also the "goldmine" of VRE, particularly solar power, with solar PV projects and CSP under development. For that reason, the 2018 National Transmission Expansion Plan included an HVDC Kimal-Lo Aguirre project (at least 2,000 MW, 1,500 km). The large development of solar plants would be increased due to the market opportunity that will provide the withdrawal of coal plants. Therefore, long-term planning studies projected that the dimensioning of the HVDC project should be revised considering scenarios where 3,000 or 4,000 MW transmission capacity are likely.
- Little north: local coal power plants (600 MW) are today competing with VRE (solar PV and wind plants) to use the main transmission lines as the highway to reach the main consumers, in the center of Chile. Therefore, there is no relevant impact.
- Centre: local coal power plants (880 MW) are embedded in a load center, with impacts on the security and quality of service if they are fully retired. Then, a set of local transmission and transformation reinforcements have been identified.
- South: local coal power plants (850 MW) are mainly connected to the main grid, therefore their withdrawal does not require local grid reinforcements.

New challenges on system planning and operation are identified because of the market opportunity to replace that capacity with more generation renewable plants competing among each other. However, security and quality of service issues like losing inertia and grid robustness are critical issues in the north of the SEN, because of the concentration of large mining demand and the radial topology of the power system, spanning 3,100 kilometers from north to south.

Impact on the German transmission development plan

The significant changes and further optimizations regarding the transmission grid related Network Development Plan process in Germany became especially active in the 2019 version of grid development plan. A main organizational difference is that as of 2019 there is no separate Offshore

Network Development Plan (looking at the grid connection of offshore windfarm projects) prepared by the TSOs, since the responsibility of essential tasks were handed over to the Federal Maritime and Hydrographic Agency. Looking at the setting of scenario horizons, already for the 2017 planning process this was more flexibilized in order to allow a better integration into the overarching ENTSO-E network development plan process (TYNDP, Ten-Year Network Development Plan). But whereas until the 2017 the German grid development process was on a yearly basis, the 2019 release was changed to a two-yearly rhythm also to the benefit of a more sophisticated planning approach but considered three time horizons (2025, 2030, 2035) instead of only two time horizons. In order to meet the new EU requirements regarding higher loadings of interconnections but also national requirements as especially the target of 65 % renewable energy share in the electricity consumption by 2030, the following aspects were considered by the 2019 planning process, allowing higher line loading:

- Instead of Net Transfer Capacities (NTC) based on the European TYNDP, for the first time a flow-based market coupling (FBMC) was applied at all German borders, considering defined critical branches.
- According to the new EU requirements, now an N-1 loading up to 75 % of thermal capacity is considered for all interconnections.
- The weather-dependent overhead line operation (i.e. temperature monitoring principle) was taken into account for all overhead lines, i.e. not only for selected ones as in the past. Thus, in periods of higher wind speed and at lower ambient temperatures an increased transmission capability is permitted compared to the standard conditions. Moreover, for relevant overhead lines high temperature or high-temperature low sag (HTLS) conductors were considered.
- Generally, a thermal limit of 4000 A is now considered for all 380 kV overhead lines (instead of 3600 A for new lines as applied in the previous plans).

Apart from higher loading of existing transmission lines, among others also an increased need for inner German point to point HVDC systems (so-called HVDC corridors) was recognised. On top of the 5 HVDC corridors already identified in earlier network transmission plans, for the main scenario 2030 of the 2019 network development plan now 3 more required HVDC corridors are defined, thus summing up in total to 8 HVDC, each one with a transmission capacity of 2 GW.

With regard to the load and infeed scenario definition describing different paths of energy system transformation, a main focus was given to flexibility options reflecting different levels of deployment of innovative technologies, esp. heat pumps, electric vehicles, power-to-gas, power-to-heat, PV battery storage, large battery storage and demand side management.

For the 2021 release of the German Network Development Plan, only two-time horizons will be analysed as done until the 2017 release but now reflecting 2035 (three different scenarios for 2035) and 2040. The matter of flexibilities and sector coupling will more reflected compared to the 2019 release, considering flexibilization of conventional generation plants, an increased use of demand-side management and intelligent and flexible deployment new power applications, especially Power-to-X technologies. The Figure 5 below shows the assumption of new types of flexibilities for the main scenario of 2035 time horizon and the 2040 scenario (same scenarios 2035/2040 as displayed with Figure 2). Not shown in this figure is the flexibility potential of electrical vehicles (the number is expected to grow from 0.2 million as of 2018 to 12.1 million in 2035 and 16.1 in 2040) as well as the flexibility potential expected from household heat pumps (in numbers from 0.9 million in 2018 to 6 million in 2035 and 8 million in 2040).

