Renewables Grid Initiative

Swissgrid "Strategic Grid 2025"

Study Brief

Purpose of Study

The main purpose of the study was to plan the Swiss transmission grid optimally for the target year 2025, taking into account the current structure of the grid and a minimal amount of network reinforcement measures required in order to accommodate the future scenarios .

All expansion measures were evaluated with a multi criteria cost-benefit analysis; the benefits include e.g. the country's economic benefit, system security and the influence on the landscape and the settlements.

Geographic Scope

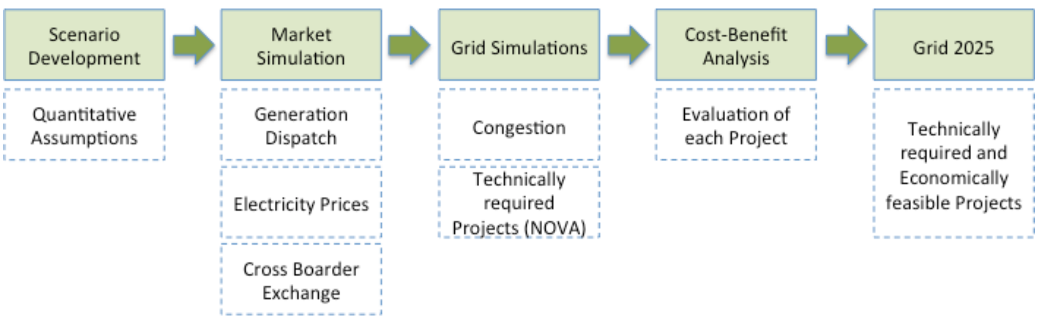
The target area of the study was Switzerland. However, as the Swiss transmission electricity network is part of the Continental European interconnected system, market and load flow simulations have to consider all the corresponding countries in order to yield valid results. Indeed, the other countries of Continental Europe, featuring different generation mixes and costs, heavily influence the Swiss transmission system, causing transit flows through Switzerland and hence influencing the utilization of the elements of the Swiss transmission grid.

Time Scale

The target year is 2025, therefore the definition of grid reinforcement measures is based on the analysis of scenarios and simulation results for this year. Additionally, developments of the electricity system from now until 2035 are analysed and discussed with stakeholders. 2035 was also chosen in order to ensure consistency and robustness of the identified measures by looking at the longer-term perspective. The study exclusively investigates the requirements for the two relevant years and not on the path to get there.

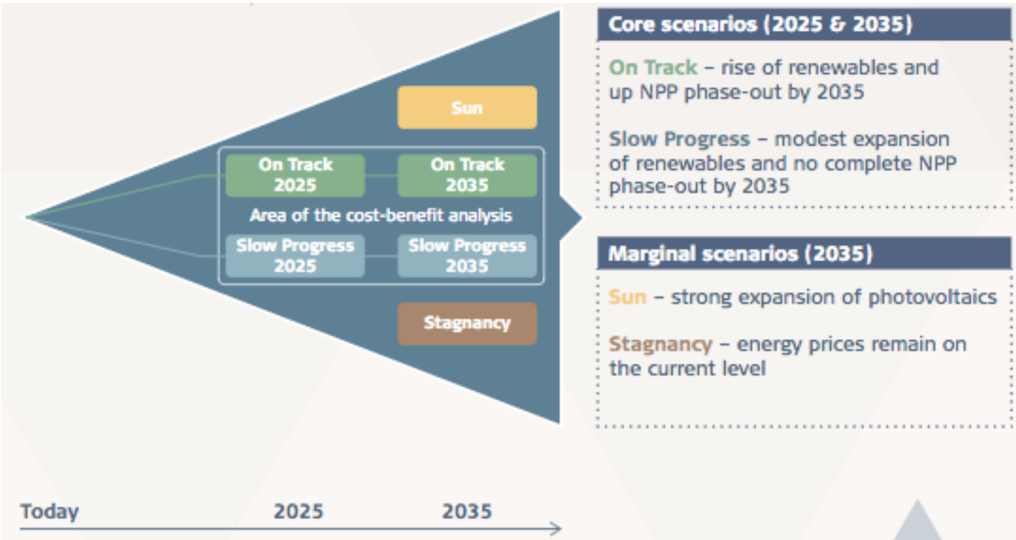
Methodology Overview

The study itself consisted of four main process stages, the scenario development, the market and grid simulations and the cost-benefit analysis. The final strategic grid for 2025 is derived based on the findings. Swissgrid is one of the first TSOs to focus on economic aspects in addition to technical requirements when it comes to defining the need of future grid reinforcement. One of the scenarios, "Sun", was developed together with Umweltallianz, which comprises several environmental NGOs.



