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Final technical report on the «Strategic Grid 2040» project (part A) and optimisation of the grid development process and vision for the grid of the future (part B)

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Contents

Part A:
Final technical report on the «Strategic Grid 2040» project

1 Executive summary

Planning the development of the transmission grid is one of Swissgrid's key strategic tasks. This represents the Strategic Grid 2040 project.

In its Strategic Grid 2040 (SN2040), Swissgrid has determined the additional expansion requirements for the transmission grid based on the SN2025 projects and taking into account the scenario framework for Switzerland (SZR CH) – target years 2030/2040 – initially developed by the Swiss Federal Office of Energy (SFOE) in 2021 and adopted by the Federal Council in 2022.

The results of the project to determine the SN2040 show that the assumptions and findings of the SN2025 were constructive and form a robust grid. The scenario framework that Swissgrid prepared for the SN2025 has proven its worth despite some unforeseen developments. Electricity exchange and the utilisation of the installed capacity of cross-border lines were within the assumed scenarios in 2015–2023. However, the electricity price reached unexpected heights in 2022 due to the energy crisis.

The confirmation of the results of the SN2025 is shown in particular by the fact that almost no overloads were found when applying the scenarios of the SZR CH to the 2040 start grid. It therefore remains crucial to implement the projects that make up the 2040 start grid. The following diagram shows the 2040 start grid and highlights the projects that have been decided on but not yet put into practice, as well as the drivers for these projects. In addition to the SN2025 projects, there are other projects based on connection requests from grid users, Swissgrid's transformer replacement programme, the need for additional transformers to enhance the grid, Studio Generale in Ticino and a grid study with Germany. In addition, compensation systems will be installed in the grid by 2040 (not shown in the diagram) to solve reactive power problems.

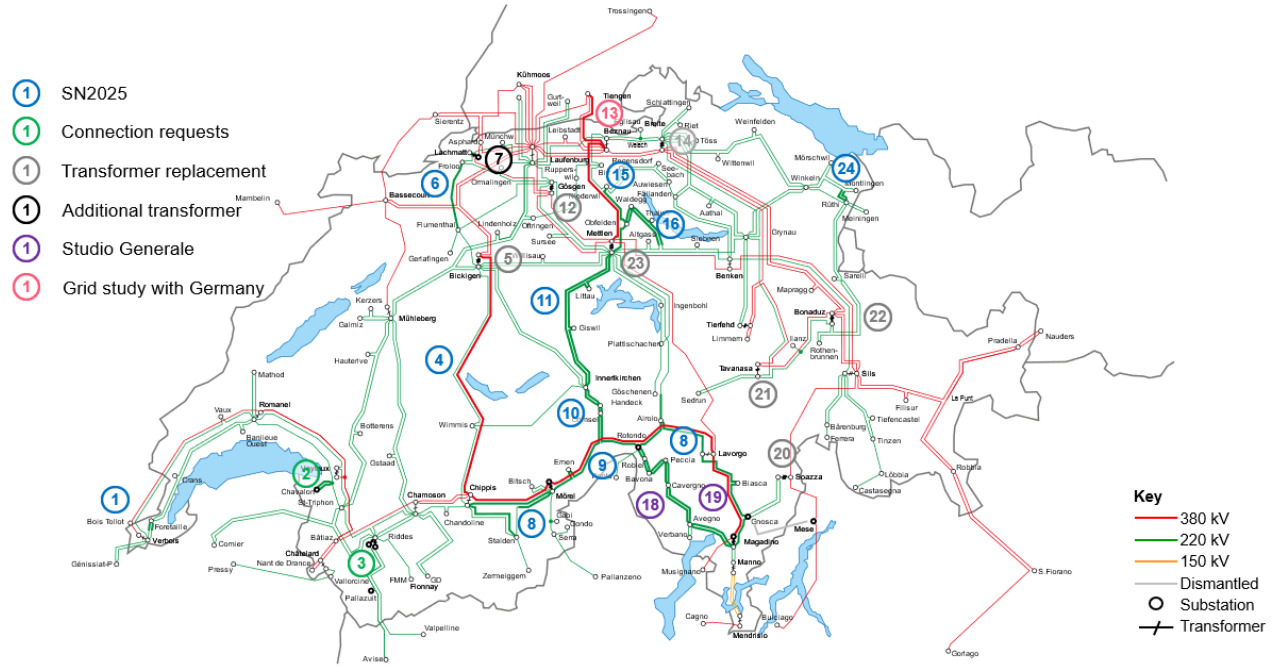


Figure 1: 2040 start grid and the projects still required to complete it

The following goals were achieved in the SN2040 project:

- Creation of a reliable data base for the year 2040: as the SZR CH only contains national target values without a regional breakdown for the grid level 1 grid nodes, Swissgrid set up an industry working group, which held ten workshops to define the methodology for regionalisation before implementing it for the first time. The differences between the scenarios drawn up by Swissgrid in 2014 for the SN2025 (target year 2035) and the scenarios from the SZR CH for the target year 2040 can be seen in the following diagram. This shows that the majority of the assumptions that Swissgrid made for the SN2025 at the time lie within the SZR CH for 2040, although such large increases in PV power or imports were not expected in the 2014 assumptions.

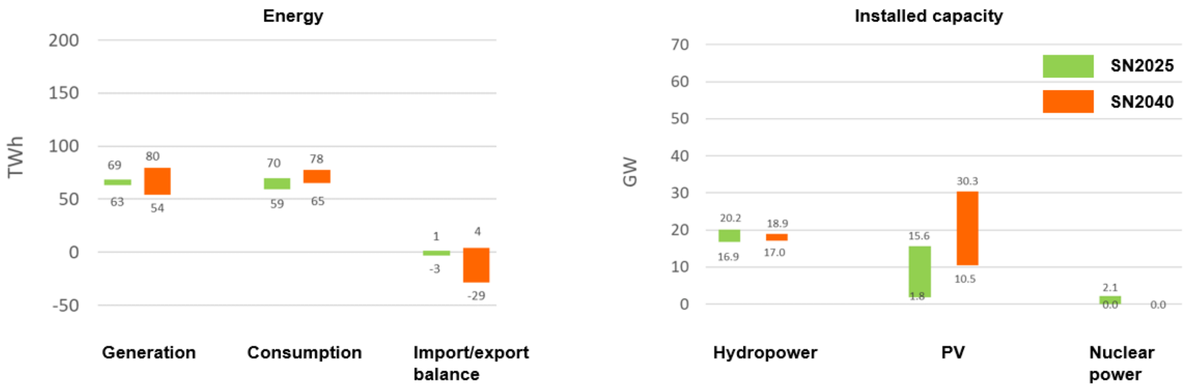


Figure 2: Comparison of the Swissgrid scenarios from the SN2025 and the SZR CH SN2040

- Recognition of the need for action on the grid side to transform the energy system: Swissgrid has applied flow-based methodology to perform market/grid simulations with the 2040 start grid and the scenarios of the SZR CH (assumption: Switzerland will be integrated into the European electricity market by 2040, which will require the conclusion of an electricity agreement with the EU). In doing so, Swissgrid has recognised grid congestion on the border with France and on the north-south axis, and has defined appropriate corrective measures.
- Switzerland is dependent on electricity imports, particularly during the winter months, a large proportion of which come from France. This means that even more efficient use must be made of the existing international interconnection lines. If the negotiations for an electricity agreement fail, Switzerland will still not be fully integrated into the European electricity market, and there will be a risk of higher unplanned flows, which could also further reduce Switzerland's import/export possibilities. The further expansion of phase shift transformers (PST) was therefore identified as a short-term measure in the SN2040. PSTs can not only reduce unwanted load flows, but also maximise import and export opportunities with foreign countries. They are easier to approve than line projects and can therefore be implemented more quickly. The 2040 start grid includes 20 PSTs that already exist or have already been decided on but are yet to be implemented. Based on the SN2040 calculations and a joint study with RTE, these PSTs will be supplemented by a further four PSTs plus two four-quadrant transformers in Western Switzerland. The added value of these extra PSTs has been successfully demonstrated, both in the event of full market integration into Europe (main benefit: optimisation of import/export opportunities) and in the event of exclusion (main benefit: reduction in unplanned flows).
- The inclusion of an additional 220 kV system between Airolo and Göschenen in the SN2040 will strengthen the north-south axis and increase local redundancy.
- Project J1 from the SN2025 («Bouclé Nord»), which has not yet been started, will be resumed as project H: «New Galmiz – Mathod line». This is to take advantage of the opportunity arising from the line construction by SBB, which is necessary in any case. The specific details still have to be analysed in a study with SBB, Groupe-E, Romande Energie and RTE. This additional connection would strengthen the north-south axis and allow the connection of further large power stations (PV + hydropower) in the Valais and wind power in the Jura, for instance.

- Furthermore, a study with the German TSOs is necessary to examine the benefits of an additional «Breite – Laufenburg» 380 kV line. This involves assessing the impact on cross-border capacity and determining the ideal connection point for a possible HVDC connection with Germany[1].
- Definition of measures for the implementation of grid connection requests: grid connection requests have been submitted for large-scale projects by grid users in Visp and Chavalon. Local grid expansion is required for these grid connections in each case.
- Recognition of the need for grid enhancement to ensure security of supply: Swissgrid has analysed possible weak points in the Swiss transmission system by examining actual and potential grid failures. Potential grid failures can be avoided by increasing the redundancy of operating facilities at certain points. More specifically, a redundant grid connection would be created for the Hauterive and Göschenen substations, as well as a second 220 kV connection between Auwiesen and Fällanden. The affected DSOs and PPOs (EWZ, CKW, EWA, Groupe-E) have been contacted by Swissgrid and recognise the added value of these grid projects.
- Identification of bundling candidates for more effective utilisation of scarce space: in order to protect the landscape, increase the chances of grid projects being approved and ideally reduce operating costs, Swissgrid has identified parallel infrastructures where bundling appears to be a possibility (routes/substations in the transmission grid, distribution grid and railway power system). Following an initial internal review and filtering process, the next step is for Swissgrid to analyse the most promising bundling candidates (13 line projects and 5 substations) with the affected distribution system operators and SBB.

Drivers	Transformation of the energy system in Europe and Switzerland (many decentralised small systems and some large-scale projects)		Security of supply	Scarce space
Methodology	**Market simulation** (Basis: SZR CH)	**Grid simulation** (Basis: regionalised data)	**Failure analysis**	**Identification of parallel infrastructures**
Results	• Power plant deployment and market prices per bidding zone • Congestion on cross-border lines between bidding zones • Price differences between bidding zones	• Limiting grid elements in Switzerland • Redispatching costs • Danger to grid security	• Restrictions on grid users due to grid outages	Bundling candidates identified: • Parallel transmission grid, distribution grid and SBB lines • Nearby substations
Derived projects	**Cross-border optimisation** A: PST Western Switzerland C: Additional 380 kV Breite – Laufenburg line H: New Galmiz – Mathod line	**National optimisation** A: PST Western Switzerland B: Visp substation (grid connection request) E: 220 kV Airolo – Göschenen G: Chavalon substation and 220 kV Romanel – St-Triphon line enhancement (grid connection request)	D: Redundant 220 kV grid connection of Hauterive substation E: 220 kV Airolo – Göschenen F: Additional 220 kV system Auwiesen – Fällanden	List of bundling candidates

Target grid = 2040 start grid plus projects A+B+D+E+F+G
(Projects C+H and bundling candidates require studies with relevant grid operators)

Figure 3: Drivers for grid development and derived projects from the SN2040

By taking into account security of supply in the distribution grids and ensuring an efficient utilisation of space, Swissgrid is acting proactively to go beyond the legal requirements for a secure and efficient supply of electricity.

- Proof of the robustness of the target grid: the target grid is created by adding projects A+B+D+E+F+G to the 2040 start grid (see Figure 3). Swissgrid has loaded the target grid with the SZR CH scenarios. No intolerable overloads were detected in the (n-1) case. The ongoing operation of the Gösgen and

[1] Cf. TYNDP project 1058 «HVDC Line DE–CH»

Leibstadt nuclear power plants beyond the year 2040 is not envisaged in the CH SZR, but cannot be ruled out. Swissgrid has therefore also analysed this case. This resulted in (n-1) violations in the Gösgen – Laufenburg – Breite region, which from today's perspective are manageable with topological measures and redispatching. The following three stress tests were also carried out.

- **Multiple failures:** used to recognise whether a cascade failure or voltage collapse is imminent if a route or a busbar in a substation fails.
- **Stress analysis:** used to recognise whether impermissible voltages occur at grid nodes that cannot be controlled with existing means.
- **Atypical, unexpected import/export flows:** used to recognise where grid congestion would occur in the cases under consideration (high exports to Italy, high imports from France).

The stress tests showed that the target grid is very robust and resistant to a wide range of possible future developments.

- Analysis of savings potential: for redundancy reasons, the lines in the transmission grid that connect the substations with each other are generally designed as double lines. The existing grid and ongoing grid projects were analysed to determine whether it is necessary to connect both lines to the substation concerned or whether two connection feeders could be saved by routing one line past the substation. The connection of both lines may be necessary depending on the feed-in/feed-out power, the operating flexibility, the length of the line or uniform load on the lines. The current solution was confirmed for all substations in the existing grid. Potential savings were found and will be taken into account in the implementation of the grid construction projects planned at the Obfelden substation and in the Maggia Valley.

1.1 Limitations of the SN2040 project

Swissgrid did not analyse the following points as part of the SN2040 due to the legal or procedural framework. In some cases, these points are examined in separate/downstream steps (expansion of cross-border capacities, local grid analyses), in other cases only at an advanced project stage (choice of technology).

- Expansion of cross-border lines: the level of cross-border capacities was accepted as a given in the SZR CH. The project did not examine whether there was economic potential for cross-border grid expansion. Corresponding checks must be carried out in the course of joint studies with the neighbouring grid operators concerned, either outside of or as a follow-up to the SN2040 project. Following the implementation of cross-border expansion projects, additional expansion within Switzerland may prove necessary or may even be avoided.
- Technological studies: no technological studies were carried out for the SN2040 project. Swissgrid performs these studies when planning each individual grid project. For example, it analyses where and how much cabling etc. is required.
- Local grid analyses: the SN2040 was determined using a European grid model of grid level 1. Swissgrid does not have access to nationwide grid data for the subordinate grid levels. Joint local grid analyses can be carried out on completion of the SN2040 project in the course of bundling/rationalisation projects and projects to investigate the effects on load flows between the transmission grid and the lower-voltage distribution grid level.
- Adequacy calculations: Swissgrid carries out these calculations on behalf of the authorities. They show whether there is sufficient generation capacity in Switzerland in the target years under consideration to cover the load at all times. These analyses therefore have nothing to do with grid planning and are performed separately from the SN2040 project.

1.2 Summary of the results of the SN2040

The «Strategic Grid 2040» (i.e. the difference between the start grid and the target grid) includes the following six projects:

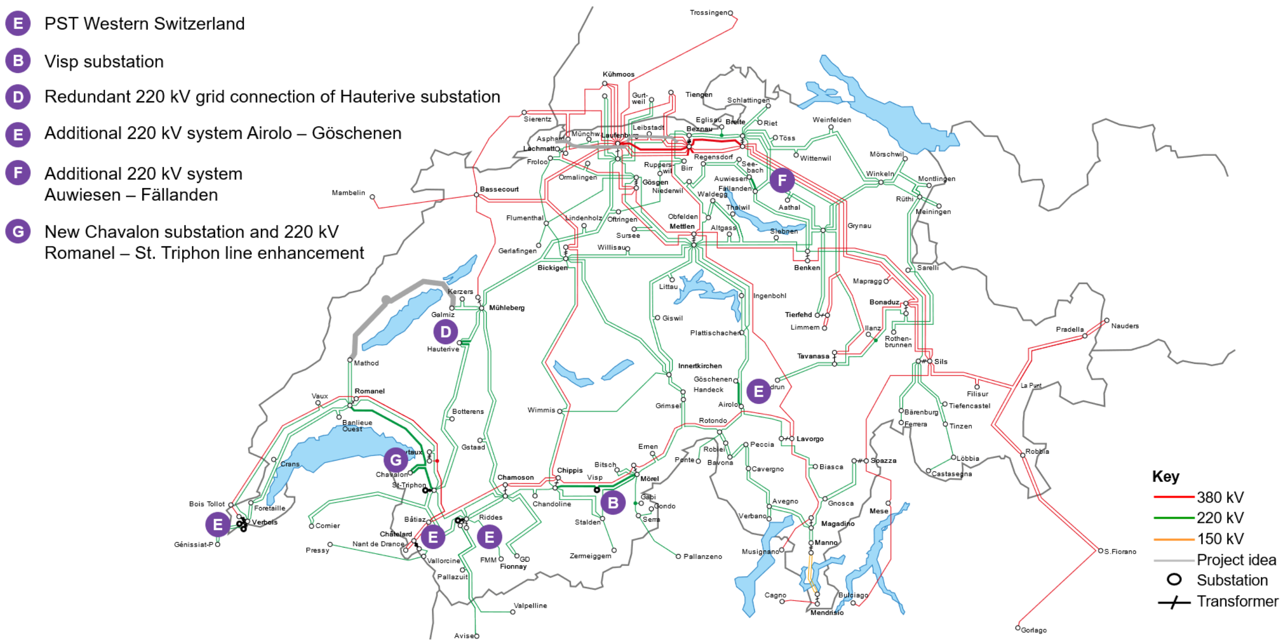


Figure 4: Results of the Strategic Grid 2040

Project	Description
PST Western Switzerland	• Installation of four new 220/220 kV PSTs in Verbois (two), St-Triphon and Riddes. • Replacement of two existing 380/220 kV transformers in Verbois and Châtelard.
Visp substation	• Lonza has submitted a grid connection request for a 500 MVA heat accumulator. • The new 220 kV Chippis – Mörel line will be connected to the grid as soon as the line has been completed. • This will require approx. 1.5 kilometres of underground cabling and a new substation in Visp with three bays.
Redundant 220 kV grid connection of Hauterive substation	• The Hauterive substation will be given a redundant grid connection by also being connected to the 220 kV Botterens – Mühleberg line. • Redundancy will be increased in the substation by creating a second busbar.
Additional 220 kV system Airolo – Göschenen	• The Göschenen substation will be given a redundant grid connection by laying a second cable through the Gotthard tunnel. • A reactive power compensation system is required in the Göschenen substation and possibly in the Airolo substation.
Additional 220 kV system Auwiesen – Fällanden	• The EWZ system that is currently operated at 150 kV will be converted to 220 kV between Auwiesen and Fällanden. The construction of two connection feeders is necessary in the two substations. • A new 150 kV line needs to be built by EWZ before the change in voltage.

Construction of a new substation in Chavalon and enhancement of the 220 kV Romanel–St-Triphon line	• A 350 MVA grid connection request for a data centre with battery storage and a photovoltaic plant has been submitted for Chavalon. • This project is subject to the construction of the new Chavalon substation and the enhancement of the existing power of the 220 kV Romanel – St-Triphon line (variant 1) or the direct connection via a new 220 kV line in St-Triphon (variant 2) or an additional 380 kV line between Chamoson and Romanel, with a connection to Chavalon via a spur line (variant 3).

Section 6.3 contains a profile of each project with a brief project description, information about the costs, the monetary and qualitative benefits, the objective and purpose, and the consequences if the project is not implemented.

2 Introduction

The grid and secure grid operations are fundamental prerequisites for prosperity and high quality of life in Switzerland. All areas of society – from the healthcare sector and the economy to individual households – depend on electricity being available at all times. The grid enables the electricity that is produced to be used everywhere, around the clock, by connecting power plants, storage facilities and consumers. The Swiss transmission grid, which is like a network of «electricity highways», has an important role to play. As the backbone of a secure supply of electricity, the transmission grid is a key element for a sustainable energy future.

2.1 New challenges

The Swiss electricity system is undergoing radical change. In its Energy Strategy 2050, Switzerland has set itself the goal of decarbonising the consumption of electricity and phasing out nuclear power for electricity generation. These decisions and social developments such as advancing digitalisation are posing new challenges for the Swiss electricity system.

On the one hand, electricity consumption in Switzerland is rising, even though existing consumers are becoming increasingly efficient. This is partly due to the switch from fossil fuels to electrical energy as part of decarbonisation. Although this electrification is reducing total consumption, it is also pushing up electricity requirements, for example due to the rise in electromobility or the replacement of fossil-fuelled heating systems with heat pumps. The ongoing digitalisation of society with new large users such as data centres is exacerbating this trend. More electricity will have to be produced or imported to cover this growth in consumption.

On the other hand, decentralised electricity generation is becoming increasingly important. Until now, the Swiss electricity system has typically been made up of large central power plants that produce electricity from hydropower and nuclear power. While hydropower remains important in Switzerland, nuclear power plants are gradually being shut down. They are being replaced by large numbers of new decentralised energy sources and power plants (e.g. photovoltaics, wind power) that generate electricity all over the country. New centralised reserve power plants that produce electricity from hydrogen, natural gas or oil will only be used for a few days a year in the event of an imminent power shortage. They are therefore of secondary relevance to the development of the grid.

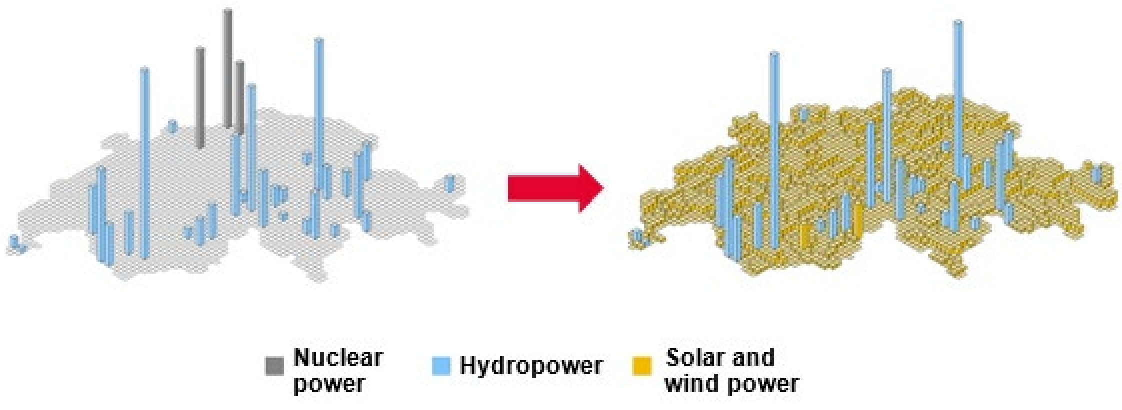


Figure 5: Fundamental change in the Swiss power plant park

The growing proportion of new renewable energy resources in the system is leading to increasingly volatile electricity generation due to the weather dependency of solar and wind power. To ensure that electricity remains available at all times, it must be stored both during the course of the day and on a seasonal basis. In addition, consumption and storage must adapt flexibly to this volatile production so that the electricity system remains balanced. Both these aspects – electricity storage and the use of flexibility – mean that new technologies need to be developed, data collected and meaningfully analysed, and appropriate markets and products created.

Similar developments are taking place throughout Europe. With 41 international interconnection lines, Switzerland is closely embedded in the continental European interconnected grid. In the winter in particular, it is dependent on being able to import electricity from neighbouring countries to cover its own electricity consumption. On the one hand, this requires sufficient electricity to be available abroad, and on the other, Switzerland needs access to the European internal electricity market. And last but not least, corresponding grid capacities are required to transport the electricity.

The grid must be adapted to meet these new challenges, both in Switzerland and throughout Europe. New generators, storage facilities and consumers must be continuously connected to the grid. But the existing grid infrastructure also needs to be modernised, locally enhanced or expanded. The necessary conversion and expansion must be planned at an early stage to ensure that the grid can continue to meet the country's needs at all times in the future and to guarantee a secure supply of electricity in Switzerland. That is why Swissgrid carries out long-term grid planning for the Swiss transmission grid: the Strategic Grid.

2.2 Strategic Grid

The «Strategic Grid 2040» is the first coordinated process for the further development of the Swiss transmission grid on the legal basis created in the «Electricity Grid Strategy», according to which the planning process must be repeated in a comparable manner every four years.

For its «Strategic Grid 2040», Swissgrid is identifying future congestion in the transmission grid and determining the resulting grid development requirements on the basis of three scenarios. These scenarios describe how electricity generation and consumption could develop by the target years of 2030 and 2040. They were developed by the Swiss Federal Office of Energy (SFOE), approved by the Federal Council in November 2022 and subsequently published by the SFOE in the «Scenario Framework for electricity grid planning» (Scenario Framework Switzerland, SZR CH). The SZR CH forms the legally binding planning basis for the «Strategic Grid 2040».

The existing grid was analysed to find weak points. If weak points were detected, grid expansion projects were suggested to create redundancy.

As well as identifying the need for grid enhancement and grid expansion, the «Strategic Grid 2040» describes the potential for bundling in the transmission grid and between the transmission grid and parallel infrastructures (distribution grid, railway power system, railways and roads). By bundling infrastructure, better use can be made of the sparse space in densely populated areas of Switzerland, which can lead to a simplification of approval processes.

However, the «Strategic Grid 2040» does not include projects that are only intended to maintain or replace elements of the transmission grid. Only a third of Swissgrid's 6,700-kilometre transmission system was built after 1980. Many systems and operating facilities will reach the end of their service life in the coming years or decades and will need to be replaced.

As the regulations for the safe construction and operation of the transmission grid have changed since its creation, Swissgrid is often unable to replace installations and operating facilities in need of modernisation on a one-to-one basis. In many cases, extensive modifications have to be carried out, or new locations and routes may even need to be found to ensure compliance with new safety distances and other requirements. As the necessary procedures are generally not simplified in these cases, the resulting approval processes are similar in scope and duration to those for grid expansion projects. Any synergies arising between the implementation of the «Strategic Grid 2040» and the replacement of grid elements will be exploited wherever possible.

2.3 Structure of the report

This report presents the data basis and the results of Swissgrid's long-term grid planning – the «Strategic Grid 2040». The framework conditions, principles and methodology can be found in the document entitled «Grid planning at Swissgrid».

The report is based on the «Process for determining the Strategic Grid», as described in the document «Grid planning at Swissgrid».

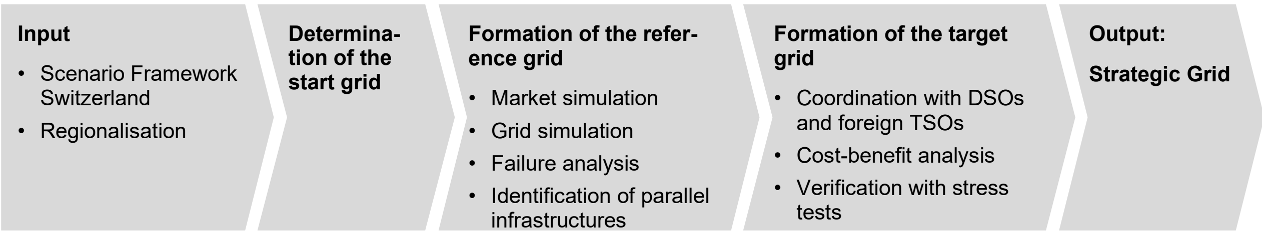


Figure 6: Process for determining the Strategic Grid

This report is structured as follows:

- Section 3 describes the data basis for Swissgrid's grid planning. This section explains how Swissgrid has regionalised the national target values for the development of electricity generation and consumption from the SFOE's SZR CH to the grid level 1 grid nodes in association with the distribution system operators and power plant operators connected to the transmission system and SBB. This section also contains information on the data basis for neighbouring countries.
- Swissgrid's long-term grid planning is based on the start grid, which is presented in Section 4.
- Section 5 describes the future congestion identified in the transmission grid following market and grid simulations. Grid enhancement/grid expansion projects are derived from this congestion. These projects are combined with projects to increase security of supply to form the «reference grid».