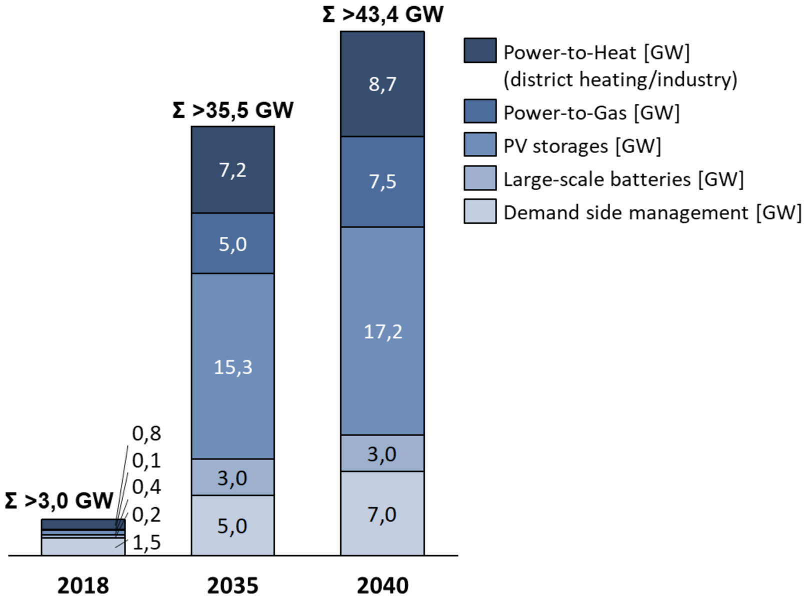

Figure 5: New flexibilities for Germany (Source: Szenariorahmen zum NEP 2035, Version 2021)

The further electrification of other sectors and progressive sector coupling as a result of the political-social guidelines for decarbonization will be reflected in the scenario setting, and the development and dissemination of energy efficiency measures and programmes will be taken into account. But all in all, an increasing power consumption is assumed, resulting from further electrification in the heating and transport sectors, from increasing use of Power-to-X technologies, and from decarbonization measures in in the industrial sector and digitalization.

In all scenarios, both the nuclear phase-out by the end of 2022 and the coal phase-out at latest by 2038 will be considered in accordance with the recommendations of the Coal Commission. On the other hand, a stronger increase in feed-in from photovoltaic systems and from offshore wind turbines will be considered compared to the 2019 scenario framework.

COMPARING THE CHILEAN AND GERMAN TRANSMISSION PLANS TO FACE DECARBONIZATION

Both countries are very advanced in integrating variable renewable energy and the impact on electricity transmission planning is a relevant issue. However, there are effects of sector coupling in Germany and Chile besides transmission planning, for instance, energy sector synergies for decarbonising efficiently.

A matter of analysis in Chile is the option to convert the existent infrastructure of coal-fired power plants in order to keep the support on the power system related to inertia, frequency and voltage control, plus keeping a strong short circuit ratio, especially in the north of the NES, where most of copper mines are located. In Germany, a previous work is under research via a project funded by the Federal Ministry of Economics (BMWI) and involving DLR (German Aerospace Center). The concept developed by DLR [5] is integrating a thermal energy storage system (liquid salts) to be fed by renewable energy and coupled into an existing coal-fired power plant in order to replace coal combustion completely. This technological solution can be a good solution for the north of Chile, where salts are locally extracted and processed to be used for thermal storage and where abundant solar energy resources are available.

For the German transmission planning process, keeping in mind Germany as part of the strong ENTSO-E interconnected and synchronous area (more concrete former UCTE area) the aspect of decreasing inertia is not yet of same priority compared the Chilean islanded conditions (without interconnections to neighbouring countries in South America). But finally for both countries, Chile and Germany, artificial inertia contributions by windfarms, PV farms and batteries will play an important role in limiting the rate of change of frequency (RoCoF, inversely proportional to inertia) and the frequency drop (nadir frequency) in case of sudden loss of generation. Of high importance for the German transmission planning process is still the enabling of bulk power flows from the VRE regions to the load centers but also to the neighbouring countries, by means of reinforcement of the existing HVDC grid topology, by new HVAC lines and so-called HVDC corridors linking the North and the South of Germany. Apart from the bulk power transmission flows, especially the following aspects of priority are subject either for the transmission planning process at the TSOs or accompanying studies by research institutes contracted by the TSOs or e.g. the Ministry of Economic Affairs:

- Dynamic line rating also for the network planning stage.
- Optimized control of the different power flow controlling assets, as the planned HVDC corridors and the already existing various phase-shifting transformers installed at the profile to the neighbouring countries.
- System flexibility measures to mitigate the power ramps incl. analysing the changing demand and characteristic by electrical vehicles, batteries combined with roof-top PV (net metering) etc.
- Proper reactive power provision to avoid violation of the voltage thresholds.
- Cross-sectoral efficiencies.