Scenarios

A scenario funnel with 2 core scenarios for the target year 2025 and the year 2035 as well as 2 marginal scenarios for the year 2035 is defined. Core scenarios in 2025 are utilised to identify technically required measures and evaluate them technically and economically. Core scenarios in 2035 and marginal scenarios are employed to evaluate the robustness of these measures towards long term changes and towards change that is less expected, but not unlikely to happen, respectively. They are however not used to identify additional grid reinforcement measures.



The green scenarios in the below table represent the core scenarios; the grey ones are the marginal scenarios.

Scenarios of Swissgrid “Strategic Grid 2025”	
“On Track”	*- Oriented towards “Neue Energiepolitik” scenario from “Energieperspektiven 2050”* *- Expansion of renewable energy sources according to the Swiss energy strategy “Energieperspektiven 2050”* *- Wind and PV capacity is 4,1 GW in 2025 and 8,2 GW in 2035* *- Withdrawal from the nuclear energy programme by 2035* *- energy efficiency triggers a slight reduction of electricity consumption*
“Slow Progress”	*- Oriented towards “Weiter-wie-bisher” scenario from “Energieperspektiven 2050”* *- Slower and hence less expansion of renewable energy sources than targeted* *- Only partial withdrawal from the nuclear energy programme by 2035* *- Continual rise of electricity consumption in Switzerland until 2035*
“Sun”	*- This scenario was developed together with “Umweltallianz”, who gave input to the underlying assumptions.* *- Based on the aim to cover electricity consumption within Switzerland completely with domestic renewable energy sources* *- Strong development of renewable energy sources within system, especially of PV* *- PV capacity in 2035 of 15,6 GW surpasses the peak load of 11 GW* *- Development of wind capacity from 0,1 GW today to 1,5 GW in 2035* *- Withdrawal from the nuclear energy programme by 2035- Small reduction of consumption in Switzerland*

"Stagnancy"	*- Recession causes energy prices to remain at todays level* *- Low expansion of renewable energy sources as state subsidies are discontinued* *- CO_2 prices remain low so that the European climate targets from 2014 are not met*

The Sun Scenario

This scenario was jointly developed by Swissgrid and "Umweltallianz" (an organisation comprising several environmental NGOs including WWF and Greenpeace) with the aim of including a 100% RES case in Swissgrid's modelling exercise. The parameters or quantitative assumptions of the Sun scenario were defined by Umweltallianz for the area of Switzerland and discussed with Umweltallianz Europe.

Unlike for the other scenarios, the influence of seasonal storage on grid expansion projects was analysed in order to determine the required amount of storage to avoid additional transmission projects compared to the base cases in 2025.

Quantitative Assumptions[1]

Assumption	**Carrying capacity of lines**
Detail	The maximal current of overhead lines is adjusted depending on the ambient temperature. The study assumes 40°C during summer, 10°C during winter and 20°C in spring and autumn.
Assumption	**Regionalisation**
Detail	Unlike for large conventional power plants, a clear allocation of small decentralised generation units to their point of connection and hence to the relevant node in the grid model is not always possible. Existing units are allocated to the substation that is geographically closest. New units are allocated by combining the current distribution as a percentage share with the expected development of each generation technology.
Assumption	**Fuel Prices and CO_2 Prices**
Detail	For the core scenarios, projected fuel prices and European price of CO_2 in (Euro/t) were not estimated by Swissgrid but completely taken from recognised external sources, specifically data that the IEA contributed to the "World Energy Outlook 2013". The data is derived from the logic, that political framework and decisions to implement measures to achieve the climate goals of not surpassing a 2-degree temperature rise compared to the preindustrial era drive the price development. Prices for uranium, lignite and shale oil are the same across all scenarios and time. Prices for CO_2, hard coal, gas, light oil and crude oil vary. The fuel price scenarios are purposely chosen in a way that creates a "fuel switch" between coal and gas plant usage in Europe when comparing the core scenarios. The "On Track" scenario assumes the implementation of measures as well as the definition of emission targets for 2035 until 2020 in several states,