- Once the necessity of these projects has been confirmed either via a cost-benefit analysis or in consultation with the affected neighbouring grid operators, they form the 2040 target grid, which is presented in Section 6. There is a profile for each project in the Strategic Grid 2040 which presents the project and explains its added value. The robustness of the 2040 target grid is demonstrated with the help of stress tests.
- Section 7 summarises the findings of Swissgrid's long-term grid planning and sets out the logical conclusions and next steps.
- Section 8 contains a glossary and a list of abbreviations.

3 Data basis for grid planning

Swissgrid's grid planning is based on the SZR CH scenarios. A grid that is sufficiently robust for an uncertain future can be planned by assuming various possible developments in terms of electricity generation and consumption.

In accordance with Art. 9a ESA, the SZR CH published by the SFOE is the binding basis for the grid planning of all grids with a rated voltage of more than 36 kV (grid levels one to three, NE1–3). The national target values from the SZR CH must be regionalised by the players in the Swiss electricity sector for their grid planning. This involves allocating individual parameters locally to a NE1 and NE3 grid node.

The objective and purpose of the SZR CH and the regionalisation process are presented in Section 7 of the document «Grid planning at Swissgrid».

The scenarios from the first SZR CH published, which form the basis for Swissgrid's «Strategic Grid 2040», are described below, including national target values. This section also explains the specific procedure for the initial implementation of the regionalisation process and summarises the results of regionalisation.

3.1 Scenario Framework Switzerland

The SZR CH contains national, aggregated data on the installed capacity per generation technology and for various consumer groups. The first edition of an SZR CH was approved by the Federal Council on 23 November 2022 and published by the SFOE. The following table summarises the key figures from the SZR CH.

Jahr	2019	2030			2040		
Szenario		Sz. 1	Sz. 2	Sz. 3	Sz. 1	Sz. 2	Sz. 3
Stromerzeugung – installierte Leistung [MW]							
Wasserkraft	15 350	17 110	17 110	17 110	19 260	19 260	19 260
Kernkraftwerke	3 330	1 220	1 220	1 220	-	-	-
Thermische Kraftwerke[1]	920	990	980	1 250	970	950	3 650
Geothermie	-	10	10	10	90	20	90
Photovoltaik	2 520	9 770	7 650	12 210	24 070	10 100	30 090
Windkraft	100	310	180	310	1 150	180	1 040
Summe*	**22 220**	**29 400**	**27 140**	**32 110**	**45 540**	**30 490**	**54 130**
Speicher – Pump- bzw. Ladeleistung [MW]							
Pumpen von PSKW[2]	2 620	3 790	3 790	3 790	5 450	5 450	5 450
Dezentrale Batterien	-	1 220	960	1 530	5 550	2 330	6 940
Stromverbrauch – Energiemenge [TWh]							
Nettostromverbrauch[3]	**57,89**	**60,35**	**63,44**	**58,74**	**67,15**	**73,86**	**61,86**
Elektrifizierung – Anzahl [Tsd.]							
Elektrofahrzeuge inkl. Plug-in-Hybride*	40	930	980	870	2 940	3 230	2 520
Wärmepumpen inkl. Grosswärmepumpen*	290	680	710	610	1 010	1 120	860

Figure 7: Key figures from the SZR CH (source: SZR CH, SFOE)

The SZR CH comprises actual data for Switzerland for 2019 and three future scenarios. All three scenarios are based on the Energy perspectives 2050+ (EP2050+) published by the SFOE in November 2020 and on the goal of net-zero greenhouse gas emissions by 2050. The target years of the current SZR CH are 2030 and 2040. Developments abroad are based on the scenarios prepared by the Association of European Transmission System Operators (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG), which were also used for the TYNDP2020.

The three scenarios from the SZR CH were linked with two ENTSO scenarios by the SFOE (see Figure 8). Swissgrid can therefore take the data for Switzerland from the SZR CH and the data for other European countries from the ENTSO scenarios assigned in each case.

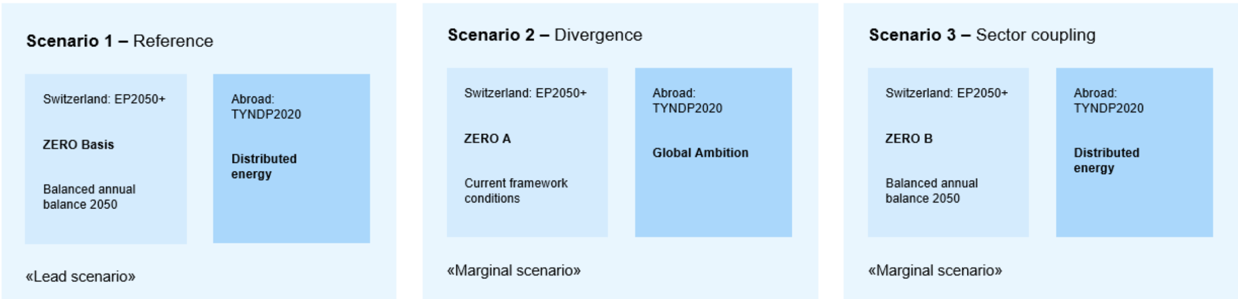


Figure 8: SZR CH scenarios

According to the SFOE, **Scenario 1, «Reference»,** is the lead scenario that is to be given priority in grid planning. It is based on the «Balanced Annual Balance 2050» alternative from the «ZERO Basis» EP2050+ scenario. It is characterised by strong electrification of the energy system and a rapid expansion of domestic, renewable electricity generation.

Development in Europe is based on the ENTSO «Distributed Energy» scenario. This assumes a large number of distributed generation systems in Europe.

Scenario 2, «Divergence», is based on the «Current framework conditions» alternative from the «ZERO A» EP2050+ scenario. It is characterised by an even stronger electrification of the energy system than in the «ZERO Basis» scenario, combined with a limited expansion of domestic, renewable electricity generation. This combination leads to a high load on the grids, especially from imports, making it an import or load scenario.

For Europe, reference is made to ENTSO's «Global Ambition» scenario, which includes a greater number of centralised large generating plants. The associated increased long-range load flows also lead to higher loads on the transmission grid.

Scenario 3, «Sector coupling», is based on the «Balanced annual balance 2050» alternative from the «ZERO B» EP2050+ scenario. It is characterised by weaker electrification of the energy system than in the «ZERO basis» scenario and a greater use of biogas and synthetic gases for power generation. Gas-fired power plants that will be operated mostly with imported hydrogen in the long term play a more important role in this scenario than reserve power plants that can feed power into the grid at short notice if required. Lower demand for electricity (synthetic sources of energy are largely generated outside Switzerland) and higher domestic electricity generation decrease the load on the grids in this scenario.

Like scenario 1, the «Sector coupling» scenario is combined with ENTSO's «Distributed Energy» scenario.

A scenario funnel can be drawn for each generation technology and for each consumer group (see Figure 9). This funnel shows the change in installed capacity and consumption between the actual value from the SZR CH from 2019 and the target years 2030 and 2040. A forecast of the development of a technology can be drawn up on the basis of currently known projects and compared with the SZR CH to check the plausibility of the SZR CH. The actual development, on the other hand, can only be verified annually and analysed retrospectively. The SFOE publishes an annual monitoring report on the Energy Strategy 2050 (link). This shows how the implementation of the Energy Strategy is progressing for each technology.

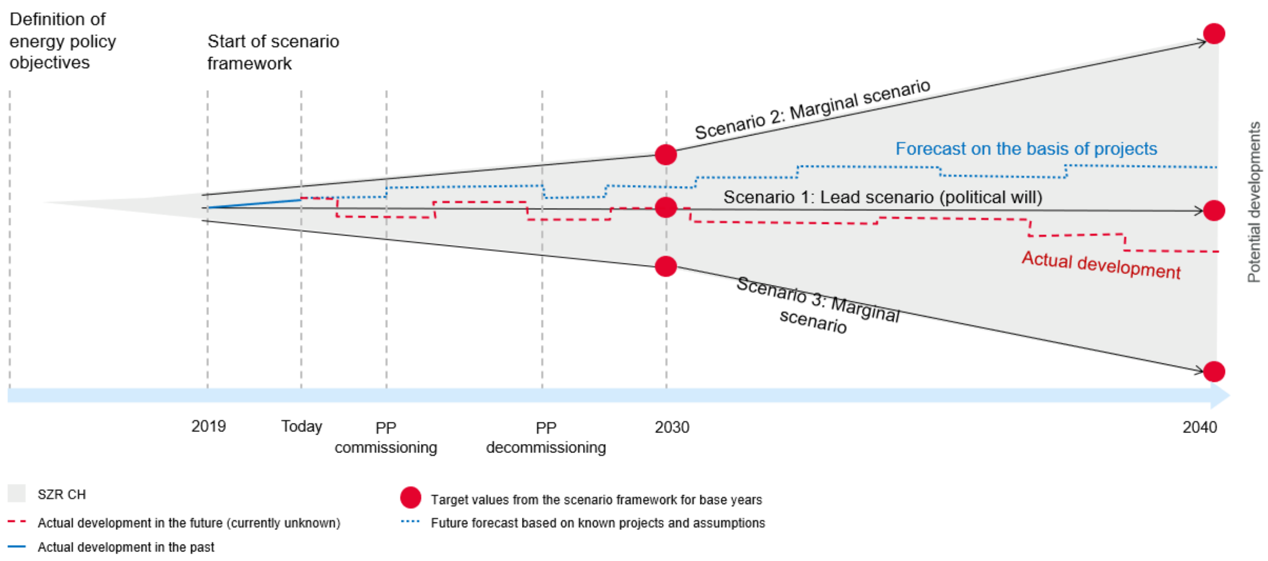


Figure 9: Diagram showing the scenario framework

The cross-border capacities (NTC values) agreed with the neighbouring countries for the year 2025 are assumed uniformly for all scenarios in the SZR-CH., i.e. there are no differences in the capacity available for cross-border electricity exchange between the scenarios.

3.2 Regionalisation process

The national target values for electricity generation and consumption from the SZR CH must be regionalised for grid planning purposes. This involves establishing whereabouts in Switzerland the assumed changes in generation and consumption are expected to take place. This is the only way to determine which specific transport requirements will have to be met by the Swiss transmission system in the future.

«Regionalisation» refers to the process for distributing the national target values from the SZR CH to the individual NE1 grid nodes per parameter. There are approximately 140 grid nodes in the Swiss transmission system (this corresponds to NE1). Grid nodes are points at which power plants, consumers and the SBB grid are connected to the transmission grid via converters or lower voltage levels (NE 3-7) via transformers (equivalent to NE 2). The results of regionalisation show how much generation or consumption could be fed in or out via each individual NE1 grid node in the years 2030 and 2040.

Figure 10: NE1 grid nodes in Switzerland

Swissgrid and the DSOs on the TS have coordinated their efforts in favour of regionalisation in an industry working group initiated and led by Swissgrid.

The DSOs directly connected to the TS were active participants in the industry working group. Representatives of VSE, the SFOE and ElCom attended the working group meetings as observers. SBB and the PPOs on the TS were asked about the plans for their systems.

At the request of the industry working group, the SFOE has officially drawn up and made available non-binding guidelines with principles for regionalisation. There are four principles. Principle A applies to installations >10 MW and principles B–D to installations < 10 MW.

- Principle A: «No regionalisation». This is because the plants are so large that only known and confirmed (large-scale) projects should be taken into account in order to avoid stranded investments in grid expansion
- Principle B: «Existing sites». This principle applies to technologies that are likely to be further developed at sites that are already connected (e.g. WIP)
- Principle C: «Potential areas». This principle applies to technologies that place special requirements on the location (e.g. wind farms in places with a lot of wind)
- Principle D: «National development». This principle applies to technologies that are expanded in proportion to the population, for example (e.g. PV on rooftops or electromobility)

As a basis for regionalisation, the industry working group collected actual data for Switzerland in 2022 showing the current power plant park for electricity generation and current electricity consumption. It also collected data up to 2040 on all known expansion and construction projects involving power plants and large users, as well as on decommissioning. The data comes from the power plant operators on the TS, SBB and the DSOs on the TS.

3.2.1 Regionalisation by generation technologies and consumer groups

Taking into account the SFOE guidelines on regionalisation and the data currently available from the power plant operators, SBB and the DSOs on the TS, the industry working group decided on different regionalisation procedures for each generation technology and each consumer group. These procedures are listed below with the corresponding results.

3.2.1.1 Hydropower

The assumptions regarding the development of hydropower are identical in all three SZR CH scenarios. The SZR CH distinguishes between small and run-of-river power stations, as well as storage and pumped storage power plants.

The industry working group defined the following procedure:

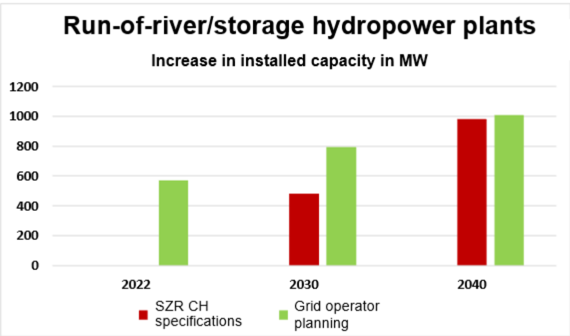
Parameters	DSOs on the TS	Swissgrid
Small/run-of-river power stations	The DSOs on the TS take into account the power plant projects known to them and, if necessary, also determine the locations where they expect further expansion to take place (regionalisation in accordance with principles B/C). They report the variation in power output per NE1 grid node to Swissgrid.	If the expansion target is not achieved, Swissgrid distributes the remaining power to be regionalised among the DSOs on the TS that have registered too little power expansion in relation to their current power.

Storage/pumped storage power plants	The DSOs on the TS ask potential investors and the operators of existing power plants about any specific projects in their area of responsibility and take these projects into account in their grid planning. They report the variation in power output per NE1 grid node to Swissgrid.	Swissgrid asks potential investors and the operators of power plants on the transmission system about specific projects.
	As the power plants in this category are generally larger than 10 MW, there is no regionalisation (principle A).	

In some cases, it is not possible to clearly allocate a hydropower plant to one of the above categories. For example, there are power plants on streams and rivers that generally operate as run-of-river power stations, but which also have a barrage and are used as storage power plants during dry periods.

The industry working group therefore decided to consider small, run-of-river and storage hydropower plants together and to report only pumped storage power plants separately.

The following diagram shows the results of the regionalisation process for small, run-of-river and storage hydropower plants in comparison with the SZR CH specifications.



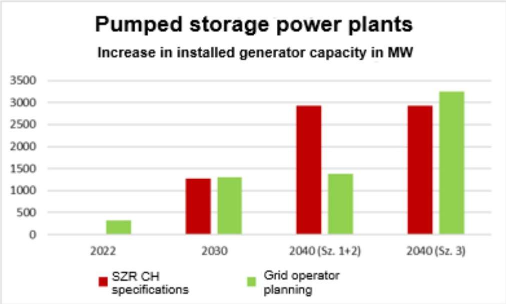
- SZR CH 2019 – installed capacity: 12,260 MW
- Grid operators in 2022 – installed capacity (incl. SBB): 12,830 MW
- Expansion between 2019 and 2040 in SZR CH: 980 MW
- Known projects until 2040: 463 MW
- Target value from SZR CH: 13,240 MW
- Value achieved on the basis of projects: 13,293 MW

Figure 11: Increase in the installed capacity of run-of-river/storage hydropower plants

The industry working group determined the installed capacity of small, run-of-river and storage hydropower plants for 2022. It is 570 MW higher than the value in the SZR CH for 2019.

The SZR CH envisages an increase in power of 980 MW between 2019 and 2040. As projects with a planned power increase of 463 MW by 2040 are already known, the target value in the SZR CH will be achieved with the power already added since 2019. The projects considered also include the 15 projects from the «Round Table» initiated by Federal Councillor Simonetta Sommaruga. Most of these projects are designed to increase annual production and/or storage volumes, while only a few also aim to increase the power of storage hydropower plants (totalling 165 MW).

The following diagram shows the results of the regionalisation process for pumped storage power plants in comparison with the SZR CH specifications.



• SZR CH 2019 – installed capacity:	3,090 MW
• Grid operators in 2022 – installed capacity (incl. SBB):	3,414 MW
• Expansion between 2019 and 2040 in SZR CH:	2,930 MW
• Known projects until 2040 (NdD, Ritom II):	1,084 MW
• Uncertain projects (Grimsel, Lago Bianco):	1,860 MW
• Target value from SZR CH; 6,020 MW	
• Target value in scenarios 1+2: 4,498 MW	
• Target value in scenario 3: 6,358 MW	

Figure 12: Increase in the installed capacity of pumped storage power plants

The industry working group determined the installed capacity in pumped storage power plants for 2022. It is 324 MW higher than the value in the SZR CH for 2019.

The SZR CH envisages an increase in power of 2,930 MW between 2019 and 2040. Five large projects with a power output of 2,944 MW are already known. The Nant de Drance project in the Valais (945 MW) has already gone into operation, while the Ritom 2 project in Ticino (120 MW, 60 MW of which is for SBB) is currently being commissioned. The Grimsel 4 project in the canton of Bern (120 MW) could go into operation by 2030. Investors have not yet decided on the implementation of the Grimsel 3 project in the canton of Bern (660 MW) and the Lago Bianco project in the canton of the Grisons (1,050 MW). A sixth project was reported to Swissgrid at the beginning of 2024 following the creation of the SN2040. This involves 800 MW to be connected to the Fionnay substation in the Valais.

Principle A will be applied for regionalisation.

The two projects with a total power of 1,710 MW that have not yet been definitively decided on (Grimsel 3 and Lago Bianco) are taken into account for grid planning by assuming their implementation in scenario 3. The 800 MW project with a connection to the Fionnay substation in the Valais was announced too late and not taken into account.

3.2.1.2 Nuclear power plants

In Switzerland, existing nuclear power plants will continue to operate until they no longer receive an operating licence from ENSI or the operator shuts down the plant, e.g. for economic reasons.

The SZR CH envisages that no more nuclear power plants will be in operation in 2040. However, grid systems are only dismantled after a nuclear power plant has been decommissioned.

An additional analysis examined the extent to which the continued operation of the Leibstadt and Gösgen nuclear power plants beyond 2040 would influence grid planning. Due to its age, the Beznau nuclear power plant is expected to be decommissioned by 2040, which is why this site was not included in the additional analysis.

3.2.1.3 Thermal power plants

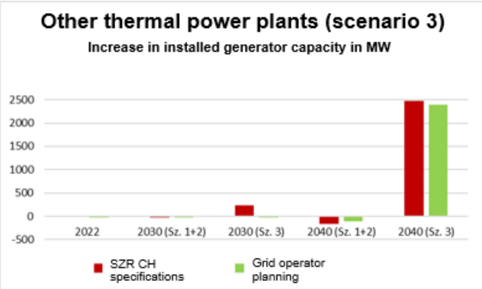
The SZR CH distinguishes between the categories of waste incineration, biomass and wastewater treatment and the categories of biogas, other thermal power plants, gas-fired power plants and geothermal energy.

The industry working group defined the following procedure:

Parameters	DSOs on the TS	Swissgrid
Waste incineration, biomass (wood) and wastewater treatment	The SZR CH does not envisage any changes, so there is no regionalisation. Known projects on the distribution grid are taken into account by the DSOs on the TS in their grid planning. They report the variation in power output per NE1 grid node to Swissgrid.	–
Biogas	Regionalisation is proportional to the population, in accordance with principle D. The DSOs on the TS report the variation in power output per NE1 grid node to Swissgrid.	–
Other thermal power plants	The DSOs on the TS document the locations at which plants of this kind will be definitively built or dismantled. They take these systems into account in their grid planning and report the variation in power output per NE1 grid node to Swissgrid.	–
Gas-fired power plants	–	In accordance with principle A, there is no regionalisation. Scenario 3 foresees the construction of large gas-fired power plants at ideal locations (no grid expansion necessary, gas procurement possible).
Geothermal energy	In accordance with principle A, there is no regionalisation. The DSOs on the TS report the variation in power output to Swissgrid based on definitive projects per NE1 grid node.	–

Power generation in **biogas plants** is to be expanded by 220 to 270 MW between 2019 and 2040, depending on the scenario. There are currently hardly any known biogas projects for utility power generation. The target capacities according to the SZR CH were therefore allocated to the areas of responsibility of the DSOs on the TS in proportion to the population.

The installed capacity of **other thermal power plants** will fall by up to 180 MW between 2019 and 2040 (scenarios 1+2). There are 15 large industrial plants and around 100 smaller plants (averaging around 1 MW each). If large installations are converted to electricity, they will be reported to Swissgrid as large user projects by the DSOs on the TS and will not be regionalised, in accordance with principle A. Any conversions of smaller systems will be regionalised in accordance with principle B, and the change in consumption will be reported to Swissgrid by the DSOs on the TS.



- SZR CH 2019 – installed capacity: 360 MW
- Grid operators in 2022 – installed capacity: 336 MW
- Decommissioning between 2019 and 2040 in scenarios 1+2: 180 MW
- Expansion between 2019 and 2040 in scenario 3: 2,470 MW
- Known dismantling projects until 2040: 90 MW
- Known expansion projects until 2040: 0 MW

Figure 13: Increase in the installed capacity of thermal power plants

Scenario 3 envisages the construction of 2,500 MW gas-fired power plants. At the time of preparing the «Strategic Grid 2040», the specific locations of these gas-fired power plants were not yet known. For its grid calculations, Swissgrid has assumed the following locations for gas-fired power plants in 2040[2] (from today's perspective, electricity transport and gas procurement are possible at these locations without expanding the upstream grid):

- 300 MW Birr
- 300 MW Mathod
- 200 MW Bickigen
- 300 MW Lachmatt
- 400 MW Beznau
- 500 MW Leibstadt
- 500 MW Gösgen

Until any specific power plant projects are known and grid connection requests have been submitted, Swissgrid will not take any grid expansion steps for these hypothetical locations.

In accordance with principle A, **geothermal power plants** are only taken into account if planning permission has been granted. In its various scenarios, the SZR CH envisages an expansion of 20 to 90 MW between 2019 and 2040. There are currently no known geothermal energy generation projects. For this reason, no corresponding power plants are taken into account for the grid calculations, i.e. the target value of the SZR CH is not achieved.

3.2.1.4 Photovoltaics

The three SZR CH scenarios include widely varying target values for the expansion of PV of 10 to 30 GW between 2019 and 2040.

The SFOE guidelines recommend working on the assumption that PV expansion will be proportional to the population. In addition, local potential areas and their quality should be taken into account. (Note: the promotion of the expansion of alpine PV and expansion along motorways was not yet an issue when the guidelines were drawn up).

[2] The selected locations and the assumed power outputs are purely hypothetical and are not based on any specific investor projects. When the strategic grid is next updated, it may be possible to replace the assumptions with specific projects.

Definition of potential areas: the actual potential area per municipality is the sum of the areas considered to be of «excellent», «very good» and «good» quality in 2021 (source: e4puls AG on behalf of the SFOE).

So far, only roof and façade areas have been regarded as potential areas. Open spaces (e.g. large-scale installations in the Alps), noise barriers, lakes, barrages and large car parks are not yet included in the potential area statistics.

Development of potential areas: as the population grows, it is assumed that the potential areas (roofs and façades) in each municipality will develop in proportion to the population. If the population declines, the potential areas are assumed to remain constant.

Utilisation of potential areas: the overall target output for each scenario is obtained for the whole of Switzerland by multiplying the potential areas in 2030 and 2040 by a degree of availability. The following table shows the target power output and the required degree of availability rounded up or down to one decimal place.

	Scenario 1 2030	**Scenario 1 2040**	**Scenario 2 2030**	**Scenario 2 2040**	**Scenario 3 2030**	**Scenario 3 2040**
Target power according to SZR CH [MW]	9,770	24,070	7,650	10,100	12,210	30,090
Degree of availability of potential areas [%]	12.5	29.0	9.7	12.2	15.6	36.3

Allocation to the grid nodes: the DSOs on the TS have notified Swissgrid of the pro rata allocation of municipalities to the NE1 grid nodes for their target grid in 2030 and 2040.

The results of the regionalisation of PV show the installed PV capacity for the target years 2030 and 2040 for each SZR CH scenario per municipality and per NE1 grid node.

At the time the «Strategic Grid 2040» was developed, only very few large-scale alpine projects were at an advanced stage of development. These projects were also taken into account at the relevant NE1 grid nodes.

3.2.1.5 Wind

The three SZR CH scenarios contain different target values of 80 to 1,050 MW for the expansion of wind energy between 2019 and 2040.

The SFOE guidelines recommend working on the assumption that wind expansion will take place in accordance with the potential areas (principle C).

Swissgrid has compiled a list of known wind projects located in the potential areas.

The industry working group made an assumption as to which wind farms have the highest probability of being built. The total installed capacity in these wind farms exceeds the target capacity in the SZR CH scenarios. To ensure that the target power output is not exceeded, the power output of all wind farms is reduced proportionally. This approach takes into account the experience that wind farms sometimes have to be scaled down during the approval process in order to be authorised.

For the regionalisation of wind expansion, each wind farm was allocated proportionally to the NE1 grid nodes.

3.2.1.6 Decentralised batteries

In the three scenarios, the SZR CH assumes that the storage capacity of decentralised batteries will increase by 2,330 to 5,550 MW by 2040 (compared to 2019).

Swissgrid distributes the additional battery power (which will most likely be connected to the distribution system) to the NE1 grid nodes in proportion to the additional PV power, and therefore also in proportion to the population, in accordance with the SZR CH.

3.2.1.7 Consumption

In the three scenarios, the SZR CH assumes an increase in consumption of 4 to 16 TWh by 2040 (in relation to 2019). It distinguishes between target values for conventional consumption, for heat pumps and for electromobility.

The SFOE guidelines recommend that consumption (conventional, electromobility and heat pumps) should be regionalised in proportion to the population in accordance with principle D. Known large user projects should be considered locally in accordance with principle A. Their electricity consumption can be deducted from the volume to be regionalised.