CONCLUSIONS

Both countries, Chile and Germany, follow very ambitious targets in terms of the decarbonization of the electricity supply, as it is demonstrated with the Figures 1 and 2. As measure of significant impact, in parallel to the ongoing massive VRE deployment now the coal phase-out will be realized for both countries, for Germany on top of the still ongoing nuclear phase-out. This requires changes in the network planning philosophies as well as much more analysis fields in context of the elaboration of the network development plans. Bulk power transmission capacity is key for both countries, and a proper provision of reactive power. However, the Chilean electricity system is still isolated while the German electricity system is well embedded into the European synchronous area, which limits the inertia decrease and allows selling the surplus of VRE infeed to the neighbouring electricity markets, sharing of control reserves etc.

System flexibility is a fundamental issue in generation, transmission and demand sides. As in Germany, Chile must analyse and settle measures to mitigate power ramps including and increasing participation of demand and storage solutions. A more active distribution grid and demand participation is expected in the future, with a growing insertion of distributed generation, including batteries combined with roof-top PV (net metering).

BIBLIOGRAPHY

[1] Araneda, J.C. and Müller-Mienack, M., “Transmission Network Planning and Delivery: comparing the German and Chilean Experiences”, CIGRE Session 2016, Paris, France, August 2016.

[2] Ministerio de Energía de Chile, “Planificación Energética de Largo Plazo: Informe de Actualización de Antecedentes 2019”, December 2019, Available: http://www.energia.gob.cl/documentos/informe-de-actualizacion-de-antecedentes-2019

[3] Olmedo, J.C. and Araneda, J.C., “Metodología para el Análisis de Escenarios de Descarbonización de la Matriz de Generación Eléctrica en Chile”, SCPP, Santiago, Chile, January 2020.
[4] Coordinador Eléctrico Nacional, “Estudio de Operación y Desarrollo del SEN sin Centrales a Carbón”, Jan.2019, Available: https://www.coordinador.cl/desarrollo/documentos/estudios-de-planificacion/estudio-de-operacion-y-desarrollo-del-sen-sin-centrales-a-carbon/
[5] En-former - The Energy Blog of RWE, “Coal-fired power plant to be converted into heat storage facility - Pilot project in the mining region of North Rhine-Westphalia saves surplus electricity from renewables”, Available: https://www.en-former.com/en/coal-firedpower-plant-as-large-heat-storage-facility/
[6] The 4 German TSOs, “Netzentwicklungsplan Strom 2030, Version 2019“, April 2019, Available: https://www.netzentwicklungsplan.de/de/netzentwicklungsplaene/netzentwicklungsplan-2030-2019
[7] The 4 German TSOs, Official draft of „Szenariorahmen zum Netzentwicklungsplan Strom 2035, Version 2021“, January 2020, Available: https://www.netzentwicklungsplan.de/de/netzentwicklungsplaene/netzentwicklungsplan-2035-2021
[8] Federal Government of Germany, „Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz – EnWG)“, December 2019, Available: https://dejure.org/gesetze/EnWG/13g.html
[9] Federal Government of Germany, „Verordnung zur Regelung des Verfahrens der Beschaffung, des Einsatzes und der Abrechnung einer Kapazitätsreserve (Kapazitätsreserveverordnung – KapResV“, January 2019, Available: https://www.bgbl.de/xaver/bgbl/start.xav#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl119s0058.pdf%27%5D__1581514257862
[10] Kommission Wachstum, Strukturwandel und Beschäftigung, „Abschlussbericht“, January 2019, Available: https://www.bmwi.de/Redaktion/DE/Downloads/A/abschlussbericht-kommission-wachstum-strukturwandel-und-beschaeftigung.pdf?__blob=publicationFile&v=4
[11] Federal Government of Germany, „Entwurf eines Gesetzes zur Reduzierung und zur Beendigung der Kohleverstromung und zur Änderung weiterer Gesetze (Kohleausstiegsgesetz)“, January 2020, Available: https://www.bmwi.de/Redaktion/DE/Downloads/G/gesetzentwurf-kohleausstiegsgesetz.pdf?__blob=publicationFile&v=6
[12] Coordinador Eléctrico Nacional, “Propuesta de Expansión de la Transmisión 2020”, January 2020, Available: https://www.coordinador.cl/desarrollo/documentos/desarrollo-de-la-transmision/propuesta-de-expansion-de-transmision-del-sen-2020/propuesta-2020/informe-2020