[1] For more detail on the assumptions contained in this list please see the "Strategic Grid 2025" brochure (German)

	causing very high CO_2 prices (50 Euro/t) but a comparably slow increase of fuel prices for the target year 2025. For 2035, fuel prices drop slightly, while CO_2 prices almost double. The “Slow Progress” scenario on the other hand assumes no change in energy policy compared to 2013, which results in low CO_2 prices (15 Euro/t) and a strong increase in fuel prices. For 2035, fuel prices rise slightly, and CO_2 prices go up to (23,4 Euro/t). The “Sun” scenario shows a high price for C02 (80 Euro/t), which reflects the political ambition to rely on renewables. Hard coal and gas prices increase drastically and are highest compared to other scenarios, as external costs are integrated in the price by political choice. The “Stagnancy” scenario recession also reflects in the fuel and CO_2 prices, which are based on todays prices and show only a very small increase. Except for hard coal, all prices are lowest.
Assumption	**Development of Load**
Detail	For the core scenarios, scenario data from the governmental energy strategy “Energiestrategie 2050” is utilised. Load is defined as the sum of consumption and grid losses, but does not take into account the self-consumption of power plants and energy required for pumping. In 2025, the peak load is expected to rise slightly in both scenarios, but stronger in “Slow Progress” (about 10%). This is due to new electricity applications that are triggered by the energy transition. When it comes to energy consumption the scenarios differ in their general trend: “On Track” assumes efficiency measures to successfully reduce the consumption by about 5% compared to 2013, while “Slow Progress” implies an increase of 5% due to a delayed realisation of the Swiss energy strategy and therefore fewer efficiency measures being implemented. The trends that the core scenarios show for 2025 persist for 2035. Their peak load of 2035 is slightly higher compared to 2025. The energy consumption keeps rising in “Slow Progress”, where no additional efficiency measures are taken, and falling in “On Track”, where more measure are taken. The “Sun” scenario shows the same tendencies as “On track”, but they don’t show quite as strongly. The “Stagnancy” scenario is based on the 2025 core scenario “Slow Progress” with consumption reduced by 5% due to the recession.
Assumption	**Demand Side Management (DSM)**
Detail	For 2025 implementation of measures that cause the adjustment of load are not expected. Consequently, the load curve is not expected to change drastically. For 2035, DSM measures reduce the growth of peak load in the “On Track” and “Sun” scenarios, but are not enough to fully compensate it. The load shifting potential in “On Track” varies with day, night and the seasons between 2% (summer night) and 8% (winter day) of the seasonal peak load. In “Sun”, the potential is 9,7% of the seasonal peak load. The other scenarios do not contain implementation of DSM.
Assumption	**Development of Storage**
Detail	No assumptions on decentralized storage are described. Pumped storage is considered generation. However, a sensitivity analysis regarding the impact that seasonal storage has on the requirement for transmission grid