In order to be able to regionalise consumption in the target years 2030 and 2040, Swissgrid has defined nationwide annual consumption profiles for conventional consumption, electromobility and heat pumps. The following diagram gives an example of the total hourly consumption profile for Switzerland for a week in summer and winter, as drawn up for the Strategic Grid 2040 project. The profiles for heat pumps (clear difference between summer and winter) and for electromobility are also shown. It can be seen that their level will increase significantly by 2040. Conventional electricity consumption, on the other hand, will decrease by up to 20% between 2019 and 2040 due to efficiency improvements.

Figure 14: Consumption profile in Switzerland in winter and summer

The profiles for conventional consumption, heat pumps and electromobility were determined with the help of «Trapunta». This software is also used by ENTSO-E. It takes into account various types of heat pumps, different types of charging behaviour of electromobility users and the composition of conventional consumers. Swissgrid has made specific assumptions for Switzerland for the various consumer groups.

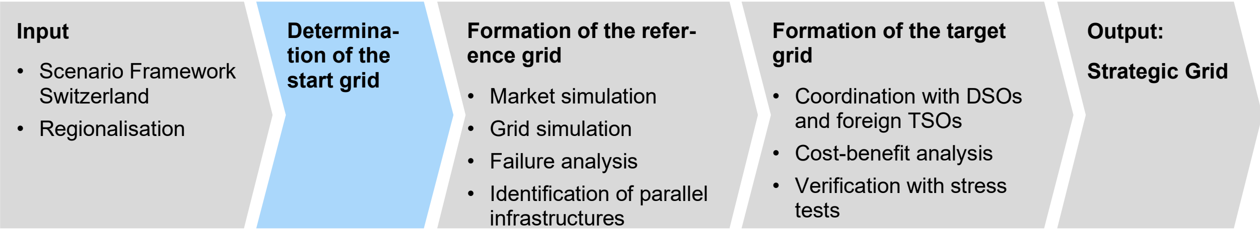
The next step was for Swissgrid to regionalise the consumption for electromobility and heat pumps to the NE1 grid nodes in the target years 2030 and 2040. This was done in proportion to the population.

Conventional consumption was regionalised separately for three groups. SBB provided specific load profiles for its converter/inverter stations for 2030 and 2040. The DSOs on the TS reported any planned large users on their grids. Typical load profiles were allocated to these users and their annual consumption was estimated. The same process applied to Lonza's large heat storage facility with a peak power output of 500 MW. It was assumed that this storage system would be essentially charged by economical PV electricity, i.e. proportionally to the PV curve during the day. For today's consumers (remaining conventional consumption) whose current load profile in the grid regions is known, it is assumed that the distribution to the grid nodes changes proportionally to local population development.

The consumption profile for each NE1 grid node in the target years 2030 and 2040 is calculated by adding together the profiles for heat pumps, electromobility, SBB, known large users and remaining conventional consumption for each NE1 grid node.

Consumption was determined for each SZR CH scenario.

4 Determination of the 2040 start grid



The start grid forms the basis for determining the reference grid. This consists of all the grid elements in the transmission grid that will be in operation in Europe in 2040.

Swissgrid used the information from the TYNDP 2020 for foreign countries to create the 2040 start grid. Where information on additional grid elements or grid topology, particularly in neighbouring countries, was missing from the TYNDP 2020, it was added:

A Topology in France (based on grid study with RTE)
B Southern Germany (grid completed, based on information from TNG, Amprion)
C Vorarlberg (target grid from Lake Constance study)
D Topology and project modelling in Italy (based on north-south corridor study).

The following Swiss grid elements are part of the 2040 start grid:

- Grid elements that are currently in operation and are not planned to be decommissioned
- Grid elements that have already been decided on and planned and will be put into operation before 2040 (based on technical multi-year planning)

Note: all the projects included in the start grid are taken as given in the course of the SN2040 and are not subject to any further evaluation.

The installed capacity of the power plants and the consumption profile per scenario were recorded for each NE1 grid node. The figures for Switzerland were available in great detail after the regionalisation process had been completed.

For other European countries, the expansion of power plants per technology was broken down by grid node for each scenario in proportion to the current number of plants per technology. This is a gross simplification. Whenever more detailed information was available for Switzerland's neighbouring countries, this was used instead.

The ENTSO-E dataset contained a load distribution to the NE1–NK for each country at an agreed, representative point in time. The hourly national consumption per scenario was divided between the NE1–NK according to this ratio.

Swissgrid will build its own reactive power compensation systems in the coming years. The associated reactive power potential, as well as that of the power plants and active grid nodes of the DSOs and SBB, was taken into account in a suitable form in the 2040 start grid.

Figure 15 shows the 2040 start grid:

Figure 15: 2040 start grid

Since the publication of the Strategic Grid 2025 in 2015, various grid projects had already been implemented by the end of 2023, as shown in Figure 16. These projects can be traced back to projects in the SN2025, but also to grid calculations carried out by Swissgrid in the meantime, to joint studies with neighbouring grid operators or to grid connection requests (see also the table below).

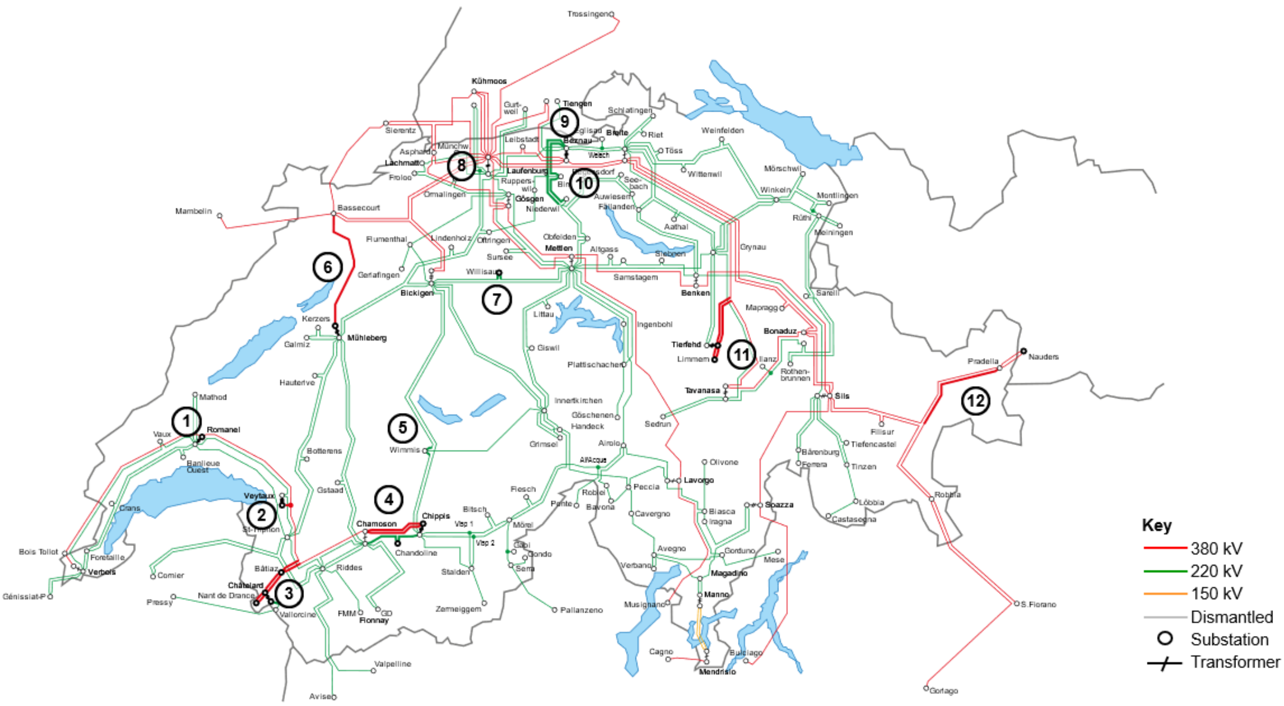


Figure 16: Grid expansion completed between 2015 and 2023

The following table lists the projects implemented since 2015 and their basis:

No.	New operating elements	Drivers
1	• 380 kV Romanel substation • 380/220 kV, 800 MVA Romanel transformer (PST)	In the start grid for SN 2025 – security of supply for Geneva – Lausanne
2	• 380 kV Veytaux substation • 380/220 kV, 2x125 MVA Veytaux transformers	Power plant connection
3	• 380 kV Bâtiaz, Châtelard and Nant de Drance substations • 380/220 kV, 450 MVA Châtelard transformer • 380 kV Nant de Drance – Châtelard – Bâtiaz – Le Verney line	In the start grid for SN2025 Power plant connection
4	• 380/220 kV Chamoson – Chippis line • 380 kV Chippis substation, 220 kV Chandoline substation • 380/220 kV, 800 MVA Chippis transformer	1-SN2025
5	• Loop-in of 220 kV Bickigen – Chippis line at Wimmis substation	2-SN2025
6	• 380 kV Mühleberg substation • 380/220 kV, 800 MVA Mühleberg transformer (PST) • 380 kV Bassecourt – Mühleberg line	3-SN2025
7	• 220 kV Willisau substation	In the start grid for SN2025 Security of supply
8	• 380/220 kV, 800 MVA Laufenburg transformer (PST)	Transformer replacement
9	• 380/220 kV, 800 MVA Beznau transformer (PST)	New transformer, increase in import capacity
10	• 380 kV Beznau – Niederwil line (operation at 220 kV)	5-SN2025
11	• 380 kV Limmern and Tierfehd substation • 380/220 kV, 600 MVA Tierfehd transformer • 380 kV Limmern – Tierfehd – Schwanden line	In the start grid for SN2025 Power plant connection
12	• 380 kV Pradella – La Punt line	3-SN2025

Other grid projects whose implementation has already been decided on are in the planning, approval or construction process. Figure 17 shows the grid projects still to be implemented by 2040.

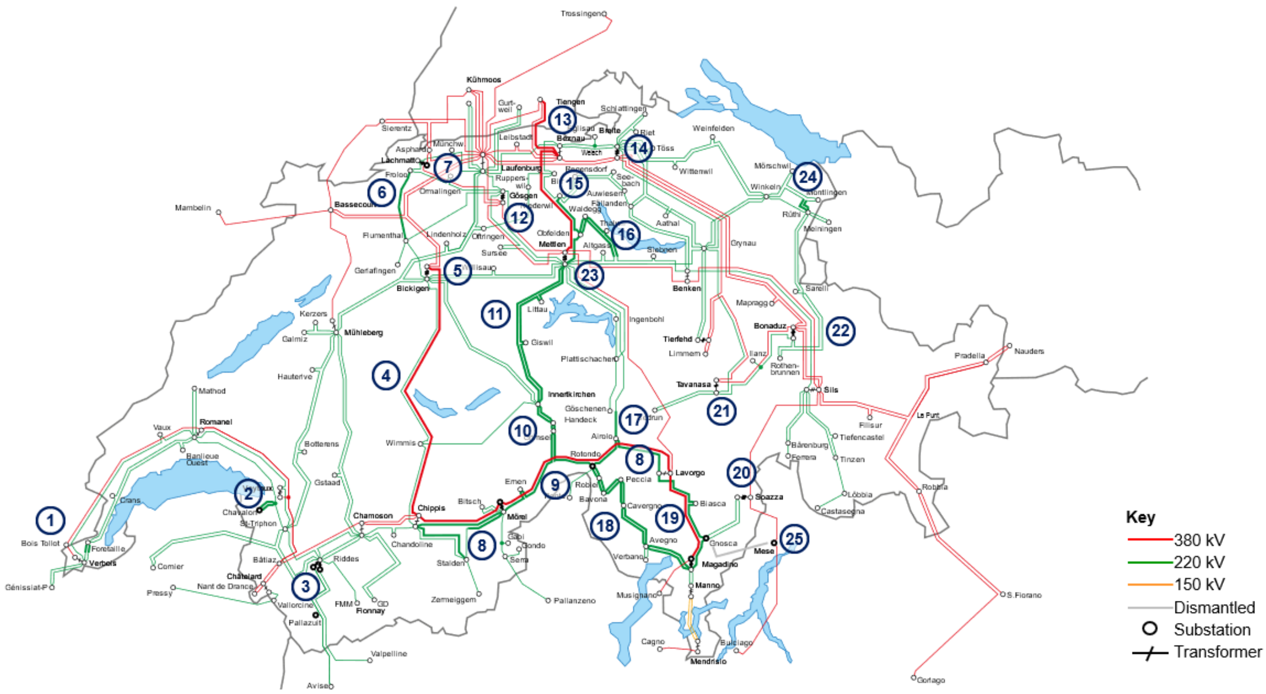


Figure 17: Grid projects still to be completed by 2040

The following table lists the grid projects that have been approved and will be in operation by 2040:

No.	New operating elements	Drivers
1	• 220 kV Foretaille – Verbois cable	8-SN2025
2	• 220 kV Chavalon connection for 100 MVA (system restoration)	Connection request
3	• 220 kV Pallazuit substation • 220/220 kV, 2x450 MVA PST Riddes (Gd-St-Bernard)	Connection request
4	• 380 kV Bickigen – Chippis line	2-SN2025
5	• 380/220 kV, 2x400 MVA (min.) Bickigen transformers (2xPST)	Transformer replacement
6	• 220 kV Flumenthal – Froloo line	J2-SN2025
7	• 380/220 kV, 400 MVA Lachmatt transformer (PST)	New transformer to increase security of supply in the Basel region
8	• 380 kV Mörel substation • 380/220 kV, 600 MVA Mörel transformer (PST) • 380+220 kV Chippis – Mörel line • 220 kV Chippis – Stalden line	4-SN2025

9	• 380 kV Lavorgo – Mörel line	4-SN2025
10	• 220 kV Innertkirchen – Ulrichen line	9-SN2025
11	• 220 kV Innertkirchen – Mettlen line	9-SN2025
12	• 380/220 kV, 2x800 MVA Gösgen transformers (PST)	Transformer replacement
13	• 380 kV Beznau – Tiengen line (Germany)	TYNDP – grid study with German TSO
14	• 380/220 kV, 2x800 MVA Breite transformers (PST)	Transformer replacement
15	• 380 kV Beznau – Mettlen line	5-SN2025
16	• 220 kV Waldegg substation and Thalwil substation • 220 kV Obfelden – Waldegg line	J3-SN2025
17	• 220 kV Airolo – Göschenen cable	Replacement and bundling opportunity
18	• 220 kV Rotondo substation • 220 kV Magadino – Rotondo lines (via Robiei, Bavona, Pecia, Cavergno, Avegno)	Studio Generale 12-SN2025 (target year 2035)
19	• 380 kV Magadino substation • 220 kV Gnosca substation • 380/220 kV, 800 MVA Magadino transformer (PST) • 380 kV Lavorgo – Magadino line • Elimination of 220 kV Gorduno substation and 220 kV Gorduno – Mese line (Italy)	Studio Generale
20	• 380/220 kV, 2x400 MVA Soazza transformers (PST)	Transformer replacement
21	• 380/220 kV, 400 MVA Tavanasa transformer (PST)	Transformer replacement
22	• 380/220 kV, 400 MVA Bonaduz transformer (PST)	Transformer replacement
23	• 380/220 kV, 2x800 MVA Mettlen transformers (PST)	Transformer replacement
24	• 220 kV Montlingen – Rüthi line	14-SN2025 (target year 2035)
25	• 380 kV Mese substation (Italy)	TYNDP

All projects included in the start grid that have not yet been implemented are included in Swissgrid's technical multi-year plan. This is updated annually and includes the planned commissioning date of the projects.

5 Formation of the reference grid

Input	Determination of the start grid	Formation of the reference grid	Formation of the target grid	Output:
• Scenario Framework Switzerland • Regionalisation		• Market simulation • Grid simulation • Failure analysis • Identification of parallel infrastructures	• Coordination with DSOs and foreign TSOs • Cost-benefit analysis • Verification with stress tests	**Strategic Grid**

There are various drivers that cause projects to be included in the 2040 reference grid. These drivers are shown in the following diagram:

Drivers	Transformation of the energy system in Europe and Switzerland (many decentralised small systems and some large-scale projects)		Security of supply	Scarce space
Methodology	**Market simulation** (Basis: SZR CH)	**Grid simulation** (Basis: regionalised data)	**Failure analysis**	**Identification of parallel infrastructures**
Results	• Power plant deployment and market prices per bidding zone • Congestion on cross-border lines between bidding zones • Price differences between bidding zones	• Limiting grid elements in Switzerland • Redispatching costs • Danger to grid security	• Restrictions on grid users due to grid outages	Bundling candidates identified: • Parallel transmission grid, distribution grid and SBB lines • Nearby substations

Figure 18: Methodology for determining the reference grid

The methods described in more detail below are used to identify the projects in the reference grid.

A **Market simulation:** a European market model, which assumes that the grid within each bidding zone is a congestion-free copper plate, is used to determine optimum power plant deployment in order to cover electricity requirements in Europe in an economically efficient manner at all times, taking into account cross-border capacities. This makes it possible to determine the electricity flows (from a market perspective) between the bidding zones. This simulation, which is based on a simplified grid model that includes the cross-border grid elements between the bidding zones, also shows the limiting grid elements for European energy exchange (see Section 5.2.2). It also shows price differences between bidding zones, which are an indication that grid expansion between these bidding zones could make sense (see Section 5.2.1).

B **Grid simulation:** this takes place using a European grid model. All European NE1 grid elements are taken into account. An n-1 outage calculation can be used to determine whether there will be congestion in the 2040 start grid if it is loaded according to the three scenarios (see Section 5.2.3). Redispatching costs can be calculated and compared with the costs of possible grid expansion.

C **Failure analysis:** if failure analyses, stress tests or grid disruptions that have already occurred reveal local weak points in the existing grid that could jeopardise security of supply, it may make sense to increase redundancy in the grid by means of grid enhancement (see Section 5.3).

D **Parallel infrastructures:** if routes from different grid operators run in parallel or substations are geographically very close to each other, bundling opportunities must be investigated when renovating these elements. This can minimise the impact on the landscape, reduce costs and increase the likelihood of obtaining planning permission. Swissgrid, SBB and the DSOs on the TS have identified candidates for bundling their grids (see Section 5.4).

5.1 Methodology with market / grid simulations

Grid congestion in the Swiss transmission grid is recognised today in daily operation by simulation in the time range from D-2 to real time. The simulation is based on input values from the current grid model and values for generation and consumption based on forecasts that improve as they get closer to real time.

In order to detect grid congestion in 2040, we use a grid model consisting of the 2040 start grid, in which all grid elements are in operation. Hourly values for generation and consumption are available per grid node per scenario. This allows congestion to be detected. In contrast to today's operation, flow-based values per line are used instead of NTC values per limit.

5.2 Market simulation

For the SN2040 project, the following assumptions are made when carrying out market simulations:

- 3 scenarios (SZR CH combined with ENTSO scenarios (see Figure 8))
- 1 climate year: 2009
- 1 target year: 2040
- Grid model: 2040 start grid from Section 4

This results in three datasets that need to be analysed.

2009 was the most representative climate year in Europe over the last 30 years. It is closest to the long-term average and has therefore been given the highest weighting in the TYNDP.

It is also a very good reflection of the average for Switzerland. Only the data for 1993 is even closer to the average for Switzerland (see Figure 19).

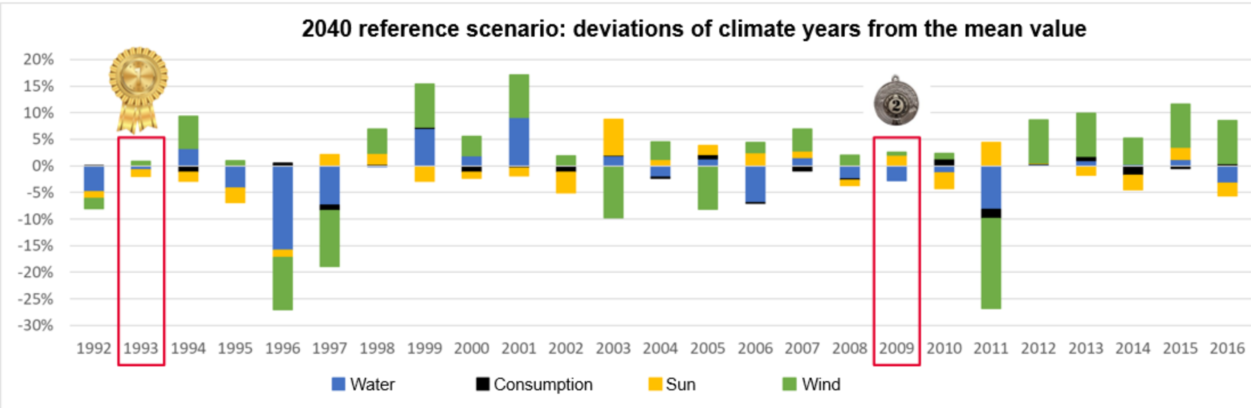


Figure 19: Analysis of climate years for Switzerland

5.2.1 Results of market simulations

The following diagram illustrates the annual production per power plant type, consumption and the annual balance (net imports and net exports) for each scenario. This value must be considered for shorter periods of time (e.g. summer, winter), particularly when energy is exchanged with other countries.

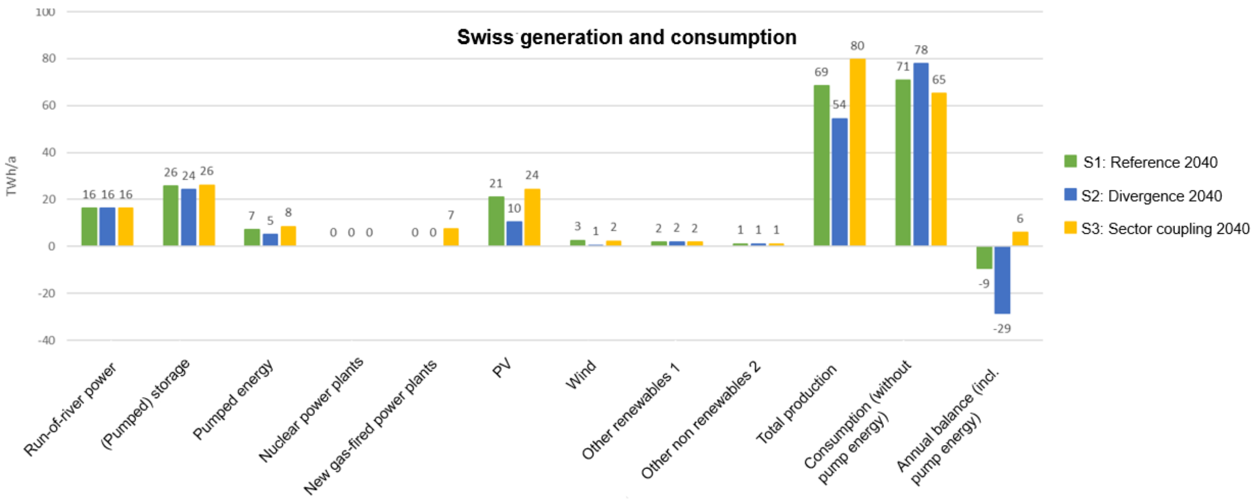


Figure 20: Annual results of the market simulation per scenario for Switzerland

According to the SZR CH, there will be no more nuclear power plants on the grid in 2040. In the course of the year, around 2/3 of production in Switzerland comes from hydropower and 1/3 from PV. In scenario 2 in particular, but also in scenario 1, Switzerland is dependent on imports, especially in winter. In scenario 3, in which Switzerland greatly expands its national production capacities (especially PV), the export balance over the year is positive, and import requirements in winter are reduced compared to today's figures.

The following diagrams show the weekly totals for each SZR CH scenario obtained from the market simulation for Switzerland in 2040 with regard to consumption, generation and imports/exports.

The diagram for scenario 1 shows that Switzerland exports on balance from calendar week 20–36 and imports for the rest of the year (net position curve). The grey areas above and below the x-axis illustrate the fact that Switzerland imports and exports temporarily each week. In the six months of winter, net imports total approx. 14 TWh.

The average load in summer is 7.3 GW with an amplitude of between 5 and 10.4 GW. In winter, it averages just under 9 GW with an amplitude of 5.3 to 13 GW.

Maximum water and PV production occur in spring and summer. During this period, the market simulation occasionally fails to find any national or international buyers for the surplus electricity. A cumulative curtailment of almost 4 TWh of PV production is therefore necessary.

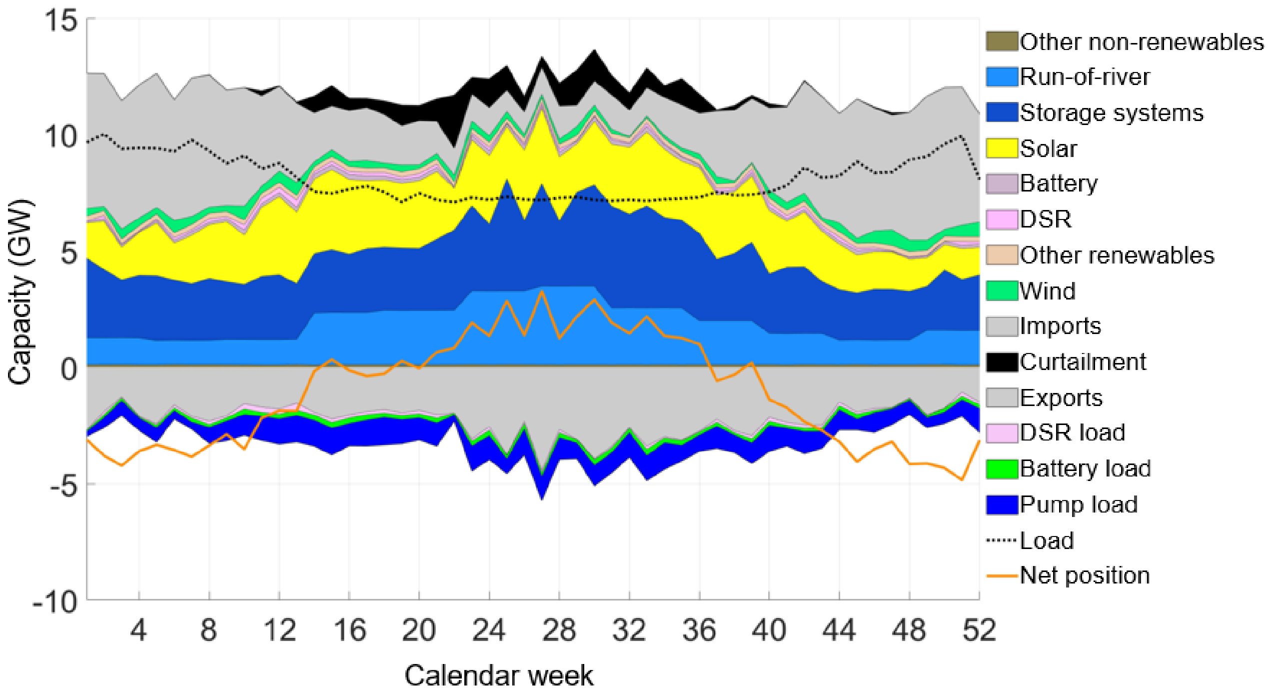


Figure 21: Scenario 1 (2040): weekly values for generation, consumption and import/export

The diagram for scenario 2 shows that Switzerland has an import surplus almost every week. The import balance for the entire year is 29 TWh, of which 24 TWh is attributable to the six months of winter. Despite Switzerland's high dependence on imports, the market simulation shows no ENS, which means that consumption can always be covered (assumption: Switzerland has full access to the European electricity market).