	reinforcement is conducted for the “Sun” scenario in order to investigate on alternative solutions.
Assumption	**Generation capacity in Switzerland**
Detail	Projected development of the overall generation fleet in Switzerland. For 2025 the scenarios are close to each other due to the small time step of 10 years from today. A strong rise of installed capacity, which is mainly caused by large hydropower projects (4 GW), is expected in both core scenarios (from 19 GW today to 24 GW (Slow Progress) or 26 GW (On Track)). Assumptions are taken based on different official sources and Swiss power plant operators. For 2035 the generation fleet varies significantly between the scenarios in terms of installed capacity and technology mix. The “On Track” scenario shows an increase of installed capacity by 5 GW due to a strong development of PV and the decommissioning of nuclear plants. “Slow Progress” shows little development of the capacity which is mainly driven by PV, whereas nuclear plants remain operating. The “Sun” scenario shows the strongest development of PV and a conventional phase-out, leading to the highest PV share of 42% of installed capacity. Consequently, installed capacity is also highest in this scenario. In “Stagnancy”, the installed capacity does not surpass 24 GW due to the underlying assumption of economic stagnation. The generation fleet is equivalent to the one in “Slow Progress” in 2025.
Assumption	**Renewable electricity development (including hydropower)**
Detail	Projected development of the renewable generation fleet in Switzerland. Both core scenarios predict development of wind and PV. However, this development is much stronger in the “On Track” scenario than in the “Slow Progress” scenario. Quantification of PV is defined based on a PV sensitivity study conducted by BFE and current registrations for PV feed-in compensation. Both scenarios show a 4 GW rise in hydropower due to several ongoing pumped storage projects by 2025, which are modelled with their location and hence point of connection known. For 2035, the core scenarios continue the trend described above. The strong development of wind and PV continues for “On Track”, causing the installed capacities to double compared to 2025. Two additional pumped storage power plants are assumed to be commissioned. The scenario “Slow Progress” shows a slower development of wind and PV and assumes no further commissioning of hydro power plants. The “Sun” scenario is based on the aim to completely cover electricity consumption within Switzerland with domestic renewable energy sources. 15 GW of PV are installed since 2013, which is twice as much as in the “On Track” scenario. Wind, biomass and geothermal power develop more than in all other scenarios. In contrast to that, only 3 hydro projects are realised, resulting in a smaller hydro fleet then the core scenarios in 2025. The “Stagnancy” scenario is equal to the “Slow progress” scenario for 2025, as the state subsidies for RES are discontinued.
Assumption	**Development of conventional power stations**
Detail	Projected development of the conventional generation fleet in Switzerland. For 2025, no gas power plants are anticipated in any scenario. In both core

	scenarios a third (one plant) of the installed nuclear capacity is decommissioned by 2025. CHP and waste power plants are built in both scenarios, however the “On Track” scenario shows a higher increase of 75% of todays installed capacity (compared to 50% in “Slow Progress”). For 2035 the “On Track” scenario assumes nuclear phase out and the commissioning of about 250 MW of non-renewable power plants, which is highest for all scenarios. In “Slow Progress” the nuclear plants keep running and almost as much non-renewable capacity is installed. The “Sun” scenario depicts full decommissioning of all nuclear, gas and other non-renewable power plants. The “Stagnancy” scenario is equal to the “Slow progress” scenario for 2025, as no investments in projects are taken after 2025.
Assumption	**Cross border capacity assumptions**
Detail	Net transfer capacity is expected to rise by 2025 for both core scenarios, but more in “On track”. The expansion of interconnectors is triggered by pumped storage in Switzerland and the development of RES in general, which explains the difference between the two scenarios. The quantification is based on planned power plant projects and the TYNDP. However, in contrast to the TYNDP, a focus is placed on covering the Swiss load and exporting energy produced in Switzerland, causing different results. PCIs are only partially included. Towards Italy, the HVDC project “Green connector” is only part of the “On Track” scenario due to its stronger development of RES. Towards Germany and Austria, the "Swiss Roof" projects are implemented in each scenario. For 2035, the net transfer capacities remain the same as in 2025 in both core scenarios in an attempt to not compromise the evaluation of projects identified in 2025 and to show long term commitment for grid efficiency. For both marginal scenarios the lower capacity values of “Slow Progress” are adopted. For the “Sun” scenario this is justified in its central concept of developing an energy system as independent as possible, for the “Stagnancy” scenario in the idea that due to recession and very slow development of RES almost no investment flows into interconnector projects.
Assumption	**Representation of other European Countries**
Detail	As the Swiss grid is part of the Continental European synchronous interconnected system, all member countries need to be part of the model in order to derive valid results. Outside of Switzerland no grid deconstruction is taken into account. For 2025, assumptions for generation capacity, consumption and NTC in and between these countries are based on different scenarios from ENTSO-E’s “Scenario Outlook & System Adequacy Forecast” as well as the TYNDPs of 2012 and 2014. The core scenarios are matched with scenarios from the external sources that tell a similar story line in order to ensure consistency. Similarly, the assumptions for the 2035 core and “Sun” scenarios are based on the TYNDP 2014. For “Stagnancy”, Swissgrid assumes the generation capacities of “Slow Progress” in 2025 for 2035, with a reduction of gas power plants as inefficient plants are decommissioned. Consumption increases 2% compared to 2013, and the net transfer capacities from the

	TYNDP are employed, all mirroring the economic recession.

Simulation phases

The simulation phases of the study run the quantitative assumptions for the scenarios through a set of simulations to derive the results. These simulations were completed sequentially, with the results from the first simulation feeding information into the subsequent simulation. This phase included:

Analysis of Current Grid Situation: First, the current grid is checked for structural congestion and its main triggers within the Swiss grid. A combination of measurement data from 1/2012 to 6/2014 and load flow simulations of potentially critical situations are analysed to identify and classify cases of structural congestion. A sensitivity analysis of the factors load, generation capacity and transit flows allows the derivation of important triggers for congestion.

Market Simulation: Simulates the market behaviour of the foreseen European generation fleet in order to determine a cost minimising dispatch that covers the demand, cross border trade flows and electricity prices for every hour of the simulated year. This is achieved in 4 steps: First, planned power plant revisions are spread over the year so that the loss of load probability is minimised. Next, the expected production from RES (including river power plants) is subtracted from the load. Then, thermal power plants are dispatched according to the merit order principle, defining the hourly electricity prices. Finally, pumped storage plants are optimised based on these prices.
The market simulation requires input on fuel and CO_2 prices, detailed information on the generation fleet, load and expected environmental conditions.

Grid Simulation: Hourly values of feed-in, load and transmission capacities are inserted into a model of the Continental European transmission network. The need for grid reinforcement measures is determined according to the PINT principle (put in one at a time) in an iterative process that is repeated until all structural congestion is resolved: Load flow analysis estimates the future network loadings and voltages. For the element with the worst congestion, i.e. where most energy has to be re-dispatched throughout the year, a network expansion measure is determined with respect to the NOVA principle, which minimises the visual and environmental impact of grid reinforcement. Then the model is updated and the process begins from the start until all technically required measures are identified. In the end, the derived grid undergoes a stress test and additional sensitivity analyses in order to check its feasibility in extreme situations.

Cost-Benefit Analysis: is done for each technically required grid reinforcement measure to evaluate its overall usefulness, thus considering quantitative criteria such as project cost, the value of avoided transmission losses and increase of social welfare as well as qualitative criteria such as the increase of reliability of supply, system stability and environmental influences. Based on the results, the measures that will be employed in the strategic grid of 2025 are selected, whereas all other measures are discarded.

Results and Conclusions

From the above simulation phases the below results and conclusions were drawn by Swissgrid.

The analysis of the current grid situation identifies 47 cases of structural congestion in the Swiss grid. In the future, transit flows, the development of new large generation

units in Switzerland and of the European generation fleet are the main drivers for additional congestion.

From 2012 to mid-2014, 29 cases of structural congestion have shown regularly during grid operation, forcing a redispatch of generating units. 18 additional cases were identified through load flow analysis, but have not influenced real life operation so far. In summer, when high production from pumped storage causes an export situation, there is congestion in the alpine region (South) whereas situations with import from the North cause congestion in the North, East and around Geneva. Outages in the 380 kV level are most likely to trigger cascade failures. Increase of the power production capacity or transit flows along the north-to-south axis are likely to happen in the future and have the highest influence on line loading, making them the most important triggers for additional congestion in the future.

Results from the market simulation show that the Swiss grid will maintain its transit function within the international electricity market.

International transit is especially present from France to Italy in all scenarios. Power exchanges with Germany and Austria on the other hand vary significantly depending on the regarded scenario. Switzerland shows a high security of supply for the 2025 scenarios without requiring additional gas power plants. For 2035 however, this is not the case in all scenarios. Especially in the "Sun" scenario Switzerland is dependant on imports during winter in order to cover its demand, if no other measures are taken.

Connection of new large generation units and development of cross boarder flows are the main drivers for the technically required grid expansion measures, whereas the increasing demand and development of RES play a subordinate role.

Market and grid simulations show that transmission projects for the target year 2025 depend mainly on the construction of large scale power plants, in order to allow them to export their electricity, and on international power flows, which depend on relative price changes between electricity markets and hence on fuel and CO_2 price development. The moderate increase of demand has no effect on the need for grid expansion. Up to a certain share of decentral RES, they cause a temporary relief of the grid utilization. If the share becomes higher, distribution grids export energy to the transmission grid and put further stress on the infrastructure.