The average load in summer is 8 GW with an amplitude of between 5.5 GW and 11.5 GW. In winter, it averages 9.7 GW with an amplitude of between 6 and 14.3 GW.

As there is less PV expansion in this scenario, there are only a few hours of overproduction in Switzerland that cannot be sold. A curtailment of 0.2 TWh is necessary.

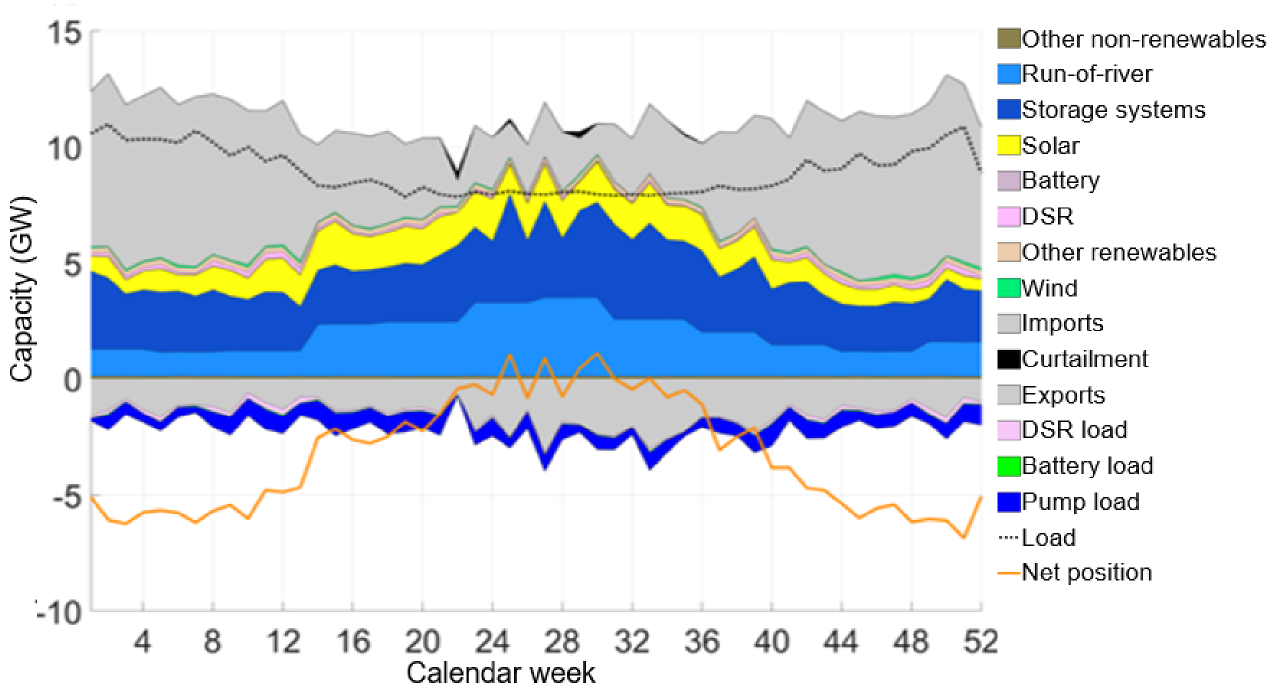


Figure 22: Scenario 2 (2040): weekly values for generation, consumption and import/export

The diagram for scenario 3 shows that Switzerland exports on balance from calendar week 12–40 and imports for the rest of the year. In the six months of winter, net imports total 4.6 TWh, which is less than in 2023.

In summer, the load is between 4.6 and 9.4 GW and averages 6.7 GW. In winter, it is between just under 5 GW and just under 12 GW, with an average of 8.2 GW.

Maximum water and PV production occur from spring to autumn. During this period, the market simulation repeatedly fails to find any national or international buyers for the surplus electricity. A curtailment of 7 TWh PV and 0.1 TWh wind is necessary.

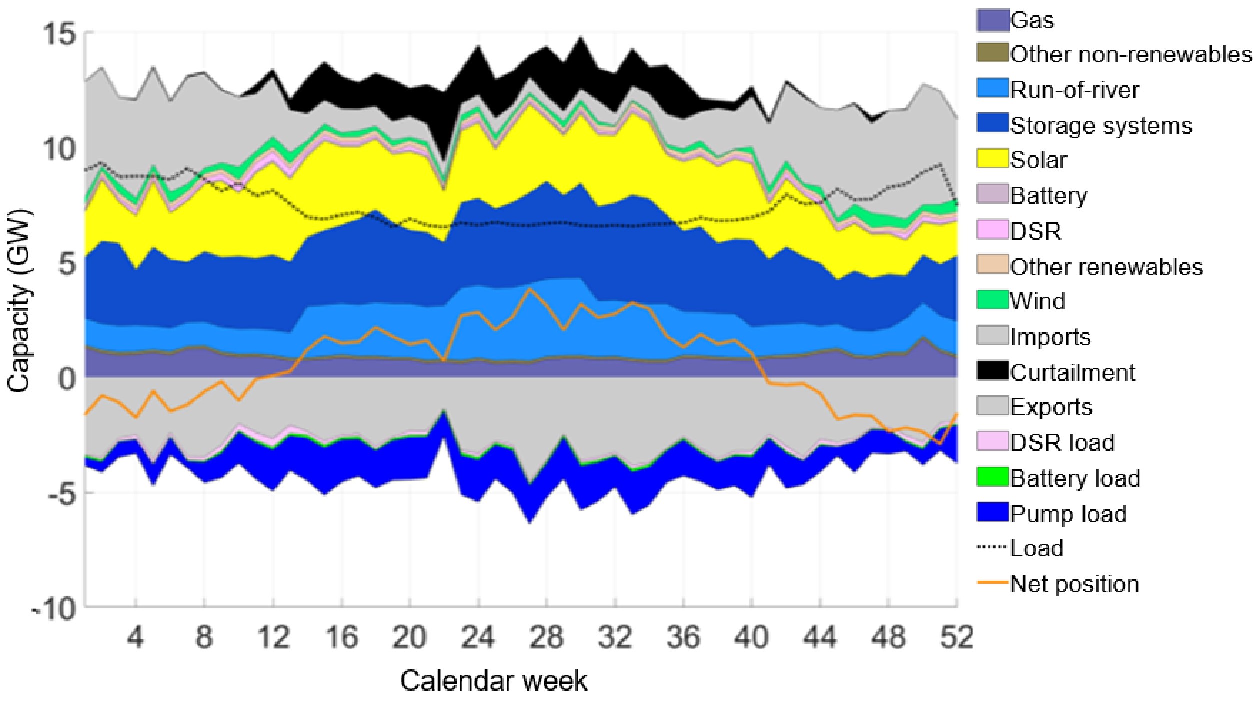


Figure 23: Scenario 3 (2040): weekly values for generation, consumption and import/export

The price in market coupling is calculated for each bidding zone on the basis of the tenders submitted by the energy suppliers. The market coupling algorithm ensures that the demand for electricity is met as economically as possible by requesting electricity from the suppliers who offer the most favourable conditions within the market coupling region.

The operators of must-run power plants (PV, wind, run-of-river) and operators of thermal power plants (NPP, coal, gas, oil) offer their electricity on the power exchange at the relevant marginal costs of their power plants. For PV, wind and run-of-river, these marginal costs are zero. For thermal power plants, the costs are based on fuel costs and start-up costs.

The results for Switzerland for the three SZR CH scenarios are as follows:

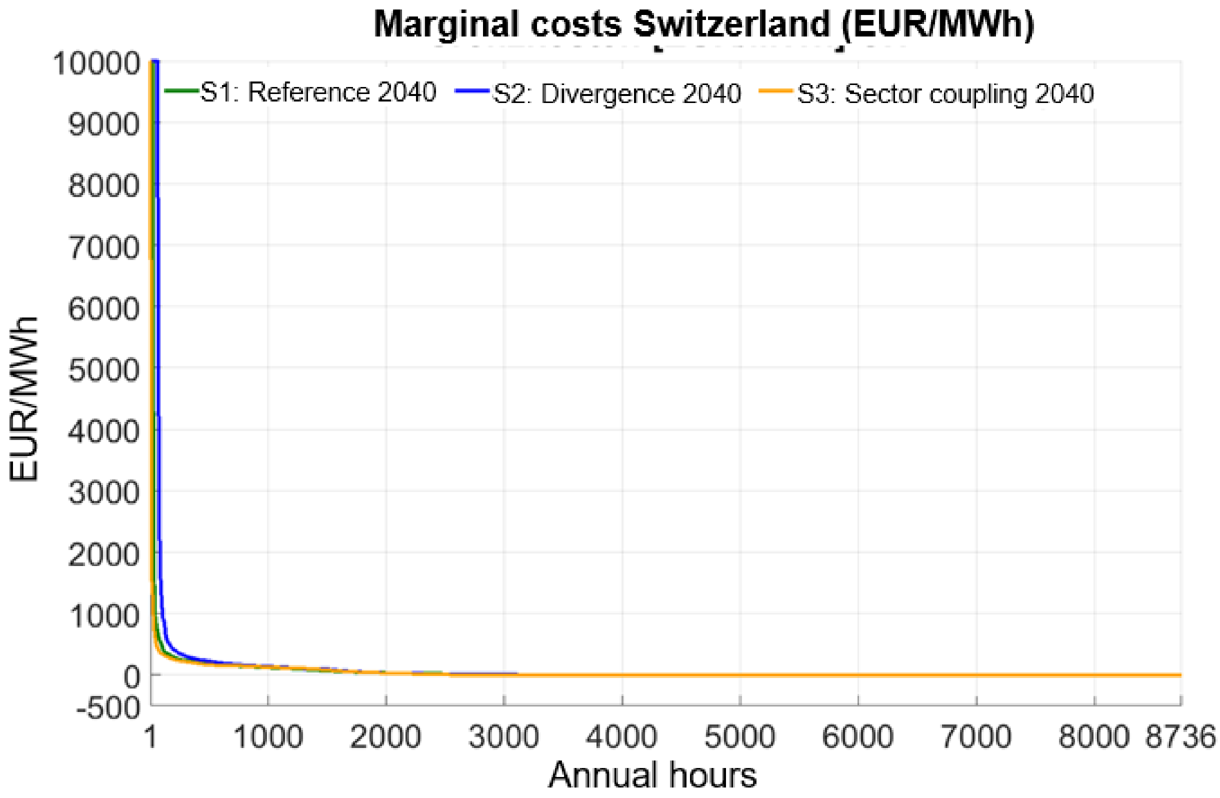


Figure 24: Annualised electricity price curve for Switzerland (2040) for the SZR CH scenarios

It is easier to understand and assess prices if they are sorted by level. It can be seen that the electricity price can be zero for approx. 5,000 hours of the year because the generation of the supply-dependent feed-in is greater than the load. During these hours, energy not only covers the load, but can also be stored. The electricity price of zero is based on an ideal market. In reality, prices can also be below zero or just above zero. **(Note:** a similar picture can be shown for each European bidding zone).

The differences between the scenarios become apparent when looking at the 3,300 hours of the year in which electricity prices are above zero.

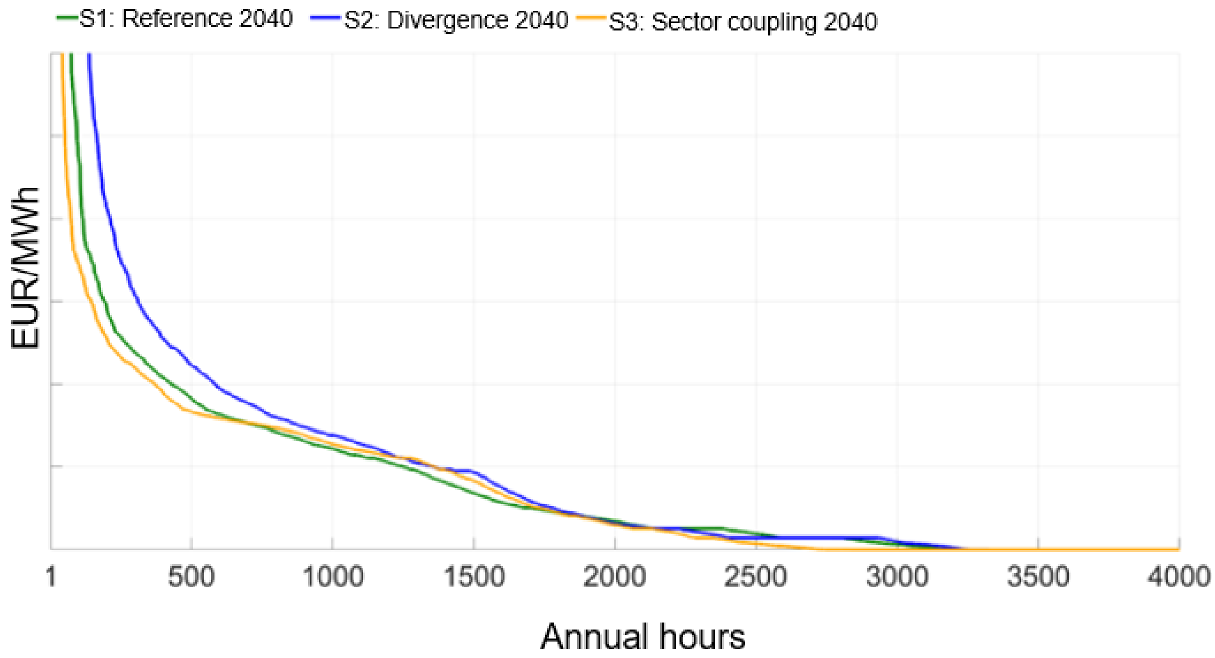


Figure 25: Annualised electricity price curve in 2040 – most expensive 3,300 hours

During these hours, the price is set by energy suppliers who specifically generate electricity for the market and who must cover their marginal costs at the very least. In scenario 2, the highest prices usually occur in Switzerland because consumption is highest there and has to be covered to a particularly large extent by imports. In approx. 500 hours, the market simulation results in market prices from EUR 200/MWh up to a maximum of EUR 10,000/MWh. During these hours, there is a power deficit, and very expensive production plants have to be activated or consumers switched off. If the load cannot be covered, the price is assumed to be EUR 10,000/MWh.

Marginal costs and start-up costs are assumed for each type of power plant for the market simulations. There is a specific installed capacity for each type of power plant in each bidding zone. As the composition of the power plant park is different in each bidding zone, each bidding zone has its own merit order list. The most expensive power plant that has to be activated to cover demand sets the market price each hour. Figure 26 shows the marginal costs for the various types of power plant as applied in the market simulation.

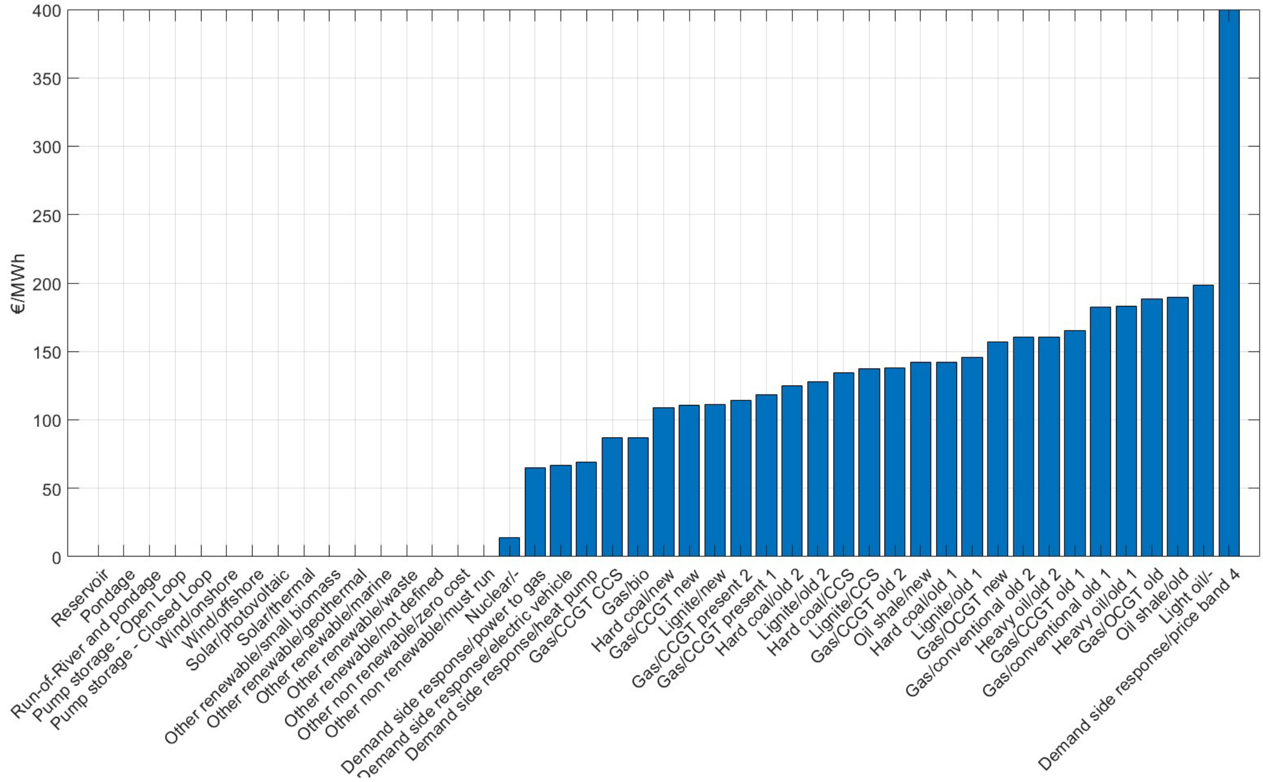


Figure 26: Marginal costs per type of power plant

Figure 27 shows the balance for each individual bidding zone for the winter half-year (top) and the summer half-year (bottom).

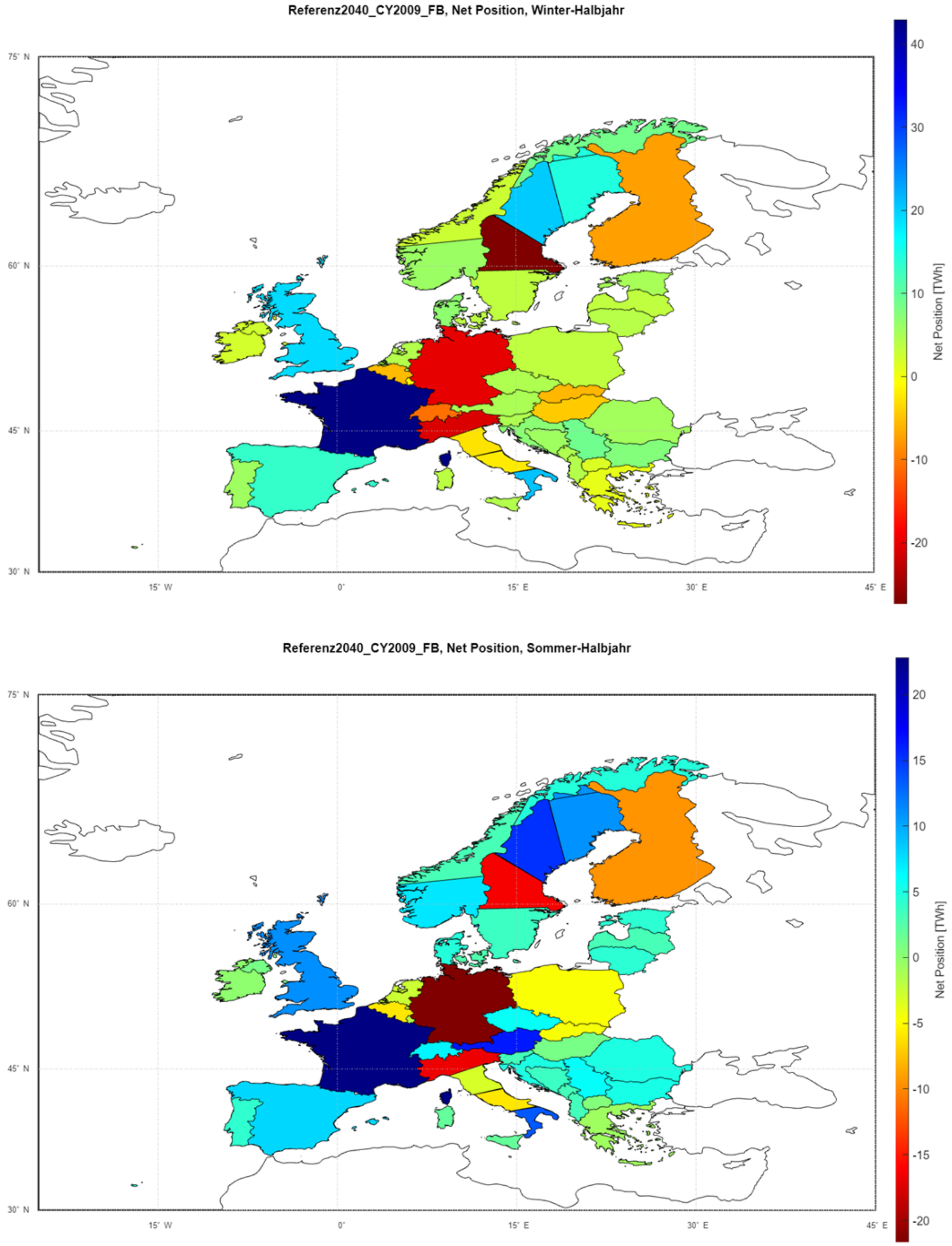


Figure 27: Balance of imports/exports per bidding zone in scenario 1 in 2040 (top: winter half-year, below: summer half-year)

Electricity is exported by France, the Iberian Peninsula, Great Britain, Eastern Europe, the Balkans and parts of Scandinavia. Germany, northern Italy and part of Sweden are net importers in both summer and winter, while Switzerland exports in summer and imports in winter.

The next step involves comparing the prices in Switzerland with those in the neighbouring bidding zones of France, Italy, Germany and Austria. Price differences are an indication that the cross-border capacity between the bidding zones is fully utilised and is not sufficient to equalise prices. If the available cross-border capacity was greater, there would be additional energy exchange between the bidding zones and further price harmonisation. The economic added value (from the perspective of Europe as a whole) resulting from energy exchange would have to be compared with the costs of grid expansion (from the perspective of the affected TSOs) in order to decide whether grid expansion makes economic sense. Even if this is the case, situations may arise in which the costs of grid expansion and economic benefits are not distributed identically between the countries concerned.

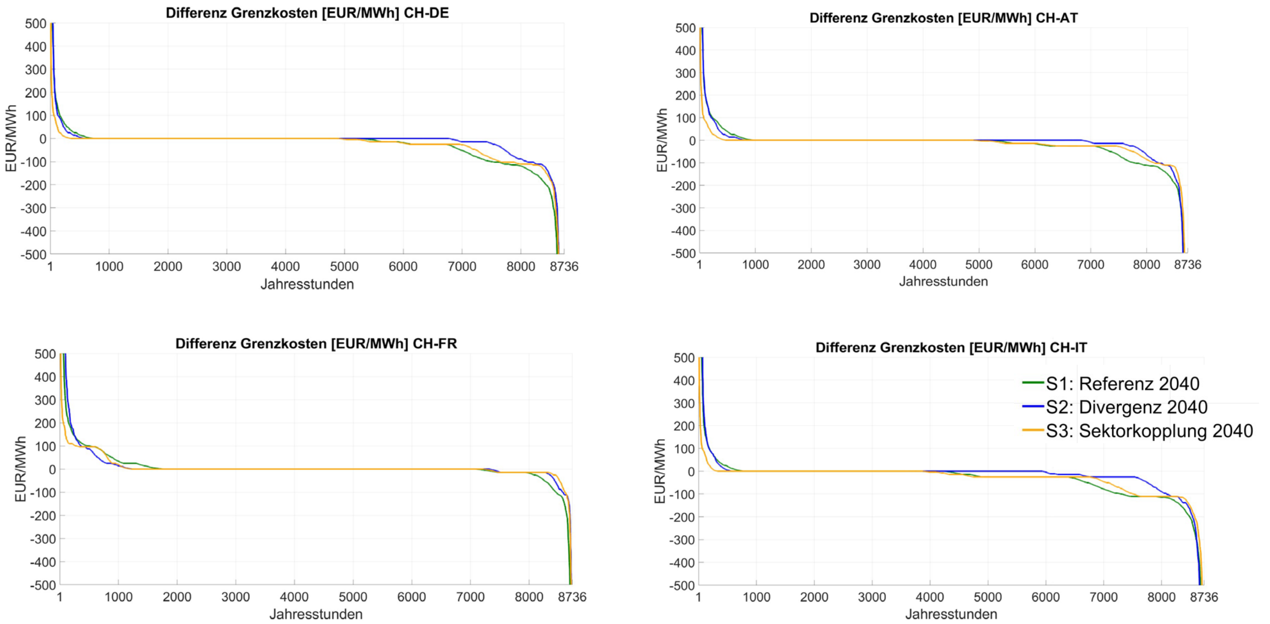


Figure 28: Annualised curves of price spreads (Switzerland – neighbouring bidding zones)

The diagrams show the following:

Extreme price spreads are visible at all borders and in both directions within a few hours. These price spreads occur in hours in which demand in a bidding zone cannot be met or can only be met to a limited extent.

Switzerland–France: the price level in Switzerland is higher than in the exporting country, France in up to 2,200 hours. This spread is greater in scenario 3 in particular, as the marginal costs of gas-fired power plants in Switzerland are higher. There is also a slight price spread in 1,000 hours in the supply direction from Switzerland to France if Switzerland sells production surpluses or wants to increase sales.

Switzerland–Germany: in a similar way to France, price spreads also occur when importing from Germany, albeit much less frequently, in 1,000 hours. In contrast, Germany, as an importer, has higher prices than Switzerland in 3,000 hours.

Switzerland–Austria: the spreads with Austria are very similar to those with Germany.

Switzerland–Italy: in a similar way to France, price spreads also occur for imports from Italy, although only in 1,000 hours, making them much less frequent than for imports from France and comparable to imports from Germany. In contrast, Italy, as an importer, has higher prices than Switzerland in 4,000 hours.

Conclusion 1: the price differences indicated suggest that it would make economic sense, especially for importing countries such as Italy, Germany and Switzerland, to connect to a large-scale supergrid so that they can obtain electricity from places where there are surpluses. This means that they would have to use their own expensive back-up power plants less frequently. Swissgrid is therefore conducting studies with foreign TSOs on possible cross-border projects outside its Strategic Grid project.

Figure 29 shows Switzerland's hourly net position in GW. In flow-based capacity allocation, the net positions are considered rather than trading programmes between individual bidding zones. The aim is to indicate how much the bidding zone imports or exports per bidding zone and per hour.

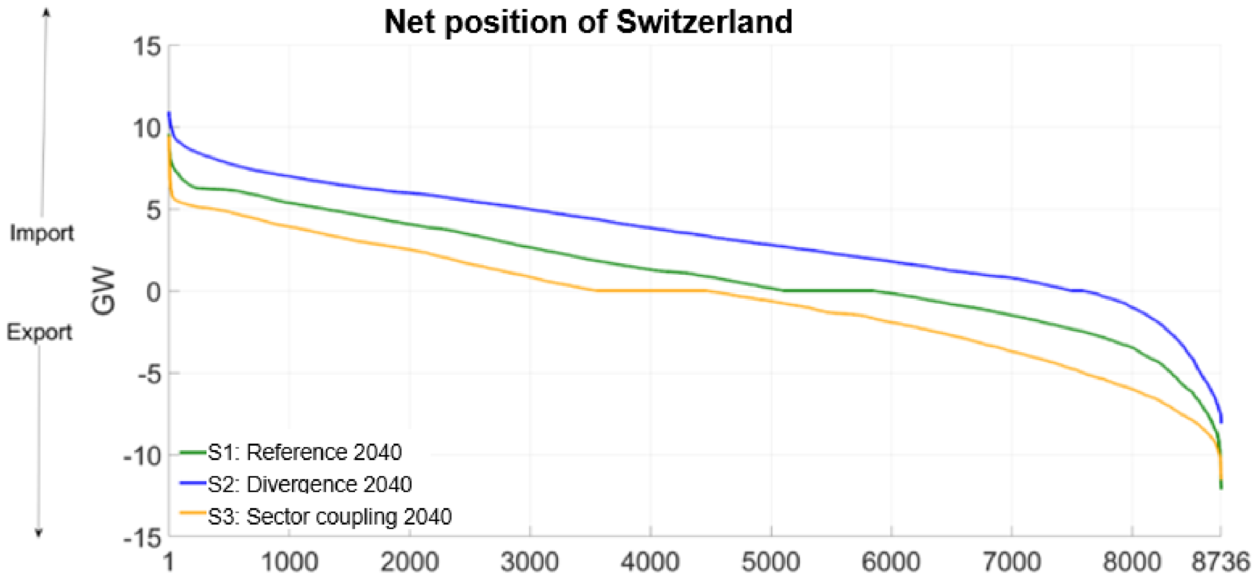


Figure 29: Net position of Switzerland per scenario in 2040

By comparison, the maximum volume exported in 2023 was 7,957 MW and the maximum volume imported was 4,664 MW.

The highest net imports occur in Scenario 2, Divergence 2040, which has the highest consumption and lowest domestic generation figures. The figure is as high as 10.9 GW. Net imports exceed 10 GW in 18 hours. This contrasts with maximum net exports of 8 GW. 80% of the time, Switzerland's net position is between 7 GW (imports) and –1 GW (exports).

In contrast, the highest net exports of 11.5 GW occur in Scenario 3, Sector coupling 2040, which has the lowest consumption and the highest domestic generation figures. In this scenario, the maximum net imports are 9.5 GW, and the net position is between +4 GW and –5 GW 80% of the time.

Scenario 1, Reference 2040 lies in between, with net maximum values of 9.5 GW of net imports and 12 GW of net exports. In the reference scenario, Switzerland's net position fluctuates between 5.4 GW and –3 GW 80% of the time.

Conclusion 2: the SN2025 was designed for a net position of Switzerland equal to +/–10 GW. Consequently, only moderate congestion is expected on cross-border lines. In addition, the 2040 start grid already includes a number of PSTs that can control flows and further reduce congestion.

5.2.2 Cross-border grid expansion requirements based on the SZR CH

(1) The flow-based analysis[3] with the European grid model for 2040[4] results in the limiting grid elements shown in the following diagram. In this initial situation, the expansion of a Swiss cross-border line would not increase Switzerland's exchange capacity because the congestion would first occur elsewhere in Europe.

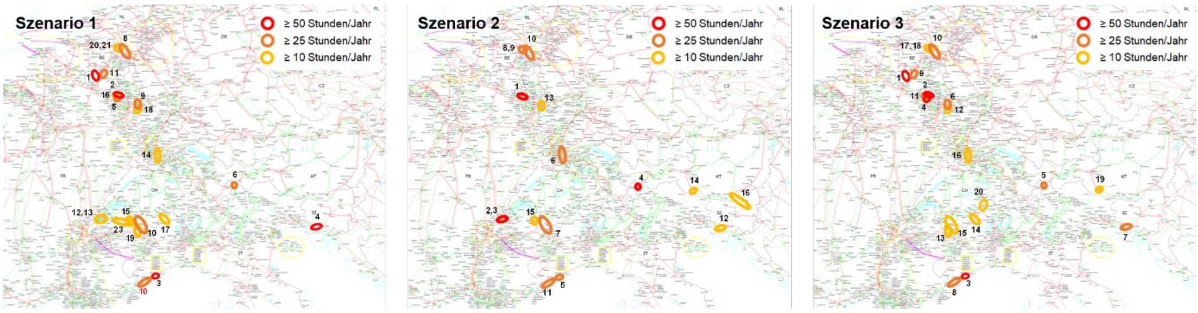


Figure 30 – limiting grid elements with relevance for Switzerland

(2) A large-scale controllable HVDC grid could overcome congestion in the AC grid. This requires studies with the neighbouring TSOs.

5.2.3 Grid expansion requirements in Switzerland based on the SZR CH

Grid expansion requirements in the Swiss transmission grid are identified by carrying out flow-based market simulation with the European 2040 start grid and the three SZR CH scenarios. The regionalised data also takes into account the known large-scale projects that are directly connected to the Swiss transmission system.

In the simulation, an optimum arrangement of PSTs is selected in the 2040 start grid which minimises the number of (n-1) violations.

The following diagrams show the limiting grid elements in the Swiss transmission system for each of the three scenarios (energy consideration followed by power consideration). This is followed by an analysis of the special case in which the Leibstadt and Gösgen nuclear power plants are still in operation in 2040. It should be noted that the failure of different grid elements can lead to the overload of one and the same grid element.

[3] This analysis assumes that there is no grid congestion within the bidding zones. Without this simplification, the calculation effort for the whole of Europe would be too great. The congestion within the Swiss bidding zone will only be determined in the next step.

[4] This grid model is the 2040 start grid, which assumes that all planned grid projects in Switzerland (SN2025) and abroad (TYNDP 2020) will be implemented.

An analysis of **scenario 1** gives the following results:

Energy consideration:

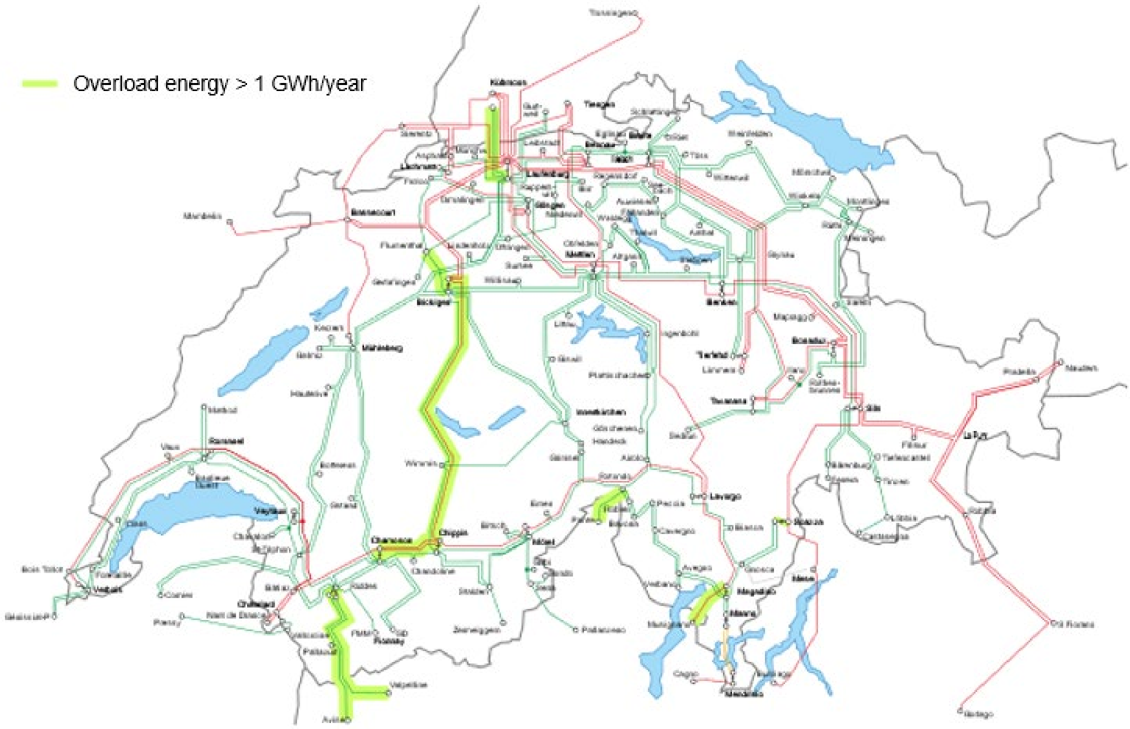


Figure 31: Limiting grid elements in scenario 1 in the Swiss transmission system (energy consideration)

Each line has a maximum transfer capacity for which it has been authorised. In the analysis, if the transmission power exceeds the maximum permissible value in an hour, the associated excess energy flow is recorded. These energy volumes are totalled over 2040 as a whole. If this «overload energy» is greater than 1 or 5 GWh per year, this is highlighted in the diagram. There may be a need for grid expansion on these lines. However, this is not necessarily the case, e.g. because:

- The line is already more powerful, but has only been authorised for a lower power in continuous operation (e.g. Bickigen – Chippis, Chamoson – Chippis): operation at higher power is possible 2% of the time, so these lines did not stand out in the following power consideration).
- Remedial actions can be taken.

Power consideration:

In the power consideration, the number of hours in which there was an (n-1) violation and the maximum number of violations are shown for each grid element. Exceeding 115% is not tolerable in grid planning because this could result in immediate outages of other grid elements.

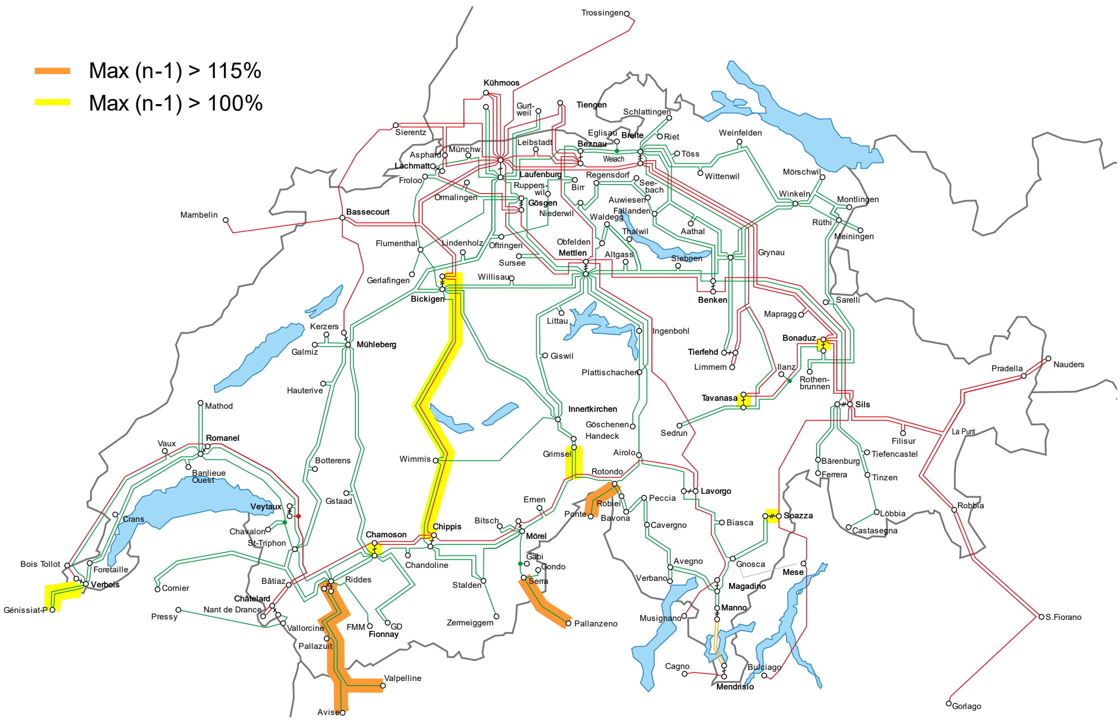


Figure 32: Limiting grid elements in scenario 1 in the Swiss transmission system (power consideration)

An analysis of **scenario 2** gives the following results:

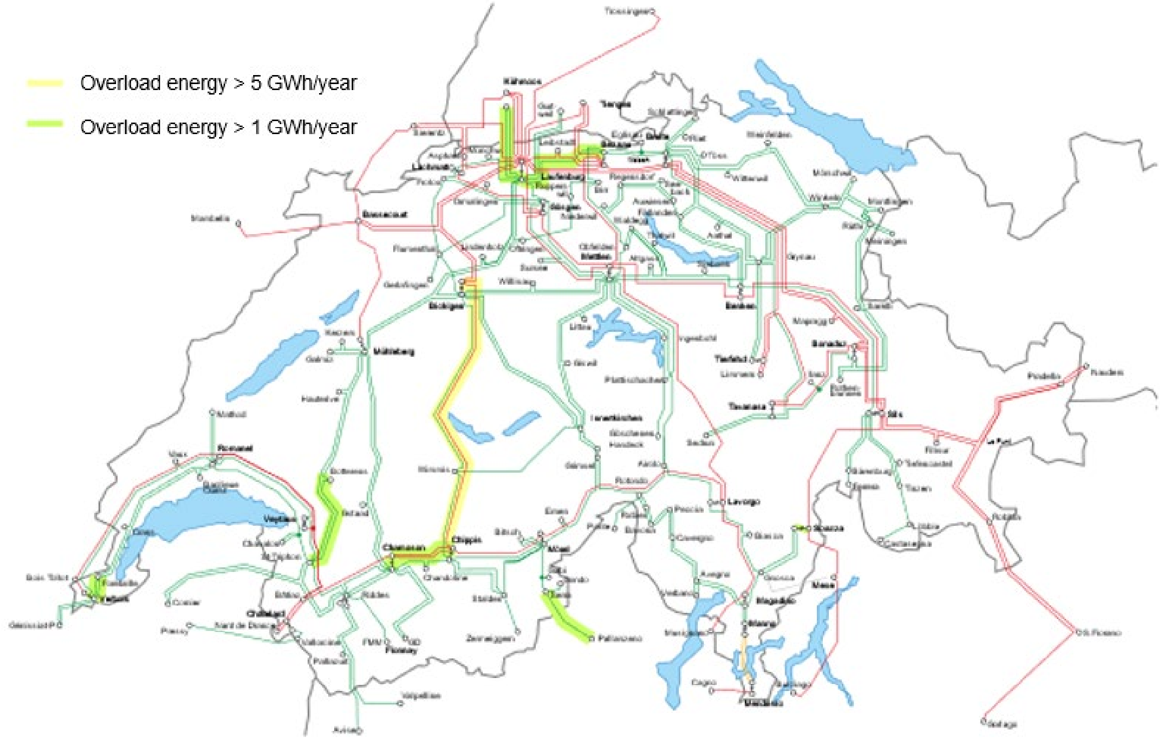


Figure 33: Limiting grid elements in scenario 2 in the Swiss transmission system (energy consideration)

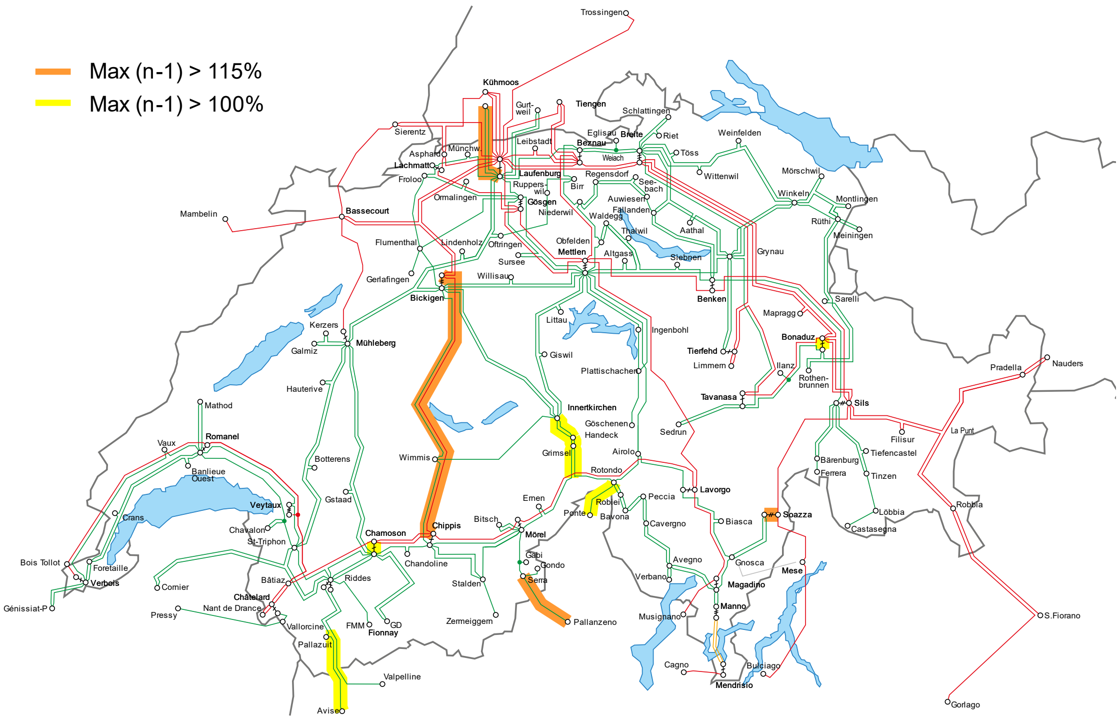


Figure 34: Limiting grid elements in scenario 2 in the Swiss transmission system (power consideration)

An analysis of **scenario 3** gives the following results:

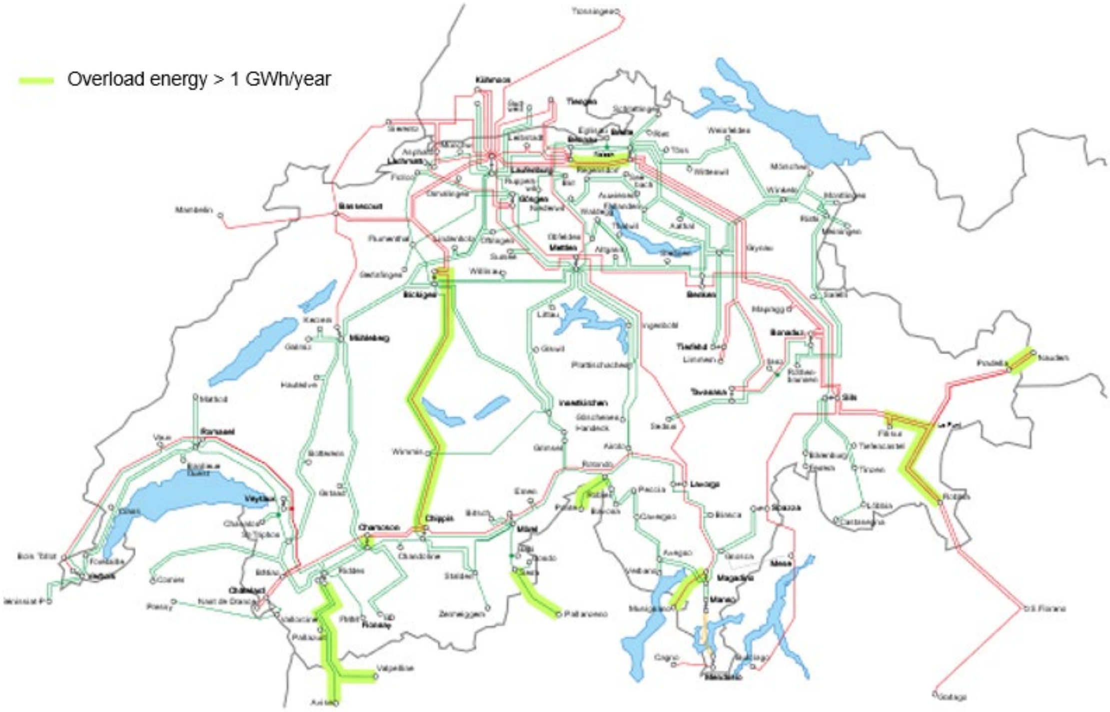


Figure 35: Limiting grid elements in scenario 3 in the Swiss transmission system (energy consideration)

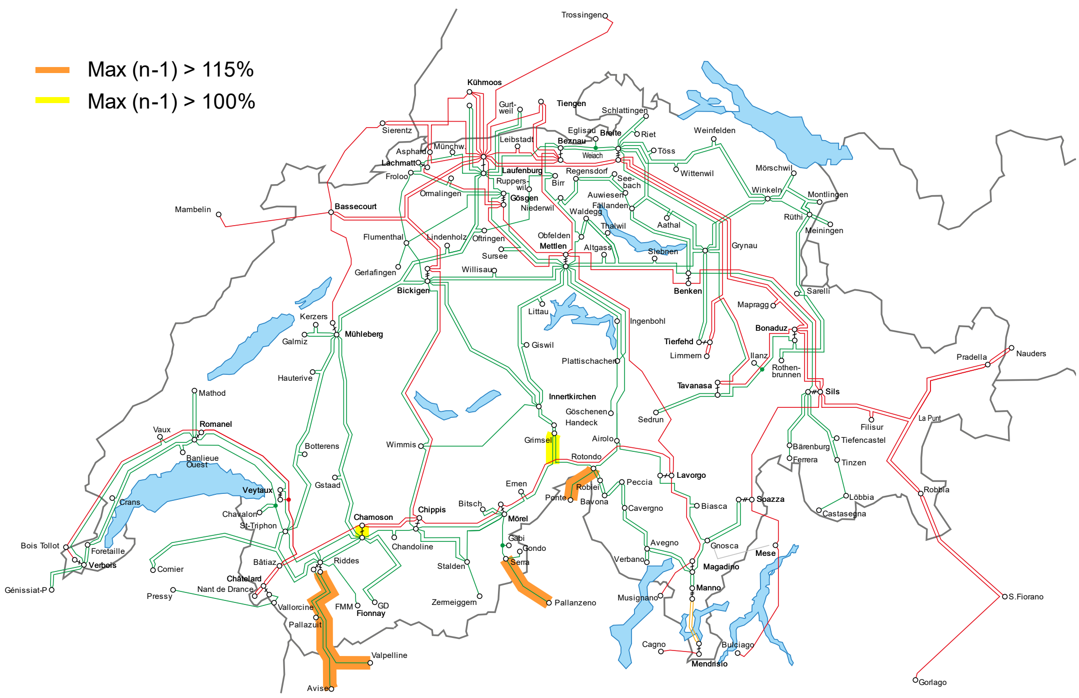


Figure 36: Limiting grid elements in scenario 3 in the Swiss transmission system (power consideration)

The congestion in Western Switzerland (south and west of Bickigen) shown in Figures 30 to 35 can be almost completely resolved by the construction of PST or four-quadrant transformers in Verbois, St-Triphon, Riddes and Châtelard. Project A: «PST Western Switzerland» is described in Section 6.3.2.1. The usefulness of these PSTs was also demonstrated in a joint grid study with RTE. The implementation of PSTs is therefore not only beneficial for Swissgrid, but also for international electricity flows.

A cross-border line from Laufenburg to Kühmoos (Germany) produces (n-1) violations in several scenarios.

The effects on the TS of continued operation of the Leibstadt and Gösgen nuclear power plants beyond 2040 (contrary to the assumptions of the SZR CH) were analysed in a specific analysis. In view of current political discussions, continued operation cannot be ruled out. The analysis shows that the interaction between the continued operation of the two nuclear power plants and the other projects in the region leads to (n-1) violations in the Laufenburg – Beznau – Breite region. These violations are moderate, occur during 150 hours per year and can be resolved by redispatching at a cost of around CHF 1 million per year, while the construction of a new 380 kV line would cost around CHF 250–300 million according to a rough estimate.

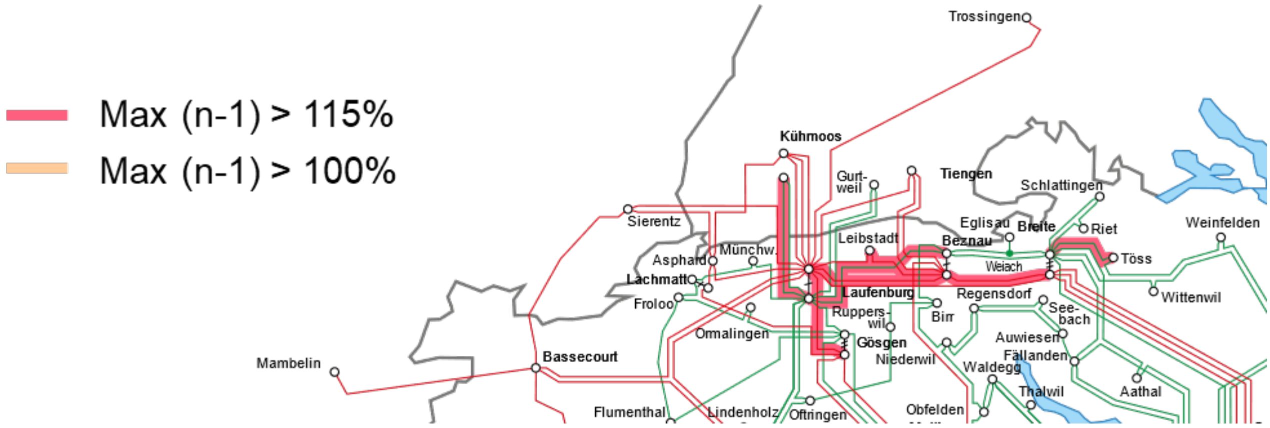


Figure 37: Grid congestion in the Laufenburg area in 2040 (Gösgen-Däniken and Leibstad nuclear power plants still in operation)

A grid study will be initiated with German TSOs to find a way to manage the recognised congestion around Laufenburg. The analyses regarding a possible HVDC connection between Germany and Switzerland and the selection of an ideal connection point in Switzerland should also be part of the study.

Lonza has submitted a 500 MVA grid connection request for the Visp site in the Valais. It would like to build a heat accumulator there. A new substation will be required for the grid connection. This project is described in Section 6.3.2.2 Project B: «Visp substation».

An investor has submitted a grid connection request for a data centre with battery storage for the Chavalon site. The connection requires the affected substation to be repaired and expanded and a new line to be installed. This project is described in Section 6.3.2.6 Project G: «New Chavalon substation and enhancement of the 220 kV Romanel – St-Triphon line».