The technically required strategic grid 2025, which is free of congestion, comprises 9 grid reinforcement projects.

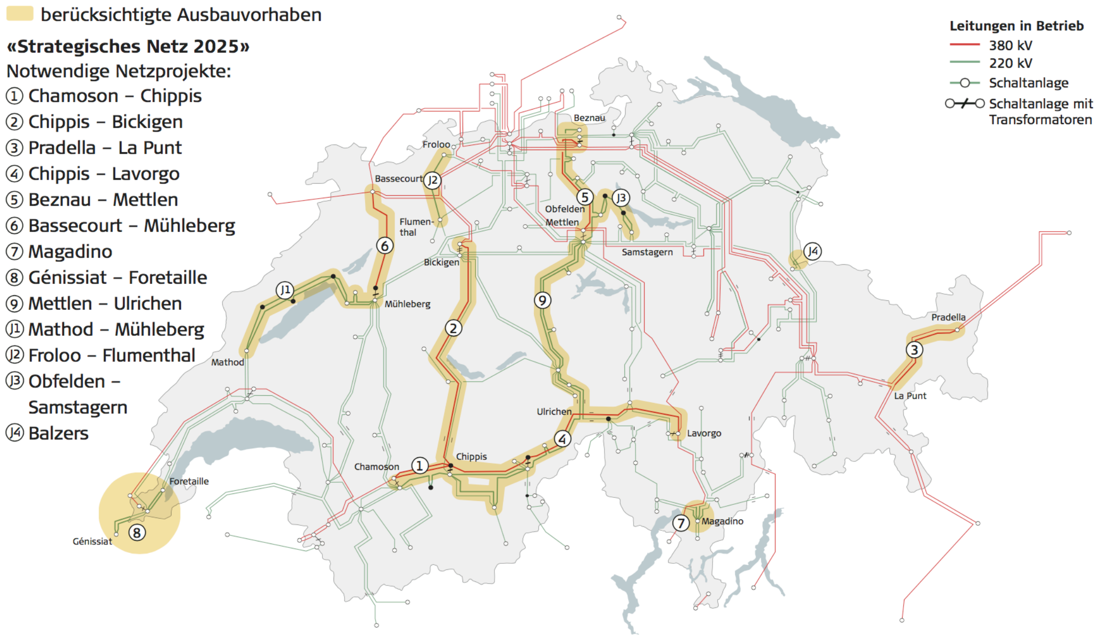
Grid simulations show that current cases of structural congestion remain present and will be accompanied by additional cases in both core scenarios if the grid is not reinforced. Most of the new cases of congestion are similar in both scenarios and can be avoided by means of the same projects. Crosschecking the technically required strategic grids 2025 with the scenarios for 2035 shows that all 9 measures identified in the Slow Progress 2025 scenario are required in all 2035 scenarios. Further projects may be required in the future depending on different developments assumed in the scenarios.

The Sun scenario requires most additional measures compared to the 9 identified in Slow Progress 2025 due to the high infeed from PV in, which is unequally distributed throughout Switzerland. These could be transmission line projects or regional storage.

The location of the additionally required projects correlates with the cantons that feature the highest shares PV generation, located in northern Switzerland and Tessin. These projects could only be avoided by compensating measures such as regional storage or peak shaving of PV infeed. 1,2 GW of storage, distributed across Basel, Bern and St. Gallen could be used to avoid the additional projects in the North when running between 77 and 392 hours per year.

All 9 technically required projects identified in the core scenarios are part of the final strategic grid 2025. In addition, 4 projects for connection of new power plants and distribution systems within Switzerland are included.

The projects identified for both scenarios are in overall robust according to the cost-benefit analysis, which includes information on economic benefit for Switzerland and Europe, contribution of the project to system security, adequacy and flexibility as well as its environmental impact. However, from a monetary perspective not all projects are beneficial for the Swiss economy. The realisation of PCI projects has not yet been decided upon and is not shown on the following map of the Strategic grid.



Due to deconstruction of old transmission lines that are no longer required the strategic grid projects do not create additional line kilometres.

370 km of transmission lines will be newly erected whereas 270 of transmission and 145 of distribution lines can be deconstructed by 2025. When comparing the strategic grid of 2015, 291 km of already planned projects are cancelled whereas only 62 km of newly identified projects will be added.