Conclusion: based on the specifications of the SZR CH, moderate congestion has been identified, particularly in Western Switzerland, which can be overcome by building PSTs. In Visp and Chavalon, there are also requests for connection to the transmission system that require grid expansion. Any need to expand the Laufenburg – Beznau – Breite line must be examined in a cross-border study with the neighbouring German TSOs.

5.3 Grid expansion requirements to increase security of supply

A few locations on the TS have been identified where the outage of a grid element could lead to regional restrictions or outages for grid users or connected distribution grids. In these cases, an expansion of the TS to increase security of supply may be justified. The following cases were identified:

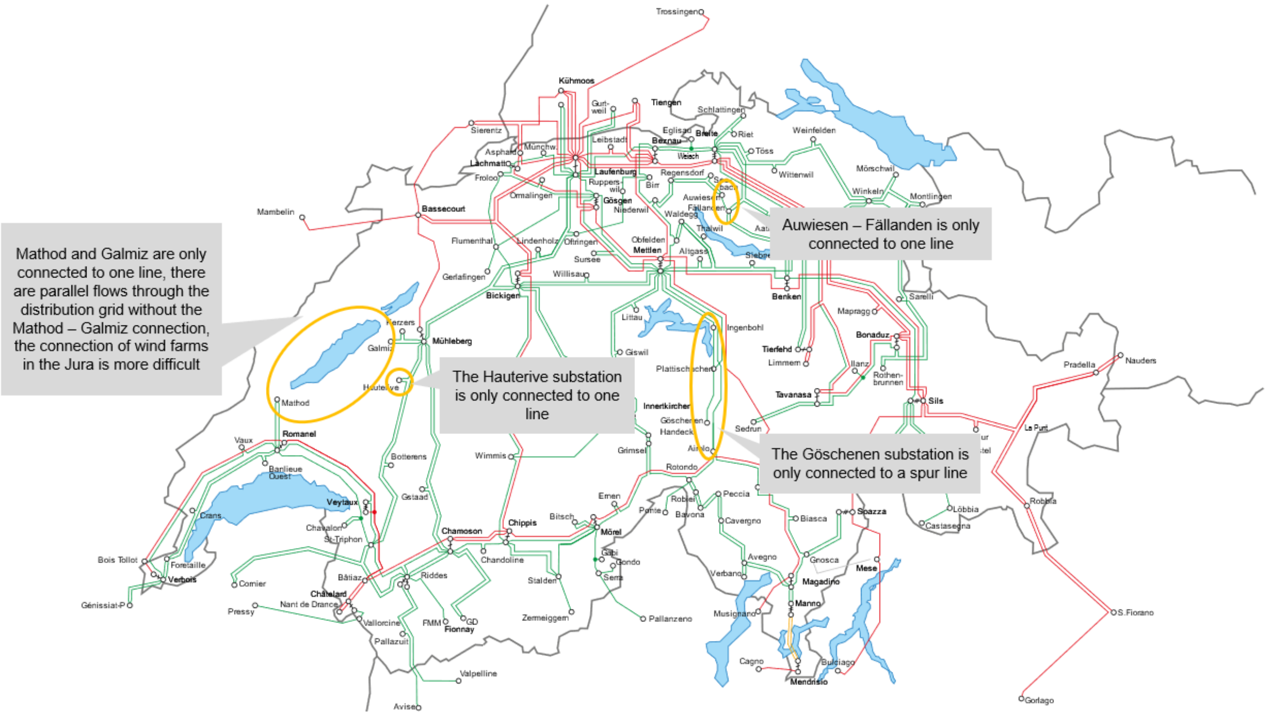


Figure 38: Increase in the security of supply of the DSOs and PPOs on the TS

There is only one 220 kV system between Auwiesen and Fällanden in the canton of Zurich. Otherwise, the 220 kV grid in the region is always designed with two systems per route. The outage or decommissioning of the Auwiesen – Fällanden line would lead to congestion and operational challenges on other NE1 grid elements and in the EWZ distribution grid in the region. The grid enhancement project is described in Section 6.3.2.5 Project F: «Additional 220 kV system Auwiesen – Fällanden».

The Göschenen substation is only connected to the Plattischachen substation via one line. The outage or decommissioning of this line would mean that the Göschenen power plant would not be able to produce at full capacity and the supply of electricity in the canton of Uri would no longer be guaranteed. An incident of this kind occurred in February 2022. A second connection to the Göschenen substation would alleviate this problem. The new line would also strengthen the north-south axis. This project is described in Section 6.3.2.4 Project E: «Additional 220 kV system Airolo – Göschenen».

The Hauterive substation is connected to the 220 kV Mühleberg – St-Triphon line. The connection to Hauterive must be enhanced in order to guarantee security of supply given that the load in this substation is forecast to increase and is of great importance for supplying Groupe-E customers and the canton of Fribourg. This project is described in Section 6.3.2.3 Project D: «Redundant 220 kV grid connection of the Hauterive substation». The necessity of this measure was demonstrated by a joint grid study with Groupe-E.

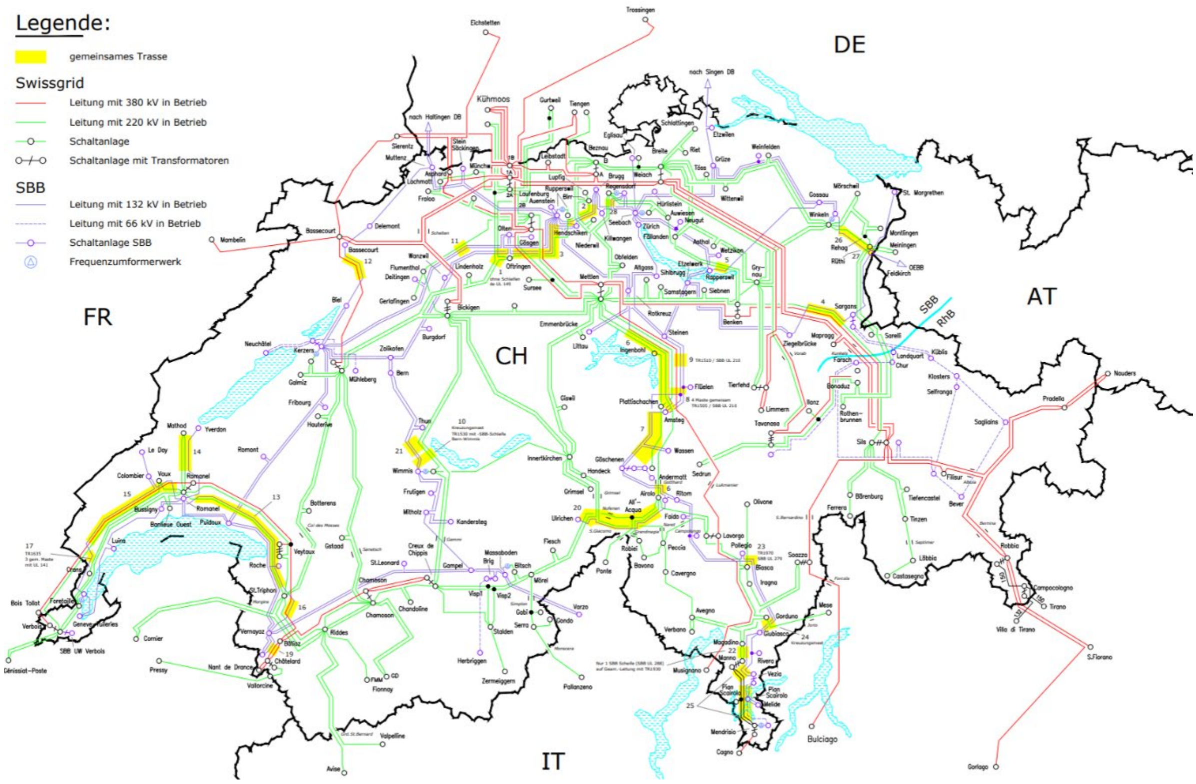
Romande Energie, Groupe-E, SBB and Swissgrid all have a transmission grid in the Lake Neuchâtel region. As SBB needs more power in this region, it will build a new 132 kV line between Yverdon and Kerzers. In addition, the load in Yverdon is forecast to rise sharply due to additional consumers. The planned expansion by SBB gives Swissgrid the opportunity to implement an additional connection bundled with the line planned by SBB. This will result in the following advantages: other NE1 and/or NE3 systems could be bundled with the SBB line. with Galmiz, Kerzers and Mühleberg at one end and Yverdon and Mathod at the other end of the new route, there are nearby substations that could be bundled in the long term. A new substation could be planned in the middle of the route to connect NE1+3 and facilitate the transport of energy generated by any future wind farms. The north-south axis for electricity transport would also be strengthened, and parallel flows through the NE3 could be reduced.

5.4 Bundling candidates for better utilisation of scarce space

As part of the «Strategic Grid 2040», Swissgrid examined potential for bundling in the transmission grid. To do so, Swissgrid analysed whether parallel routes or closely spaced substations could be merged or rationalised without compromising security of supply. Ideally, bundling should be implemented when systems need to be renovated. In certain cases, this would be well after the target year of 2040.

Furthermore, as part of the «Strategic Grid 2040», Swissgrid also examined the potential for bundling grid renovation, grid enhancement and grid expansion projects of the TS with parallel infrastructure projects including power lines for the lower grid levels and SBB, as well as other linear infrastructures such as the road and rail networks. Project bundling reduces costs and, under certain circumstances, minimises the impact on the landscape, the environment and the population.

5.4.1 Existing and agreed bundling



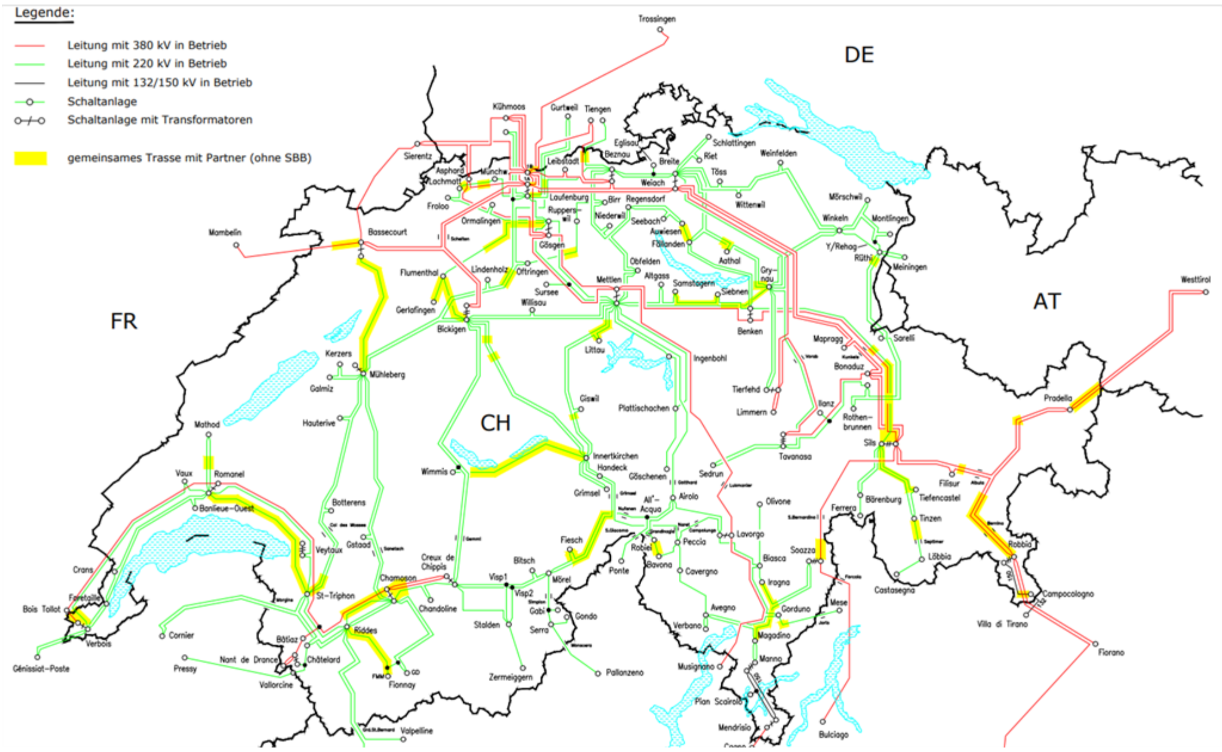


Figure 39: Existing bundling with SBB (top) and DSO lines (bottom)

Figure 38 shows that many line sections on the TS are already bundled with parallel infrastructures.

Projects being implemented that are already included in the 2040 start grid:

- 2027: 220 kV Thalwil substation – connection by cable in the Uetliberg tunnel, where empty conduits for possible cabling had already been laid during the construction of the tunnel
- 2029: relocation of the 220 kV Gotthard line to the new second tube of the Gotthard Road Tunnel and dismantling of the line over the pass
- 2036: decommissioning of the 220 kV Iragna substation, relocation of the distribution grid connection to the nearby Biasca substation
- Installation of the 220 kV Grimsel line as a cable either in existing tunnels and a newly constructed tunnel (main variant) or in the multifunctional Grimsel railway tunnel (alternative variant) [Federal Council decision of 25 February 2023]

5.4.2 Recognised bundling potential

The following diagram shows the bundling candidates for routes.

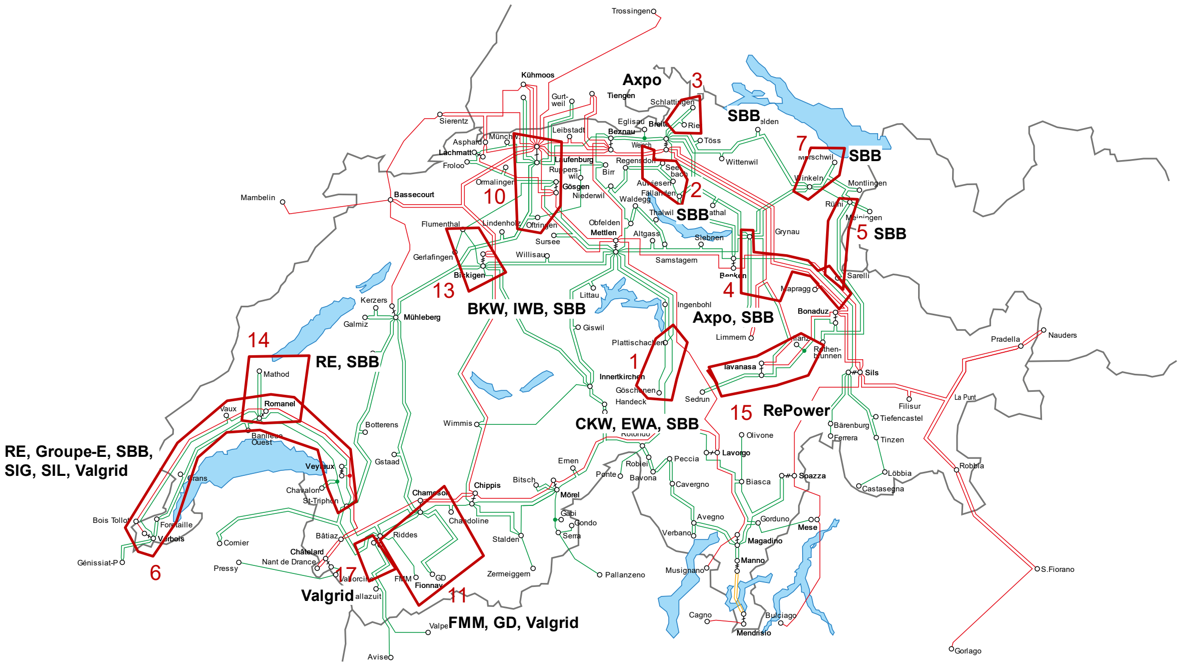


Figure 40: Bundling candidates for routes

The following diagram shows the bundling candidates for substations.

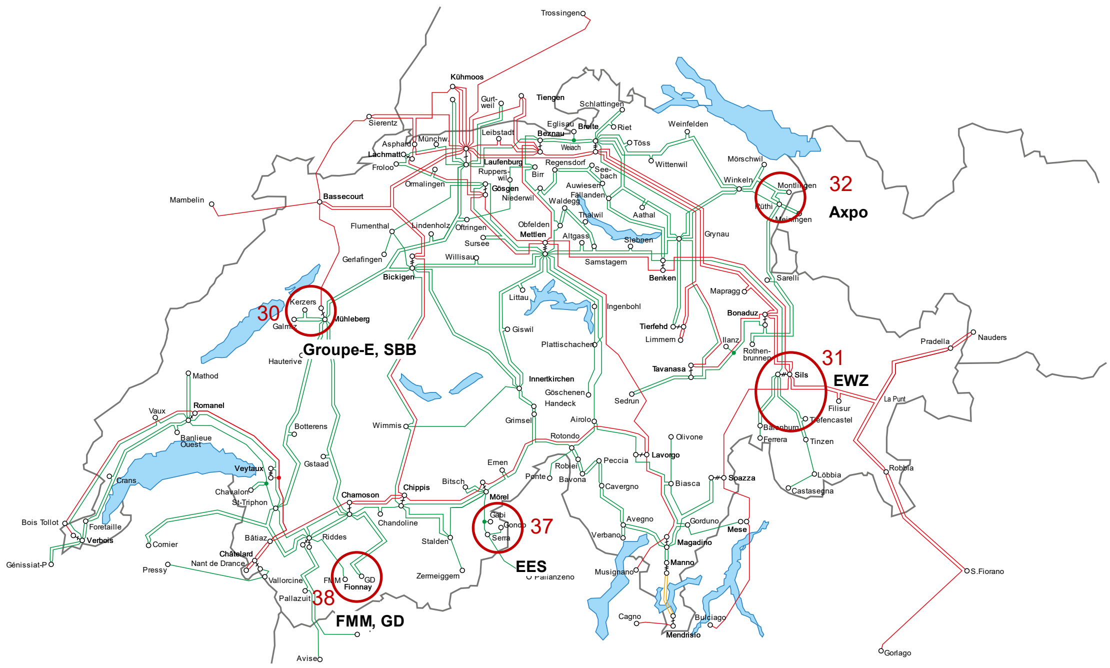


Figure 41: Bundling candidates for substations

All bundling candidates are still subject to review and agreement with the partners involved. Bundling would only take place if and when existing systems need to be renovated. The aims of bundling are to reduce the overall costs of all bundled infrastructures, to reduce the impact on the environment and to simplify/accelerate approval processes. Furthermore, bundling should not jeopardise security of supply.

5.5 Principles of grid expansion

The planning principles in Section 5 of the document «Grid planning at Swissgrid» apply. The following points are also taken into account.

In the AC grid, the following principles apply when selecting the appropriate voltage level for grid expansion:

- Always 380 kV for transit axes.
- For lines to power plants or consumer centres, the current grid situation is analysed and a decision is then made on a case-by-case basis before opting for 220 or 380 kV. If operation at 380 kV appears possible and expedient in the long term, expansion will take place to 380 kV, even if initial operation is at 220 kV.

Economically efficient grid expansion can take place on the transmission or distribution grid in order to resolve grid congestion (the cause and effect do not have to be in the same location). The coordinated renovation and further development of NE1–3 (Studio Generale) is currently underway in Ticino – one of the first projects of its kind. Efforts are being made to apply this regional grid coordination approach throughout Switzerland. However, the current rule for planning the transmission system is that it must be able to operate n-1 securely on its own. The downstream grid levels have therefore not yet been taken into account in grid planning outside Ticino. In the «Regional Coordination of Grid Planning» working group, the idea is to exchange mutual information on the strategic grids developed by Swissgrid, the DSOs on the TS and SBB. If necessary, joint grid studies can be initiated by the affected grid operators.

5.6 2040 reference grid

The 2040 reference grid is now derived from the above analyses, which are based on the SZR CH scenarios, projects to strengthen security of supply and the list of bundling candidates.

Drivers	Transformation of the energy system in Europe and Switzerland (many decentralised small systems and some large-scale projects)		Security of supply	Scarce space
Methodology	**Market simulation** (Basis: SZR CH)	**Grid simulation** (Basis: regionalised data)	**Failure analysis**	**Identification of parallel infrastructures**
Results	• Power plant deployment and market prices per bidding zone • Congestion on cross-border lines between bidding zones • Price differences between bidding zones	• Limiting grid elements in Switzerland • Redispatching costs • Danger to grid security	• Restrictions on grid users due to grid outages	Bundling candidates identified: • Parallel transmission grid, distribution grid and SBB lines • Nearby substations
Derived projects	Projects with economic potential (still to be reviewed with partners)	Projects to eliminate congestion and new grid connections	List of projects to improve the security of supply of distribution grids and power plants	List of bundling candidates

2040 reference grid

Figure 42: 2040 reference grid

Section 6 describes the formation of the 2040 target grid. The target grid may deviate from the reference grid if coordination with other grid operators, the cost-benefit analysis or the stress tests reveal a need for modification.

6 Formation of the 2040 target grid

Input
- Scenario Framework Switzerland
- Regionalisation

Determination of the start grid

Formation of the reference grid
- Market simulation
- Grid simulation
- Failure analysis
- Identification of parallel infrastructures

Formation of the target grid
- Coordination with DSOs and foreign TSOs
- Cost-benefit analysis
- Verification with stress tests

Output:

Strategic Grid

The 2040 target grid includes various classes of projects:

- Strategic Grid 2040: projects whose necessity was confirmed in the course of the analyses and whose implementation is definitely planned
- Projects that still require further studies and/or coordination with the grid operators concerned (DSOs or foreign TSOs)
- Bundling candidates whose inclusion will be addressed after consultation with the relevant partners

The Strategic Grid 2040 includes the following grid projects:

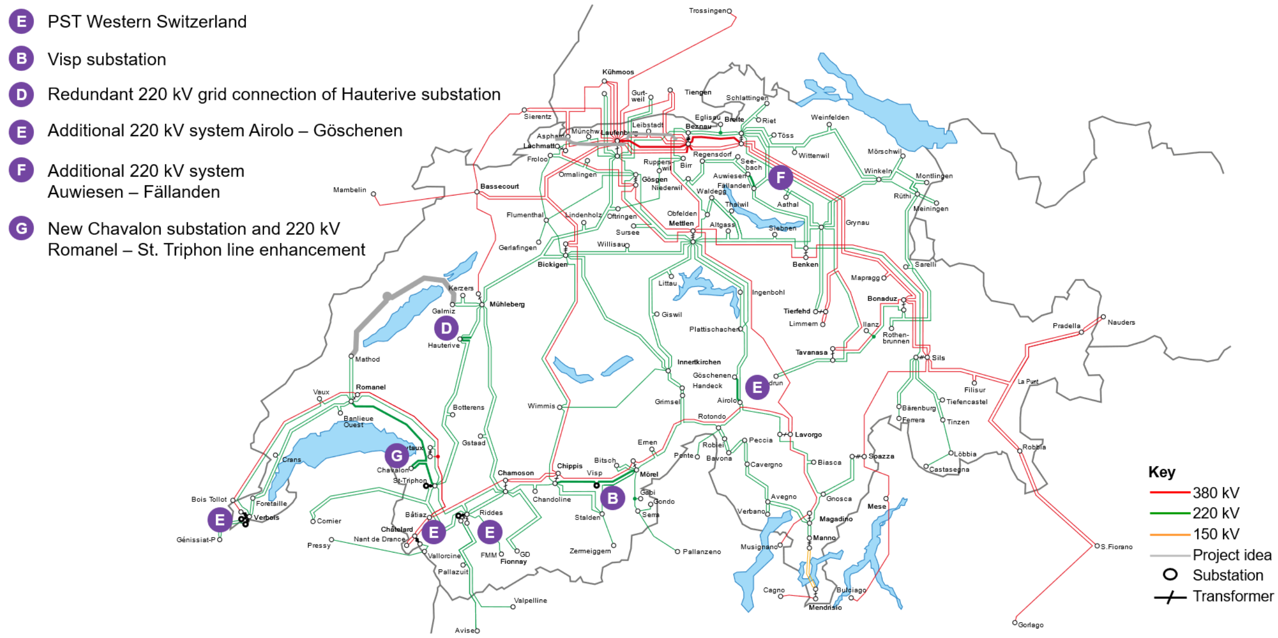


Figure 43: Strategic Grid 2040

The following diagram shows the projects that still require studies with other grid operators:

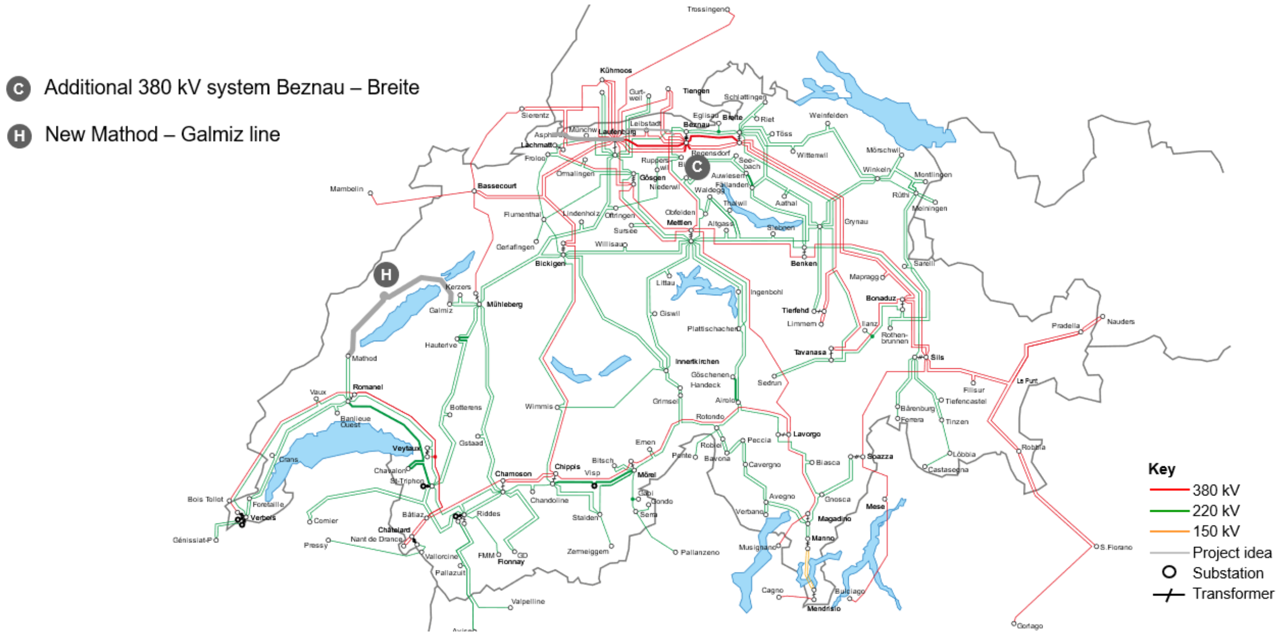


Figure 44: Projects that still require grid studies

The following diagram shows all the bundling candidates. Joint studies with the bundling partners must show whether the bundling idea will be pursued. This coordination process was started in 2024 and was still ongoing by the time this final report was completed.

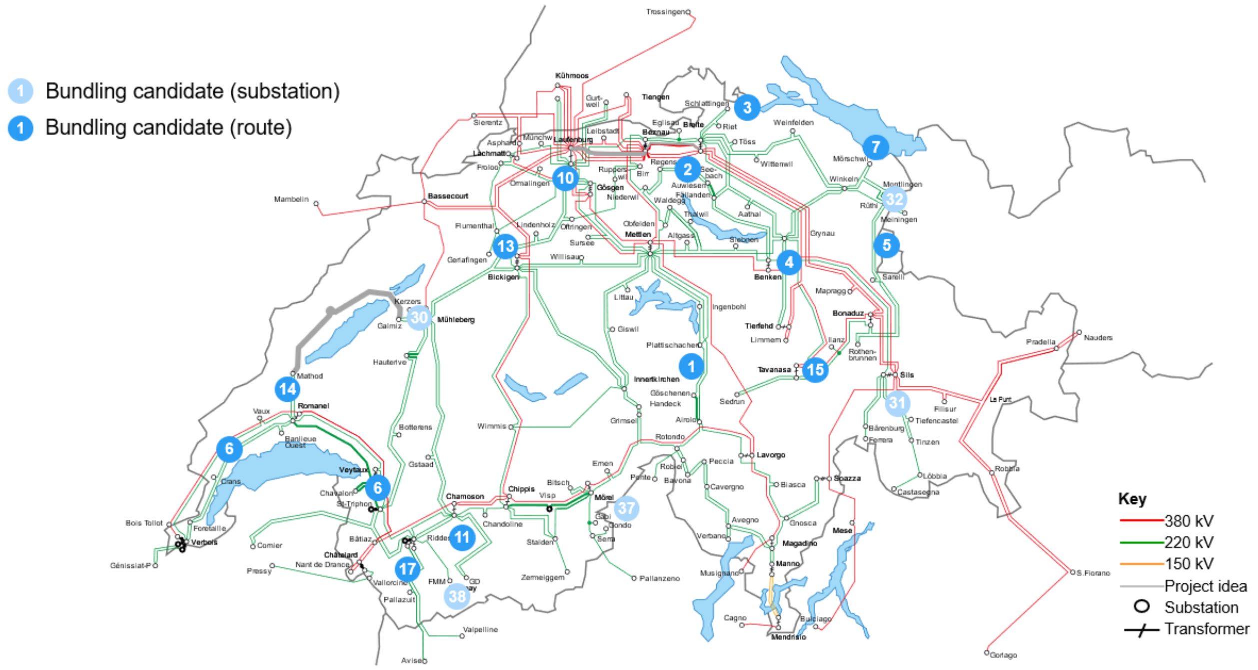


Figure 45: Bundling candidates

The following tables show the bundling candidates for routes:

No.	New operating elements	Bundling partner
1	Plattischachen – Göschenen	SBB, CKW, EWA
2	Regensdorf – Seebach – Auwiesen	SBB
3	Schlattingen South	SBB
4	Linth plain – Lake Walen	SBB, Axpo
5	Rüthi – Sarelli	SBB
6	North shore of Lake Geneva	SBB, RE, SIG, Groupe-E, Valgrid, SIL
7	Winkeln – Mörschwil	SBB
10	Laufenburg – Gösgen/Oftringen	
11	Riddes/Chamoson – Fionnay	FMM, GD, Valgrid
13	Flumenthal – Bickigen	BKW, IWB, SBB
14	Romanel – Mathod/Yverdon	SBB, RE
15	Sedrun – Ilanz	RePower
17	Riddes – Pallazuit	Valgrid

The following table shows the bundling candidates for substations:

No.	New operating elements	Bundling partner
30	Galmiz – Kerzers – Mühleberg	SBB, Groupe-E
31	Sils – Tiefencastel	EWZ
32	Montlingen – Rüthi	Axpo
37	Gondo – Gabi – Serra	EES
38	Fionnay FMM – Fionnay GD	FMM, GD

6.1 Coordination with DSOs and foreign TSOs

Swissgrid coordinates all recognised grid expansion with the relevant DSOs in Switzerland, as well as with the neighbouring foreign TSOs. If there is a need for more in-depth analysis, the grid operators initiate a corresponding study, and the grid expansion requirements may be modified accordingly. Section 6.3.3 presents two of these studies.

6.2 Cost-benefit analysis

To determine the target grid, all the projects in the reference grid are individually subjected to a cost-benefit analysis (CBA). The project can be either a new construction project, an expansion project or a bundling project.

By carrying out market and grid simulation with the reference grid with and without the project to be assessed, the monetary benefit of the project can be determined for various benefit categories.

In addition, the CBA provides qualitative information on other benefit categories that cannot be evaluated in monetary terms.

Based on the CBA results, a decision is made as to whether a project will be included in the «Strategic Grid 2040».

The cost-benefit analysis includes the following cost and benefit categories:

- **Monetary benefit and additional, non-monetary Swissgrid benefit categories**[5]: monetary (unit: CHF/a), physical (example of unit: t/a) or qualitative (example of unit: 0 / + / ++)
- **Cost categories:** monetary (unit: CHF/a)

The following cost and benefit categories are applied:

Costs
C1: CAPEX
C2: OPEX

Benefits
B1: Increase in socio-economic welfare
B3: Integration of renewable resources
B5: Reduction of electric system losses
B9: Reduction of redispatching/countertrading

Additional Swissgrid benefits
Z1: Improvement in security of supply (vertical)
Z2: Resilience

monetary => integrated into the cost-benefit calculation

Figure 46: Cost/benefit categories of the «Strategic Grid 2040» project

[5] The CBA methodology used by Swissgrid is based on an ENTSO-E document. Individual benefit categories have been adapted for Switzerland and are labelled «Additional Swissgrid benefits».

6.3 Project profiles

This section presents the grid expansion projects.

For each project in the Strategic Grid 2040, there is a profile that explains the objective and purpose of the project and states the costs, as well as the monetary and qualitative benefits.

6.3.1 Explanation of the structure and content of a project profile

The following overview table forms the main part of each project profile. The individual parameters are listed to ensure uniform interpretation:

Total investment costs	**CHF millions**	**xx**
Commissioning	**Year**	**20xx**
Determination of monetary benefit		
NPV (cost-benefit)	**CHF millions**	**xx**
Qualitative benefits		
Increase in security of supply	--/-/0/+/++	xx
Increase in grid security	--/-/0/+/++	xx
Resilience	High / Medium / Low / 0	xx

Benefit «B3: Integration of renewable resources» has been omitted from the table as it is not relevant to any SN2040 projects.

The individual components of the table are presented in the following subsections.

It should also be noted that Project A is the only project from the Strategic Grid 2040 that will be of monetary benefit. The qualitative benefits are decisive for the other projects.

6.3.1.1 Total investment costs

This is the amount that would have to be invested today to build the project (CAPEX).

For grid enhancement measures, only the costs for the enhancement itself are recognised. If, for example, line replacement is combined with enhancement, the costs of a 1:1 replacement are deducted in order to determine the additional costs of grid enhancement.

As far as grid bundling is concerned, the costs are borne by several companies. In this case, a proportion of the costs is allocated to the transmission system depending on the individual situation.

If the expansion of the transmission system reduces the need for expansion of the distribution system, the DSO saves costs, the amount of which is unknown to Swissgrid. This information will be indicated.

6.3.1.2 Commissioning

The target year for the commissioning of the project is specified here.

The commissioning date is subject to considerable uncertainty because it depends on the approval process and the procurement of materials.

6.3.1.3 Determination of the NPV

This methodology was only used for project A.

The **NPV of the project** is calculated by deducting the project costs (investment and operating costs) from the **monetary benefits** (energy-related benefits and the reduction of electric system losses and redispatching costs). Simulation calculations are carried out to determine the monetary benefits – once with the reference grid and once with the reference grid without the project under consideration. The difference in the results shows the added value of the project for various benefit categories.

The **energy-related benefits** (B1: Socio-economic welfare) represent the sum of the increase in producer surplus, consumer surplus and congestion surplus, which is determined with the help of a market simulation.

- **Consumer surplus** – results from the difference between the buyer's solvency and the actual market price for electricity procurement. In principle, elastic solvency/demand is required to determine consumer surplus. In the simulation, however, the load is inelastic, i.e. theoretically, solvency in the simulation is infinite. It is therefore not possible to calculate the consumer surplus for a single simulation, merely the difference between two simulations (with/without project). A rising (falling) consumer surplus for Switzerland is when the project causes the price of electricity in Switzerland to fall (rise).
- **Producer surplus** – results from the difference between the market price for electricity and the generation costs for the electricity produced. A rising (falling) producer surplus for Switzerland is when the project causes the revenue from the sale of the electricity produced in Switzerland to increase (decrease). This means that even if prices fall, the producer surplus can rise if the quantity effect of rising production exceeds the price effect.
- **Congestion surplus** – results from the product of the price difference between Switzerland and the neighbouring country and the aggregated physical flow between the countries. Half of the congestion surplus is allocated to Switzerland and half to the neighbouring country.

Reduction of electric system losses and redispatching/countertrading costs: a new grid project causes a change in load flows. If this reduces electric system losses and/or the activation of redispatching/countertrading, the costs for the procurement of electric system losses and redispatch energy decrease.

6.3.1.4 Qualitative benefits

Non-monetary benefit categories, which can nevertheless justify the implementation of a project, are evaluated in this part of the table.

Increase in security of supply and grid security: in particular, this shows the results of the stress tests where, for example, entire routes (i.e. all the transmission lines mounted on the same pylons) and busbars fail. If the project results in the operating facilities still in operation being less heavily overloaded or even reduces the risk of a cascade outage, this increases grid security. Security of supply is increased if, for example, a distribution grid is connected to the transmission grid at additional points.

--/-/0/+/++: The symbols illustrate whether the project slightly or strongly improves security of supply/grid security, whether it results in no change or whether it causes a slight or strong deterioration in the situation. A justification for the evaluation is provided for each project.

	Grid security	Security of supply
(--)	Project increases the number of (n-1) violations	Project reduces security of supply in several distribution grids
(-)	Project increases the load on other grid elements	Project reduces security of supply in a distribution grid
(0)	Project does not lead to any change	Project does not lead to any change
(+)	Project reduces the load on other grid elements	Project ensures that the outage of an existing grid element does not cause a supply disruption
(++)	Project reduces the number of (n-1) violations	Project ensures that two grid elements can now fail without causing a supply disruption

Resilience: a project whose necessity has been identified for various scenarios particularly increases the resilience of the target grid.

- High: if the project is technically necessary in all scenarios.
- Medium: if the project is only technically necessary in two scenarios.
- Low: if the project is only technically necessary in one scenario.
- Otherwise, the project has no added value for resilience.

6.3.2 Description of projects in the target grid

6.3.2.1 Project A: «PST Western Switzerland»

Project description

The «PST Western Switzerland» programme envisages the installation of four new 220/220 kV PSTs and the early replacement of two 380/220 kV transformers. In detail, these are:

- 2 new 220/220 kV PSTs, 600 MVA in Verbois;
- 1 new 220/220 kV PST, 500 MVA in St-Triphon;
- 1 additional 220/220 kV PST, 500 MVA in Riddes;
- Replacement of the existing 380/220 kV transformer in Verbois with a four-quadrant 380/220 kV–800 MVA transformer;
- Replacement of the existing 380/220 kV transformer in Châtelard with a transformer with higher phase-shifting capability.

Overview table of CBA results

Total investment costs	**CHF millions**	**205**
Commissioning	**Year**	**2030**
Determination of monetary benefit		
NPV (cost-benefit)	**CHF millions**	**>100**
Qualitative benefits		
Increase in security of supply	--/-/0/+/++	0
Increase in grid security	--/-/0/+/++	+
Resilience	High / Medium / Low / 0	High

Objective and purpose of the project

- To control unwanted flows via the Swiss grid resulting from the implementation of the EU's Clean Energy Package in Switzerland's neighbouring countries.
- To increase exchange capacities with neighbouring countries, especially France.
- To reduce the expected future redispatching demand by 60–80% in the region (depending on the operating mode of the PSTs).
- To increase grid security in Western Switzerland by reducing line overloads.

What will happen if the project is not implemented?

- Parallel lines will be loaded unevenly and it will not be possible to make full use of the transport capacity of the existing grid.
- Unwanted flows via Switzerland triggered by foreign countries may reduce the feed-in/feed-out options of Swiss grid users.
- Additional redispatching costs will arise.
- Fewer operational resources will be available to address line congestion.

Monetary benefits

The project is associated with a major monetary benefit. According to a study carried out jointly with RTE, the annual economic added value plus the change in countertrading and costs resulting from energy losses amount to around CHF 22 million for Switzerland alone. With an investment sum of around CHF 205 million, the project is expected to pay for itself in less than 15 years. Over the lifetime of the project of at least 30 years, this results in a positive NPV of > CHF 100 million for Switzerland (depending on the chosen scenario). The project is therefore economically worthwhile.

Qualitative benefits

The PST will increase grid security in the transmission grid by preventing the overloading of grid elements. In particular, it will limit unwanted flows through Switzerland, which arise especially as a result of the exclusion of Switzerland from the European electricity system.

Resilience: the project reduces overloading of grid elements in all three SZR CH scenarios.

The project has already been analysed in a joint study with RTE, as the affected TSO, and RTE has agreed to its implementation because it will also be of benefit to France.

6.3.2.2 Project B: «Visp substation»

Project description

Lonza is planning to build a large heat accumulator with a power output of up to 500 MW at its plant in Visp. A direct connection to the 220 kV grid will be necessary for this high power output. In the future, the electricity requirements will be generated in particular by the large-scale alpine photovoltaic plant in the Visp valley and other photovoltaic plants in the Valais. The heat accumulator can make the best possible use of the high PV peak. Ensuring that electricity is consumed close to the generation location and that consumption is geared towards generation provides optimum relief for the grid and promotes the integration of renewables. The grid connection will be made to the new 220 kV Chippis – Mörel line following its completion. This will require approx. 1.5 kilometres of underground cabling and a new substation in Visp with three bays.

Overview table of CBA results

Total investment costs	**CHF millions**	**55**
Commissioning	**Year**	**2040**

The costs are made up of approx. CHF 45 million for the underground cable and approx. CHF 10 million for the substation. Lonza would have to bear the costs for its field, which represents about 1/3 of the costs of the substation.

Since the driver for this project is a grid connection request, an actual cost-benefit analysis is unnecessary.

Objective and purpose of the project

A new substation, including corresponding line entries, will be needed in order to obtain a power output of 500 MVA from the transmission system. (Note: according to the TC, connection to the transmission system is appropriate from a power output of 150 MVA).

What will happen if the project is not implemented?

- Lonza will not be able to implement its heat accumulator project.
- Swissgrid will not be able to meet its obligation to implement the grid connection.

6.3.2.3 Project D: «Redundant 220 kV grid connection of the Hauterive substation»

Project description

The Hauterive substation, which is currently only connected to one 220 kV system on the Mühleberg – St-Triphon line, will be connected to a second 220 kV line in order to increase security of supply.

The redundant grid connection will be created by also connecting the Hauterive substation to the 220 kV Mühleberg – Botterens line.

Redundancy will be increased in the substation by creating a second busbar.

Overview table of CBA results

Total investment costs	**CHF millions**	**12**
Commissioning	**Year**	**2035**
Qualitative benefits		
Increase in security of supply	--/-/0/+/++	++
Increase in grid security	--/-/0/+/++	0
Resilience	High / Medium / Low / 0	0

Objective and purpose of the project

- To increase security of supply in Groupe-E's distribution grid, particularly in the canton of Fribourg.
- To increase exchange capacity with the transmission grid in the Hauterive substation.

What will happen if the project is not implemented?

- An outage at Hauterive substation may lead to supply disruptions in the Groupe-E grid or in the canton of Fribourg.

There is a joint grid study with Groupe-E which shows the necessity of the second connection.

6.3.2.4 Project E: «Additional 220 kV system Airolo – Göschenen»

Project description

The spur line from Mettlen via Plattischachen to Göschenen will be extended to Airolo by laying a second 220 kV cable through the new Gotthard tunnel tube and providing compensation systems at the Göschenen substation and possibly also at the Airolo substation. As a result, outages or failures of the Plattischachen line to Göschenen will no longer automatically lead to an outage of the Göschenen substation.

An Airolo-Göschenen grid construction project is currently being implemented. The existing overhead line from Mettlen to Airolo over the Gotthard Pass will be replaced by a cable that will be laid as an infrastructure bundling project in the newly constructed tube of the Gotthard Road Tunnel. This cable project with compensation systems in Airolo and Göschenen will be carried out by 2029. This line will bypass the Göschenen substation, as is already the case today.

The aim is to plan and approve the additional cable project separately so that the planning and implementation of the current project will not be affected. However, as many synergies as possible should be utilised and, when implementing the first cable, solutions should be chosen that will facilitate the laying of the second cable.

The described variant with two 220 kV systems in the new tube of the Gotthard tunnel has a financial advantage and will cost a total of CHF 156 million. CHF 107 million has already been incurred for the first cable and the basic installation. The second cable will therefore only cost CHF 49 million.

Overview table of CBA results

Total investment costs	**CHF millions**	**49**
Commissioning	**Year**	**2035**
Qualitative benefits		
Increase in security of supply	--/-/0/+/++	++
Increase in grid security	--/-/0/+/++	+
Resilience	High / Medium / Low / 0	0

The project has no added value in the monetary benefit categories.

Objective and purpose of the project

- To increase redundancy on the north-south transport axis (in particular to the Lukmanier line and to transport the electricity generated by the power plant on the Innertkirchen – Ulrichen line).
- To ensure the ability to transport the electricity generated by the Göschenen power plant.
- To increase security of supply in the Reuss valley/canton of Uri.

What will happen if the project is not implemented?

The outage or decommissioning of the Plattischachen – Göschenen line would mean that production at the Göschenen power plant would only be possible at a greatly reduced level via the distribution grid and that there could be a supply disruption in the EWA-energie Uri grid in the Reuss valley. In addition, the line over the Grimsel Pass would be overloaded, meaning that power plant production may have to be restricted.

6.3.2.5 Project F: «Additional 220 kV system Auwiesen – Fällanden»

Project description

The EWZ system currently operated at 150 kV will be converted to 220 kV between Auwiesen and Fällanden. The construction of one connection feeder is necessary in each of the two substations.

EWZ is planning to renovate its 150 kV grid. As soon as the Fällanden – Letten connection is completed, EWZ will no longer be dependent on the 150 kV Fällanden – Auwiesen connection and could dispense with it in favour of a second 220 kV connection. From today's perspective, the EWZ line project will not be implemented until well after 2040.

Overview table of CBA results

Total investment costs	**CHF millions**	**5**
Commissioning	**Year**	**2050**
Qualitative benefits		
Increase in security of supply	--/-/0/+/++	+
Increase in grid security	--/-/0/+/++	++
Resilience	High / Medium / Low / 0	0

swissgrid

The project has no added value in the monetary benefit categories.

Objective and purpose of the project

- To facilitate grid operations and outages.
- To improve the connection to the Auwiesen and Fällanden substations.

What will happen if the project is not implemented?

The outage or decommissioning of the current Fällanden – Auwiesen line would weaken the transmission grid and mean that the Fällanden and Auwiesen substations are only connected to stubs.

Improving the connection of the Auwiesen and Fällanden substations will increase security of supply in the city of Zurich, which is welcomed by EWZ.

6.3.2.6 Project G: «New Chavalon substation and enhancement of the 220 kV Romanel – St-Triphon line»

Project description

Swissgrid has received a grid connection request for Chavalon for an end consumer with an installed load of 350 MVA. In order to provide the required installed load, a substation must be built in Chavalon and the conductors must be enhanced on the Romanel – St-Triphon line with a loop in Chavalon.

There are various other implementation options. Clarifications are needed with the investor to determine the definitive requirements and to check how flexibly electricity exchange with the TS can be adapted if necessary. This analysis will determine which option ultimately makes the most sense for the investor and Swissgrid in terms of implementation time and costs.

Overview table of CBA results

Total investment costs	**CHF millions**	**71**
Commissioning	**Year**	**2040**

Objective and purpose of the project

Swissgrid has received a connection request for a data centre in combination with a battery storage system and a photovoltaic plant. A 350 MVA grid connection is required to implement the project.

What will happen if the project is not implemented?

Swissgrid will not meet its legal obligation to provide a grid connection.

6.3.3 Description of projects that require studies

6.3.3.1 Project C: «Additional 380 kV system Laufenburg – Beznau – Breite»

Project description

An additional 380 kV system will be built between Laufenburg, Beznau and Breite. There are various options for the actual implementation, which still need to be analysed in detail. Possibilities include looping the existing 380 kV Breite – Laufenburg line into Beznau.

Objective and purpose of the project

To strengthen the existing grid to enable:

- current grid connection requests or project ideas from new grid users to be implemented and, at the same time, to allow the continued operation of the Gösgen and Leibstadt nuclear power plants beyond 2040,
- cross-border capacity between Germany and Switzerland to be increased by up to 1,500 MW on the Swiss side,
- the grid to become more robust and resistant to outages and to make it easier to find dates for shutdowns for maintenance work, especially in the winter. Otherwise, there is a risk of reduction in import/export/transit capacities.

Next steps

A joint study with the German TSOs will be carried out to analyse whether this project can increase cross-border exchange capacity. In addition, this project could be a prerequisite for implementing project ideas that integrate Switzerland into the large-scale European electricity transport system. This system transports electricity from the wind farms in the North Sea and from large solar parks in Italy to Switzerland and from the storage power plants in the Alps to the consumer centres in Germany and Italy. One possible solution is to use HVDC lines, as investigated in studies with neighbouring TSOs. Whether Project C and further grid enhancement measures are required as accompanying measures depends partly on the grid connection point of a possible HVDC line.

6.3.3.2 Project H: «New Galmiz – Mathod line»

Project description

An analysis will be carried out between the Galmiz and Mathod substations to determine how the project already included in the SN2025 can be implemented on the north-western shore of Lake Neuchâtel with reasonable dimensions.

The dimensioning (number of systems and voltage of 220 or 380 kV) and the positioning of substations (connection between NE1+3) will depend to a large extent on the long-term expansion of wind power, as well as the economic development of the region. Swissgrid will start by clarifying the requirements with the DSOs in the region. This will involve estimating the long-term potential of wind power rather than simply taking into account the wind projects that are currently known. This will result in a topological target grid.

The second step will be to search for a route as part of a regional grid coordination process in consultation with SBB, the DSOs and the affected cantons. The possible bundling of different infrastructures will also be examined.

The aim is to agree on a topographical target grid for the region between all the parties in two to three years.

Objective and purpose of the project

- To take advantage of the opportunity to efficiently develop the Jura Arc region with SBB and the DSOs and to facilitate the connection of potential future wind farms.
- To achieve bundling from the point of view of landscape/environmental protection, as well as in terms of costs.
- To connect the substations in Galmiz, Kerzers, Yverdon and Mathod redundantly to the transmission system, which will increase security of supply.
- This will allow parallel flows through the distribution grid to be reduced.
- The lines from Mühleberg to St-Triphon and Chamoson are already heavily loaded today, especially with high hydropower production in the Valais. Decommissioning and outages mean restrictions on production, which will be reduced by the project.
- The project will allow the possible further expansion of alpine photovoltaic plants and hydropower in south-west Switzerland (e.g. the planned 800 MW pumped storage power plant in Fionnay).
- Electricity exchange with France may be improved by this project.

Next steps

Study with Romande Energie, Groupe-E and separate clarification of cross-border capacity with RTE necessary to find the best option.

Subsequent convening of a working group for regional grid coordination.

6.4 Verification of the target grid with stress tests

Stress tests and analyses were carried out with the 2040 target grid. Its robustness must be proved, even in extreme situations.

The target grid for the stress tests was derived from the 2040 start grid plus the projects from the Strategic Grid 2040, as shown in Figure 42. The projects that still require further studies and the bundling candidates (Note: bundling generally hardly changes the electrical properties of the grid) are not part of the target grid for the stress tests.

The following stress tests were carried out with the target grid, among others:

A Firstly, the target grid was subjected to an (n-1) analysis with the three SZR CH scenarios and checked to see whether there would be any overloading of Swiss grid elements (see Section 6.4.1).

B This was followed by an analysis of the multiple failures with scenario 1 of the SZR CH, with the outage of entire routes and busbars. Checks were carried out to determine whether a large-scale failure is imminent or whether the grid is sufficiently robust (see Section 6.4.2).

C The voltage analysis with scenario 1 of the SZR CH examined whether there are impermissible voltage values in individual grid nodes that cannot be controlled with existing means of compensation in the 2040 start grid (see Section 6.4.3).

6.4.1 (n-1) analysis

In a similar way to the analysis with the 2040 start grid, the target grid was also loaded with the three SZR CH scenarios to determine which grid elements are overloaded for how many hours and to what extent.

The result is that the number, duration and level of overloading of grid elements with the target grid compared to those with the 2040 start grid decreases in all scenarios. This is thanks to Project A: «PST Western Switzerland» and Project E: «Additional 220 kV system Airolo – Göschenen».

6.4.2 Multiple failures

This analysis was carried out using the target grid with the topology/switching status chosen by default for Scenario 1, «Reference».

The aim of this stress test was to detect which multiple failures could lead to a cascade failure or a voltage collapse. This type of incident means that there is a large-scale supply disruption with a cause in the transmission system. If a risk of this kind was recognised during grid planning, countermeasures would have to be taken.

Multiple failures are very rare events. They can be caused by a variety of reasons (planned and unplanned), such as environmental events (storm, avalanche, thawing permafrost), targeted attacks (sabotage, war) or planned shutdowns for construction/maintenance measures. One recent example was the failure of the Albula line in October 2018 when four pylons buckled in a hurricane. The failure did not lead to a cascade effect, but the transport capacity to Italy had to be reduced for months until the line had been repaired.

Multiple failures are understood to refer to busbar and route failures.

- **Busbar failure:** in the course of the stress test, it is assumed that exactly one busbar, and consequently all the lines connected to it, fail. In substations with several busbars, several stress tests are carried out in which one busbar fails after the other.

- **Route failure:** in this case, all the transmission line systems installed on pylons along the route will fail. If the systems on the route change, a distinction is made between various multiple failures.

It is assumed that only one busbar or one route will fail at the same time (exception: crossing points of two routes. In this case, both routes fail).

The analysis showed that the target grid is very robust and resistant to multiple failures. Robustness was achieved locally by installing «Special Protection Schemes» (SPS), for instance at power plants, so that they can reduce production very quickly. Studies are being carried out at two other locations in the grid to determine how robustness can be increased even further.

6.4.3 Stress analyses

The aim of these analyses was to determine the need for reactive power compensation systems in the target grid for each grid node in order to keep the voltage within the permissible range. The demand was compared with the available supply for the 2040 start grid and the potential need for expansion was recognised.

The analysis showed that there are only minor deviations in voltage, which are unproblematic. This means that the compensation systems available in the 2040 start grid are also sufficient for the target grid.

7 Findings, conclusions, next steps

7.1 Findings and conclusions

The implementation of all projects from the SN2025 is crucial and will create a robust 2040 start grid.

The simulations carried out on the basis of the SZR CH with the 2040 start grid showed almost no overloads, which is an indication of the sustainable design of the SN2025.

Large-scale projects (power plants, storage facilities, consumers) that require a connection to the transmission grid can only be implemented quickly (within a few years) if no grid expansion is necessary. Swissgrid should indicate the installed load available for each NE1 grid node and grid region in order to pinpoint locations that make sense from a grid perspective. The grid should also be robustly expanded in economic growth regions or areas with potential for wind/PV to avoid slowing down economic growth and the transformation of the energy system. The current SZR CH does not contain the necessary information for this, as it does not look far enough into the future and only contains national values.

The implementation of grid projects can be accelerated and made more efficient if the infrastructure operators Swissgrid, DSOs and SBB coordinate their road and rail projects regionally. This process is called regional grid coordination. It is common practice in road and railway construction and in the electricity sector in Ticino. Swissgrid and SBB would like to establish this approach throughout Switzerland.

7.2 Studies following the creation of the SN2040

Further grid studies with DSOs and FTSOs

- **Project opportunity of «Boucle Nord»:** grid study with SBB, Romande Energie and Groupe-E and separately with RTE
- **Additional 380 kV system Laufenburg – Beznau – Breite:** grid study with the German transmission system operators Amprion and TransnetBW
- **Local studies** with DSOs, SBB and PPOs, in particular with regard to bundling candidates
- **HVDC supergrid studies:** extension of cross-border calculations already initiated or carried out – particularly the north-south corridor study and «That's a Cable» (TAC) study
- **Study with Terna** on expansion options at the border between Switzerland and Italy
- **Greenconnector:** as part of the procedure initiated by World Energy for an exemption under VAN (Merchant Line), ElCom has asked World Energy to update its evaluation of the Greenconnector. Swissgrid has suggested performing this reassessment on behalf of World Energy by adopting a similar approach to the assumptions and methods of SN2040.

- **System controllability:** several pilot projects to increase system controllability are currently being implemented, or feasibility tests are being carried out (e.g. Dynamic Line Rating). Swissgrid is responsible for ensuring overall coordination to support studies and operating concepts.

8 Glossary and abbreviations

8.1 Glossary

ENTSO-E scenarios	ENTSO-E and ENTSOG jointly develop a scenario framework for electricity and gas in Europe every two years.
ERAA (European Resource Adequacy Assessment)	Annual, comprehensive adequacy analysis by ENTSO-E, prescribed by the Clean Energy Package (CEP) as a tool for assessing the need for capacity mechanisms.
Bidding zone	In this zone, a uniform market price applies at a given time or for a given billing period (hour or quarter hour). It is therefore referred to as a market area, price area or bidding zone. For market players, a bidding zone is an area without any congestion where there are no restrictions on energy exchange. The grid operators control congestion within the bidding zone by implementing topological measures or by redispatching generators, storage systems or consumers. Bidding zones are often identical to national borders. In Switzerland, this applies to a large extent, whereby the Swiss bidding zone also includes peripheral areas of neighbouring countries, and peripheral areas of Switzerland belong to foreign bidding zones. In Italy and the Scandinavian countries, for example, there are several bidding zones on the national territories.
GO List	List of guarantees of origin: a list of all existing Swiss power plants.
Market simulation	For each bidding zone, hourly curves showing load, solar radiation and wind, as well as the composition of the power plant park (separated by technologies), fuel and CO_2 prices etc., are available for the target year based on the scenarios set out in the SZR CH and on the ENTSO scenarios. For each bidding zone and each scenario, the simulation indicates the hourly market prices, power plant deployment, the emissions resulting from the power plant deployment and the net position of the bidding zones. The latter is determined in an FBMC calculation. The prices in these bidding zones are equalised by exchanging energy between bidding zones.
minRam criterion	The 70 % minRAM criterion means that according to the EU requirement (Clean Energy Package), at least 70% of the transfer capacity of each CNEC must be made available for cross-border trading.
Grid node	A grid node in the TS is a substation where power plants and/or distribution grids and/or converter/inverter stations are connected to the TS.
Grid simulation	The load and production from the market simulation are allocated to the grid nodes in the start grid via a defined key (mapping). Grid congestion can now be detected. Projects are added until there is no more congestion. The grid achieved by this is called the reference grid. Results of the grid simulation include the

	necessary grid expansion projects, location and frequency of grid congestion and voltage violations, electric system losses, etc.
NOVA principle	The NOVA principle stands for grid optimisation before grid enhancement before grid expansion. It aims to minimise the impacts of grid expansion on the environment and the landscape. If more efficient grid operation is not sufficient to manage the congestion that has been identified, the first step is to pursue grid optimisation and, if this is not effective, grid enhancement and, as a last resort, grid expansion.
RAM	Remaining available margin. The relative capacity of a CNEC available to the market.
Reference grid	This is the Swiss transmission grid which does not show any significant structural congestion when applying the scenarios for the target year.
SEW	Socio-economic welfare: the SEW of project X is the difference in the sums of the profits of consumers, producers and transmission system owners that arise with and without project X. ENTSO-E authorises two methods for determining SEW: the generation cost approach and the total surplus approach. The total surplus approach allows for country-specific project assessment and is used by Swissgrid.
Start grid	This refers to the transmission grid in Switzerland and the transmission grid in other continental European countries. It includes all the grid elements that are currently in operation or will be in operation by the target year.
Strategic Grid	This is the entirety of the grid expansion and grid decommissioning projects in Switzerland by means of which the start grid is transformed into the target grid.
Scenario framework	There is a national scenario framework (SZR CH) and a European scenario framework (ENTSO scenarios). The first SZR CH was published by the SFOE in November 2022. It is updated every four years.
Target year	The target year is the year for which the next Strategic Grid is determined.
Target grid	This is the Swiss transmission grid which is actually targeted for the target year. By applying the CBA procedure to the additional projects from the reference grid and carrying out stress tests, it becomes clear which projects offer sufficient added value and should therefore actually be implemented.
Area of responsibility	Each municipality in Switzerland (including Liechtenstein and municipalities abroad that are part of the Swiss electricity system) is allocated to exactly one area of responsibility of a DSO on the TS. The DSOs on the TS have agreed on this. The area of responsibility construct is only used to clearly allocate municipalities to the DSOs on the TS for the purpose of forwarding data to Swissgrid as part of actual data acquisition and regionalisation. The role of the DSO on the TS in this context is as a data provider. The areas of responsibility have nothing to do with grid ownership, responsibility for grid operations or end customer supply, etc.

8.2 Abbreviations

AG RKN	«Regional Coordination of Grid Planning» working group
SFOE	Swiss Federal Office of Energy
CBA	Cost-benefit analysis
ElCom	Federal Electricity Commission
ENS	Energy not supplied
ENTSO-E	Association of European Transmission System Operators
ENTSOG	European Network of Transmission System Operators for Gas
EP	Energy perspectives
ESTI	Swiss Federal Inspectorate for Heavy Current Installations
FACTS	Flexible AC transmission system
FBMC	Flow-based market coupling
HVDC	High-voltage direct current transmission
WIP	Waste incineration plants
PPO	Power plant operator
MW	Megawatt
NE	Grid level
NTC	Net transfer capacity
PECD	Pan-European Climate Database
PST	Phase shift transformer
PV	Photovoltaics
ROK	Spatial Planning Conference
SBB	Swiss Federal Railways
ESA	Electricity Supply Act
ESO	Electricity Supply Ordinance
SÜL	Transmission Lines sectoral plan
SZR CH	Scenario Framework Switzerland
TSO	Transmission System Operator
TYNDP	Ten-year network development plan

TS	Transmission system
TSO	Transmission system operator
DETEC	Federal Department of the Environment, Transport, Energy and Communications
DSO	Distribution system operator

Part B:
Optimisation of the grid development process and vision for the grid of the future

9 Proactive suggestions for the further optimisation of the grid development process

In the course of the SN2040 project, a number of requirements and legal framework conditions were identified that Swissgrid believes to be insufficient or in need of improvement.

The implementation of a grid project takes around 15 years on average and the service life of a system is between 50 and 100 years, depending on the operating facilities. Swissgrid therefore considers the planning data for a target year in 16 years to be insufficient. The European energy system is undergoing great upheaval, and it is difficult to predict its definitive status. Decarbonisation of industry, building heating, transport, digitalisation, hydrogen economy, huge wind farms in the North Sea and the Mediterranean, solar farms and sector integration are just some of the keywords.

As well as carrying out multiyear planning based on the SZR CH as legally prescribed, Swissgrid has therefore also created a vision for the grid of the future that goes well beyond the horizon of the federal government's scenarios. In line with the principle of «Think globally and act locally», Switzerland should broaden its perspective when designing its future energy system and look even further to the future. With its vision for the grid of the future, Swissgrid is aiming to work with the authorities, industry partners and research institutions to develop a long-term vision for the energy system and the transmission grid based on it. The next SZR CH should cover a longer time horizon and a broader range of possible future developments, and also include information on Switzerland's degree of self-sufficiency, sector integration and desired networking with Europe.

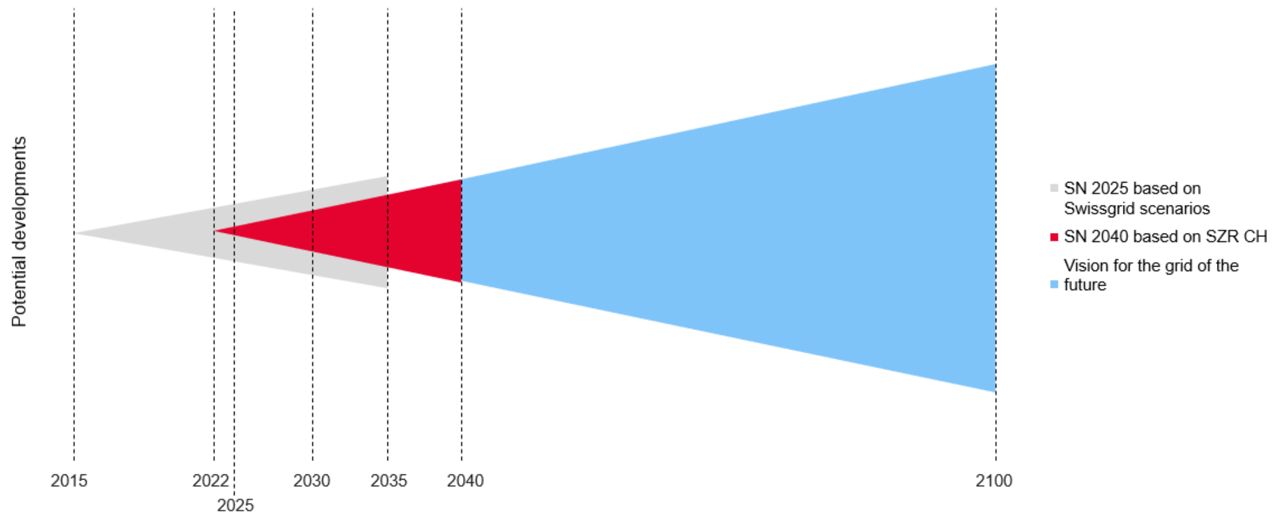


Figure 47: Scenarios and planning horizons as a basis for long-term grid development

Swissgrid is proactively suggesting the following improvements to the authorities:

- The SZR CH should be updated every four years by law. This requires updated energy perspectives as a data basis.
- The SZR CH only contains data for the year 2040, but no prospects for the period beyond that. Longer-term scenarios that take into account more disruptive developments would help to build an even more sustainable, robust grid for the future. The long implementation periods from the SN2025 show that a horizon of less than 20 years is too short for grid planning. With its vision for the grid of the future, Swissgrid provides its own picture of long-term grid development.

- In addition to the national target values, the SZR CH should also include coordinated cantonal target values, which would make regionalisation to the grid nodes easier, especially for distribution system operators at grid level 3. Swissgrid has neither the expertise nor the legal mandate to forecast local economic developments. The ES2050 figures are currently not harmonised with cantonal energy strategies, which can lead to conflicting objectives, particularly for distribution system operators. To date, there is no coordination process between the federal government and the cantons that could solve this problem.
- In Europe, the course is currently being set for large-scale grid development. There are a number of specific expansion targets for cross-border capacities and plans for new HVDC corridors and an offshore grid. A European hydrogen grid is also in preparation. Switzerland, which is located at the heart of Europe, risks being bypassed in the development of a possible HVDC supergrid and hydrogen grid. The next SZR CH should therefore include target values for Switzerland's level of self-sufficiency and/or the desired exchange capacities. The extent to which Switzerland wants to import and export electricity and how Switzerland wants to be integrated into Europe in the long term are political decisions. In addition, Switzerland is heavily dependent on developments in other European countries (both in terms of generation capacity – i.e. import opportunities in particular – and in terms of grid development).
- In addition to the SZR CH, there should also be an up-to-date overview of existing and planned power plants in Switzerland. The investment portfolio is available via Pronovo's GO list. An overview of planned projects was compiled by Swissgrid at great expense for the SN2040 project. As well as being of use to Swissgrid, it would be of great benefit to authorities, infrastructure operators and research institutions if such a list were available and centrally maintained. Swissgrid cannot publish its list without a legal basis because it has only received information from investors for the purpose of grid planning.

10 Vision for the grid of the future beyond the SN2040

Swissgrid has developed a vision for the grid of the future. These considerations have not yet played a role in the creation of the SN2040. However, they should help the SFOE to update the energy perspectives and the SZR CH and serve as a guideline for Swissgrid for long-term considerations with regard to grid planning.

The vision for the grid of the future was created thanks to a survey of experts from all areas of Swissgrid. It is a qualitative observation and not (yet) the result of simulation calculations. It will subsequently be validated with external experts and foreign TSOs. The results to date can be summarised as follows:

- The grid of the future should guarantee security of supply in an environmentally friendly and economically efficient manner at all times.
- It should ensure Switzerland's integration into the European electricity system. This requires a stable regulatory basis in relation to Europe (electricity agreement).
- The flexibility of generators, storage facilities and consumers and the control of flows should be optimised using all the available technologies.

The number of grid operators is constantly decreasing, and distribution system owners are outsourcing their operational business to service providers, as the high future requirements for planning and operation can only be met by highly specialised grid operators.

- The grid is being expanded in line with demand and in an environmentally friendly manner. Cabling is only installed where absolutely necessary and bundled, if possible with fewer, but harmonised voltage levels than today. The DC grid and NE1–3 are planned and built in a coordinated manner by the grid operators on the basis of harmonised grid models and scenarios.
- Measures are taken to maintain the current power quality (frequency/voltage stability) in order to manage the additional requirements resulting from the increased PV/wind power feed-in.
- Nature conservation/environmental protection requirements are applied in such a way that they achieve their objective and do not make infrastructure development impossible. Technical progress is constantly being utilised (air-insulated cables, SF6-free switchgear, hybrid DC/AC lines, etc.).

- An HVDC supergrid is already gradually being created in Europe. Various submarine cables have been laid between continental Europe and Scandinavia, the British Isles and the Mediterranean region. HVDC lines have already been built between Belgium and Germany, France and Italy and France and Spain in order to overcome grid congestion in the AC grid. As shown in the following diagram, many other projects are in the planning, approval and construction process. Plants worth several hundred billion CHF are currently being planned around Switzerland to connect generation and load centres with large storage facilities.

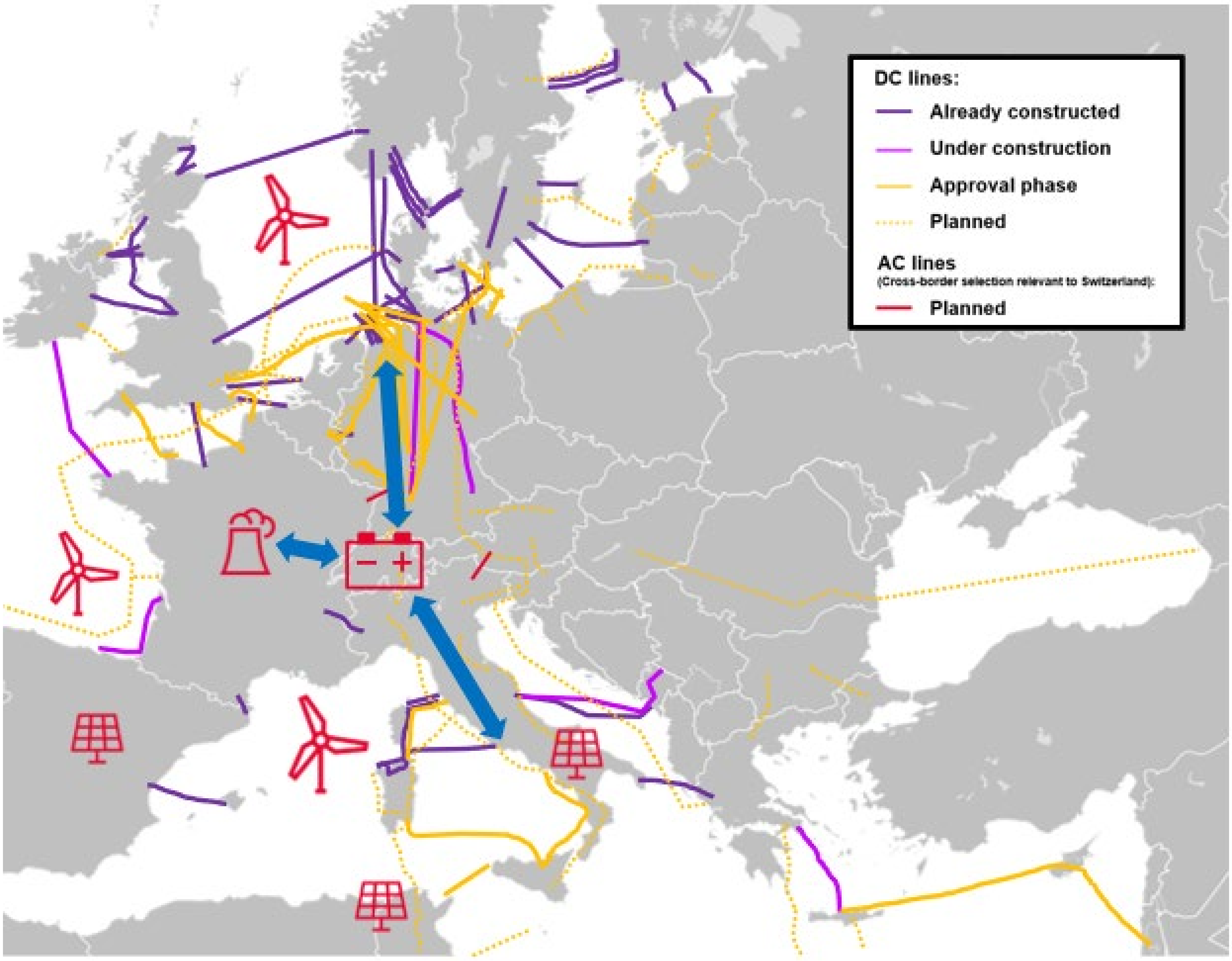


Figure 48: Existing and planned HVDC connections in Europe. This «supergrid» connects new generating plants with storage facilities and load centres.

- The HVDC supergrid is intended for the long-distance transmission of large volumes of energy and is operated at a voltage of 525 kV and a transfer capacity of 2 GW per line. Electricity flows are very easy to control with direct current technology. From the current perspective, two HVDC connections each to Italy, Germany and France, and a maximum of four converter stations to connect the Swiss 380 kV AC transmission grid appear to make sense (n-1 security). A 380 kV connection also appears to be sufficient in the future for the (currently limited) exchange with Austria. The structure shown in the figure below also gives Switzerland redundancy at HVDC level. The next step is to validate and concretise the grid of the future. To this end, Swissgrid must develop a methodology and a grid model that enable high-level grid simulations to be carried out with long-term scenarios.

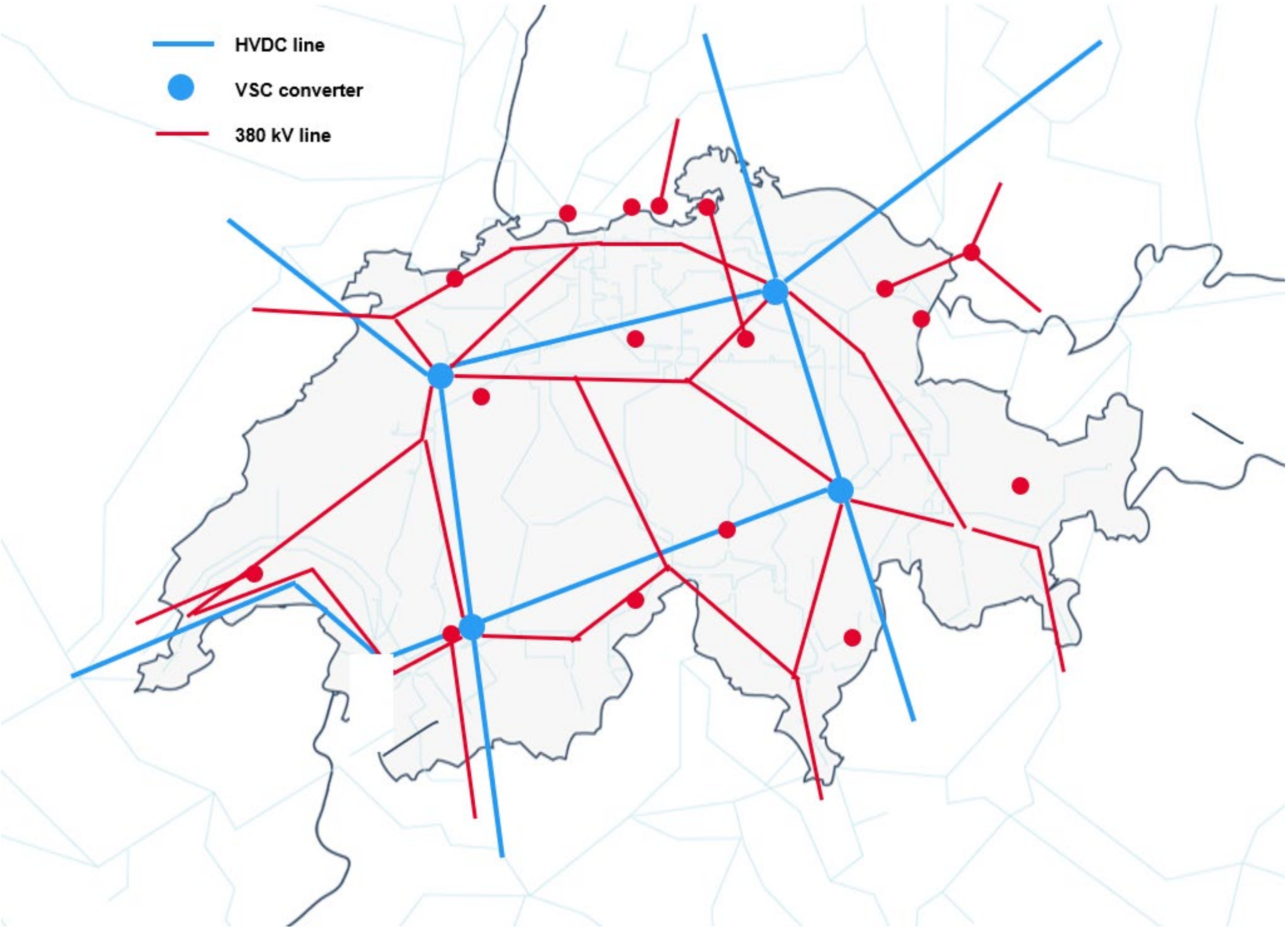


Figure 49: Vision of the Swiss transmission system for the second half of the 21st century (illustrative)

- The meshed 380 kV grid connects the production and load centres in Switzerland and neighbouring countries with the connection points to the DC grid. The number of 380 kV cross-border lines can be reduced if necessary, as international electricity exchange should essentially be controlled by the DC grid. Large consumers and generators are directly connected to the 380 kV grid. The AC grid is used as efficiently as possible by maximising the transmission capacity with dynamic line rating[6], improving controllability with PSTs and power electronics (e.g. FACTS) and adjusting flows on the DC lines as effectively as possible. Today's 220 kV lines will be converted into 380 kV lines if they are required for long-distance transport or – if they are used for distribution – will be operated at a lower voltage as part of the national distribution system. Individual 220 kV lines can continue to be operated at certain points, e.g. to connect existing large power plants or distribution grids with a high load.

[6] Dynamic Line Rating (DLR) has not yet been taken into account in the Strategic Grid 2040 project.

Swissgrid is working on this technology. This is already being tested on individual lines with physical and virtual sensors. In the new control system that Swissgrid is currently procuring, the option of using DLR will be integrated and supported by the system.

The efficiency of grid operations can be increased, for example, by analysing real-time data from the lines (temperature, wind speed, sag, etc.) as part of Dynamic Line Rating or by applying curative measures such as remedial actions or using flexibility from generators, consumers and storage facilities. For grid planning, these operational options are only of secondary importance in view of the long planning cycles and taking into account the permanent, guaranteed availability of flexibility.

Swissgrid currently sees DLR as a means of increasing the operational security of the existing grid in order to be able to respond to constant changes in the weather. However, DLR is not (yet) a means of dispensing with relevant grid expansion on this basis.

- Ideally, the NE3 is largely operated at the same voltage (e.g. 110 or 150 kV), thereby achieving standardisation at a high power level.

11 Next steps towards the grid of the future

- **Further development of the methodology for determining the Strategic Grid**
  In the future, the possibilities for system control, flexibility utilisation and sector coupling are to be taken into account on the basis of the knowledge known at the time. There is still a great deal of uncertainty in this respect.
- **Establishment of «regional grid coordination» methodology to speed up approval processes**
  Projects that affect several cantons, that have the potential to be bundled with power lines of DSOs, SBB or with road and rail infrastructure projects that affect residential areas or protected areas should be coordinated with all the affected operators and authorities (infrastructure operators, federal offices, cantonal authorities for spatial, environmental, energy and landscape planning) at an early stage. It also makes sense to involve municipalities and environmental associations as soon as possible. Swissgrid, SBB and AET are already using the methodology in Ticino (Studio Generale) and it is already common practice in the planning of the road and rail network. Swissgrid will work to ensure that regional grid coordination becomes the standard for grid planning throughout Switzerland.
- **Vision for the grid of the future**
  Long-term extreme scenarios will be used to demonstrate the viability of an HVDC supergrid. The vision will be validated and further developed with national and international experts from industry, research institutions and authorities. Resources relating to direct current technology and innovative technologies for system controllability are to be built up at Swissgrid. The next step is for Swissgrid to endeavour to provide quantitative proof of its vision for the grid of the future and to draw up a possible transformation plan from the current grid to the long-term target grid. This will require a project to be launched involving representatives from the authorities and research institutions.

12 List of figures